# DEVELOPING THE BEHAVIOURS THAT WE VALUE IN PHYSICS KNOWERS THROUGH IMPLEMENTING ASPECTS OF THE INVESTIGATIVE SCIENCE LEARNING ENVIRONMENT (ISLE) APPROACH IN A SOUTH AFRICAN HIGH SCHOOL

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## ABSTRACT

Situated in Physics Education Research, this study focused on physics learning through the Investigative Science Learning Environment (ISLE) approach. The ISLE approach is underpinned by the belief that students should learn physics through doing physics, and that all aspects of the learning experience should seek to enhance student well-being. The ISLE approach was introduced in the physics classrooms of two, well-resourced, independent South African high schools.

Physics provides a context in which to develop behaviours that assist learning and that promote a learning-orientated mindset. Physics students need to be able to (i) actively engage to facilitate learning, (ii) connect the domains of a problem to construct a coherent knowledge structure, (iii) transfer their understanding of a concept to a new context, and (iv) grapple with concepts and problems. These behaviours, which are valued in physics students, should be modelled through activities so that students can be trained to adopt these practices.

The Specialization dimension of Legitimation Code Theory (LCT) was used as the analytical framework for this study and translation devices were developed and used to code the activities in terms of the behaviours that they value. Both quantitative and qualitative data were collected in a mixed methods approach, and inductively determined codes were thematically analysed.

The ISLE activities, as well as activities that were developed, based on ISLE principles, were found to legitimate the behaviours that we value in physics knowers. The student experience of the ISLE approach demonstrated the development of these behaviours for many students, although there remained a strong emphasis on performance. Activities that model all four of the valued behaviours were particularly effective.

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**ABBREVIATIONS: (in alphabetical order)**

| | |
|---|---|
| CAPS | Curriculum and Assessment Policy |
| CLASS | Colorado Learning Attitudes about Science Survey |
| DBE | Department of Basic Education |
| FET | Further Education and Training |
| G | Grade |
| GET | General Education and Training |
| IEB | Independent Examination Board |
| ISLE | Investigative Science Learning Environment |
| LCT | Legitimation Code Theory |
| NGSS | Next Generation Science Standards |
| NSC | National Senior Certificate |
| PER | Physics Education Research |
| TIMSS | Trends in International Mathematics and Science Study |
| TME | Testing Multiple Explanations |
| UDI | Universal Design for Instruction |
| UDL | Universal Design for Learning |

**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 |

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**Dedication**

To my whole family:

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To Ben:

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To Rebecca and Alice:

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"All things come from You, and of Your own do we give You."
(Church of the Province of Southern Africa, 1989)

With profound gratitude and acknowledgement that I did not do this alone.

# CHAPTER 1: INTRODUCTION

*"…if everyone could adequately answer how they know something it would subvert everything because those in power could no longer hide behind logical fallacies and weak or unsubstantiated claims."*

(Etkina, Brookes and Planinšič, 2019, p. 2-30)

This study describes the introduction of the Investigative Science Learning Environment (ISLE) approach in a South African high-school physics classroom. This approach is novel in the South African high-school context. The dimension of Specialization from Legitimation Code Theory (LCT) was used to make visible the underlying principles of epistemic relations and social relations legitimated by ISLE activities, enabling us to see to what extent the knowledge and the knower is valued in these activities. New ISLE-inspired activities were developed, and the students' experience of the ISLE approach was evaluated.

In this introductory chapter, I will provide a background to my study by discussing the value of science education to justify the importance of this work. As the study is conducted in a South African high school, I will then explain the South African context, as well as elaborating on science education in South Africa. This background provides the context for the problem statement and the research questions, which I have sought to address. The background also gives the rationale and significance of this work, which is presented at the end of the chapter.

## 1.1 Introduction to the study

The importance of science education provides the rationale for a study that improves students' ability to access and apply physics knowledge. Physics is an important subject because of the thinking approach that it develops, and the opportunities for further study and potential employment that a physics course offers.

In the past 40 years, there have been many attempts to make physics introductory courses more accessible to students and, as a result, there has been a shift in focus from physics *teaching* to physics *learning* in Physics Education Research (McDermott, 1991; Mazur, 1995; Redish, 2014; Meltzer and Otero, 2015). Students who develop appropriate behaviours are more easily able to access the content and apply the principles of physics. Thus, the student's *approach* to learning is particularly important in learning physics and needs to be developed and guided. It is no longer considered that knowledge is a commodity that is given out by the teacher, but rather that it can be constructed or developed through the learning process. However, most activities (and teachers) focus on building content knowledge (Adendorff and Blackie, 2022), overlooking the importance of guiding students to become physics knowers, through emphasising and developing behaviours that enable physics learning.

In this study, I have considered which behaviours we value in the physics classroom and which ones, in particular, we choose to develop. Although there are many behaviours that we value in physicists (Van Heuvelen, 2001), I have chosen to focus on the valued behaviours that require students to

- actively engage with concepts while learning;
- transfer their knowledge to new contexts;
- make connections between the concrete, mathematical and conceptual representations of a concept (or problem), often aided by a visual representation;
- grapple with concepts.

Each of these valued behaviours will be described in a number of contexts through the study, as they align with the physics education literature and resonate with the approach that I have implemented. In this introduction, I explain what is meant by each of these valued behaviours.

- Physics requires an active learning approach (Freeman et al., 2014). 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”. Active learning requires students to assume responsibility for their learning, alongside the teacher, giving students agency in the process of their learning (OECD, 2019a). Approaches where students are actively engaged in knowledge construction have been found to be more effective than traditional methods of teaching where students sit passively in a class while the teacher delivers content. The effectiveness of active learning has been shown in a number of studies through the learning gains of students and their ability to transfer concepts to new contexts (Van Heuvelen, 1991b; Mazur, 1995; Hake, 1998). Active learning and engagement are particularly necessary in physics, although these are behaviours that students should adopt in all their learning. Active learning is discussed in detail in Section 2.1.2.

- A key concept in physics is being able to transfer knowledge to new contexts. This requires students to see the underlying physics in a problem, rather than the surface features of the problem and is a vital skill for problem solving (Sweller, 1988). Not only is the ability to transfer knowledge a valuable behaviour in physics, but it is important for students to be able to transfer knowledge to new contexts in anything that they learn. Transfer is facilitated by cumulative learning (Steenkamp, Rootman-le Grange and Müller-Nedebock, 2021) and is discussed in Section 2.2.1.

- Being able to connect abstract concepts to concrete situations and being able to express both in a mathematical representation are hallmark behaviours of physics experts. Experts are able to translate between the concrete, abstract and mathematical aspects of a scenario or a problem, maintaining coherence (Greeno, 1989). This behaviour is valuable in physics, but also in chemistry (Johnstone, 2009) and in some problems in mathematics. Connecting representations is discussed further in Section 2.3.1.

- The phrase that I have used to describe the final behaviour that we value and wish to develop, requires more explanation, as it is perhaps not a common term used in the literature. I tell my students that they need to 'fight' with concepts, but *grapple* encompasses this sentiment more exactly. According to the Oxford Thesaurus, grapple has the meaning "to catch hold of" and to "apply oneself to" (Waite, 2012). Grappling suggests sustained and focused engagement with a problem or concept, which can lead to deeper understanding and requires effort and tenacity.

Learning is not comfortable; neither is change. Fawcett wrote about the three stages that students experience in response to change: 'Comfortable Dependence' when they continue to do what is expected of them or what they were doing previously; 'Anxiety' when they realise that things have changed; and 'Comfortable Independence' when they settle into the new normal and become self-directed learners (Fawcett, 1998). Teachers need to scaffold this process and support students as a new approach is introduced.

The solution to a physics problem is not always immediately obvious and students (and even experts, at times) may have to attempt a few approaches before they find one that yields an appropriate solution. This requires (and develops) perseverance and tenacity. Not only does physics require these characteristics, but it also sometimes requires students to struggle, which is uncomfortable. As students are learning, they will not always understand a concept immediately and may need to sit with it, interrogate it, try it out in different scenarios and contexts and test it. This is grappling. It is vital for constructing a deep understanding of physics and can serve students in other contexts as well. Learning requires engagement and grappling. Taking short cuts, such as copying out a solution instead of trying to solve a problem independently, or being told what steps to follow in solving a problem instead of trying a few approaches to find one that is congruent, denies the opportunities for growth and learning that grappling affords. Grappling is evidenced in the *process* of constructing understanding or solving a problem, rather than in the *solution* that is reached.

The behaviours that we value have to be developed in a context (Van Heuvelen, 2001) and physics provides a rich context, which encourages scientific reasoning (Willingham, 2008). The knowledge, or *outcome*, of learning physics is often the focus of Physics Education Research (McDermott, 1993), but this study will emphasize the importance of the *process* of learning and the behaviours that this process values and develops, as these behaviours are important for students to access physics knowledge.

In this study, I have introduced aspects of the Investigative Science Learning Environment (ISLE) approach to teach physics in a South African high-school setting, choosing activities that develop these valued behaviours and that suit our context. The ISLE approach encourages students to think like physicists through tasks that mimic the practices of physicists and all tasks are underpinned by an emphasis on enhancing student well-being (Etkina, Brookes and Planinšič, 2019; Brookes, Etkina and Planinšič, 2020). The ISLE approach is described in detail in Chapter 3. I have not found any published work that describes the application of the ISLE approach in the context of a South African high school. I have used the Specialization dimension of Legitimation Code Theory (LCT) (described in Chapter 4) to explore how the activities that I chose, legitimate or value the behaviours that we hope to develop. The dimension of Specialization considers how ‘knowledge’ and ‘knowers’ are legitimated in each activity or subject area (Maton, 2014). Both ISLE and LCT emphasize that activities should be explicit in their purpose and in their basis of achievement, so that all students have an equal opportunity to participate and succeed.

## 1.2 Background to the study

A physics classroom provides an appropriate context to develop the behaviours that we value in physics and beyond. An understanding of science equips our students for future learning opportunities, as well as shaping their thinking. Thus, equipping students to construct an understanding of science and to access science knowledge is important and necessary. My study was conducted in a South African high-school setting and so it is also important to understand some aspects of both the South African schooling system and the nature of science teaching in South African high schools.

### *1.2.1 Why is science education important?*

Internationally, science education is seen as important. In an age of the information revolution, where information is readily available to all, it is increasingly important that citizens are able to process, evaluate and apply this information. Such skills can be taught through the scientific process of investigation and so this is valued in international curricula. In the past two decades, there has been a shift to emphasize the development of scientific skills through the United Kingdom curriculum (UK Government, 2015) and the Next Generation Science Standards (NGSS) curriculum in the United States of America (NGSS Lead States, 2013). The United Kingdom curriculum describes the importance of science:

> *"Science has changed our lives and is vital to the world's future prosperity, and all pupils should be taught essential aspects of the knowledge, methods, processes and uses of science. Through building up a body of key foundational knowledge and concepts, pupils should be encouraged to recognise the power of rational*

*explanation and develop a sense of excitement and curiosity about natural phenomena. They should be encouraged to understand how science can be used to explain what is occurring, predict how things will behave, and analyse causes." (UK Government, 2015, p. 56)*

Our students need process-orientated thinking and other skills that employers now require. They cannot be stagnant thinkers who merely have knowledge, but, rather, they need to be able to apply their skills to solve problems. We need to equip them with the skills that they need for employment and to be prepared for the dynamic nature of the 21st century workplace. These skills may include critical thinking skills, reasoning and adaptability, as well as communication and collaboration (Van Heuvelen, 2001; Buckingham Shum and Crick, 2012). The term 'critical thinking' is often used and requires thinking with an open mind that is able to reason and dispassionately consider the evidence available to draw a considered conclusion (Willingham, 2008).

Not only do we need citizens who can use information generally, we also need specialists in the science-related fields where there is considerable development and innovation at the moment. The NGSS justify the importance of a practice-based science curriculum:

*"There is no doubt that science - and therefore, science education - is central to the lives of all Americans. Never before has our world been so complex and scientific literacy is critical to making sense of it all. Science is also at the heart of America's ability to continue innovating, leading, and creating jobs for the future. That's why all students - regardless of whether they pursue college or STEM careers - should have access to a high-quality K-12 science education." (NGSS Lead States, 2013, NGSS Front Matter)*

A priority of the Sustainable Development Goals is to increase the proportion of adults and young adults who have skills that are relevant and empowering for employment and entrepreneurship and to see the country into the 4th

Industrial Revolution (StatsSA, 2019). Such skills need to be a product of our education system (StatsSA, 2019). Science is considered a 'gateway subject' to higher education and it is encouraging to note that between 2010 and 2018 there was a 34.4% increase in the Science, Technology and Engineering graduates from South African higher education institutions (Rasool, 2021).

The physics content that is taught at school is often forgotten beyond the classroom. Besides, in the age of internet search engines and Artificial Intelligence, factual information is easily accessed and so retaining it is not as important as it may have been in the previous century. Different skills are needed in the 21st century. In the modern working environment, simple activities are increasingly automated and skilled workers are required to use data to solve complex problems creatively, to make decisions based on evidence, to justify their opinions and decisions and to communicate and collaborate with others (Etkina and Van Heuvelen, 2007; Etkina, Karelina and Ruibal-Villasenor, 2008).

It is increasingly important to equip students with the skills to be able to search for, engage with, critically evaluate, apply and use information, rather than to remember facts (Duggan and Gott, 2002). The procedural skills of science (the ability to collect meaningful data, look for a pattern in data and come up with an explanation for observations) are important for so many professions (Etkina, 2023). In science-affiliated industries, procedural knowledge is often more important than conceptual knowledge, which tends to be very context-specific and can be learnt on the job on a need-to-know basis (Duggan and Gott, 2002). All citizens should be able to evaluate information and consider the validity of the source of the information (Duggan and Gott, 2002). The physics classroom can provide a context to help students develop these skills that will be useful and applicable in other aspects of their lives (Etkina, Karelina and Ruibal-Villasenor, 2008).

In the specific context of this study, the majority of students continue to tertiary study. It is important that a culture of learning, as well as the will and confidence to learn (Wilson-Strydom, 2015) and the skills of learning are developed at school to assist university readiness. At tertiary level, students are expected to work independently towards understanding and to take ownership of their learning as autonomous learners (Ellery, 2021). In our context, at high-school level, students are given more guidance, but should be developing autonomy and independence in preparation for future study.

### *1.2.2 The South African context*

The South African schooling system provides education for children from the age of 6. There are thirteen years of schooling divided into two bands: General Education and Training (GET) and Further Education and Training (FET). The GET band accommodates students from Grade R (age 6) and then Grade 1 to Grade 9 (up to the age of 15), while the FET band includes Grades 10-12. Schooling is compulsory from the age of 7 until a student turns 15 or reaches Grade 9 (South African Schools Act 84 of 1996). Approximately 30% of students in South Africa drop out of school after Grade 9, not completing Grade 12 (OECD, 2019b). This has a significant impact on the employment prospects for these students in a country where the unemployment rate hovers around 50%, with 66% of the youth (ages 18-25 years old) being unemployed (OECD, 2019b).

The NCS is a document that sets out the general aims or learning outcomes of the South African curriculum and then provides specific aims for each subject. This document "aims to ensure that children acquire and apply knowledge and skills in ways that are meaningful to their own lives." (Department of Basic Education, 2012). The NCS aims to equip all students for 'meaningful participation in society' and to prepare them for further study or the workplace. One of the principles stated in the document is "active and critical learning: encouraging an active and critical approach to learning, rather than rote and uncritical learning of given truths" (Department of Basic Education, 2012). This concurs with research that cognitively challenging and interactive classroom tasks retain students' motivation and interest more than rote learning tasks, particularly for younger students (Mant, Wilson and Coates, 2007).

The National Curriculum Statement is supported by the National Curriculum and Assessment Policy Statement (CAPS), which provides specific assessment guidelines for teachers. This document specifies content and skills that should be taught for each subject. Section 1.2.3 will elaborate on the aims pertaining to teaching science. Amongst the general aims of the NCS given in the CAPS (Department of Basic Education, 2012, p. 5), are four that resonate with this study: the NCS

> *"aims to produce learners that are able to:*
>
> - *identify and solve problems and make decisions using critical and creative thinking;*
> - *work effectively as individuals and with others as members of a team;*
> - *communicate effectively using visual, symbolic and/or language skills in various modes;*
> - *demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation."*

The schooling profile in South Africa is significantly impacted by socio-economic factors. Schools in South Africa fall into four main categories, based on the resources that they have, which usually determines the fees that students pay to attend the school. Low- or no-fee public schools in rural or urban areas are often poorly resourced, while schools in urban areas tend to be better resourced. Fee-paying public schools are better resourced than no-fee-paying schools in the townships. In addition to the public schools, there are independent schools, which often charge high tuition fees and are thus accessible to only the wealthy or a few who are awarded scholarships to attend such schools.

Public schools fall under the administration and governance of the Department of Basic Education (DBE) and write the final assessments administered by the DBE. Independent schools have greater freedom in what material is taught, as well as how it is taught, and many such schools prepare their students to write the assessments administered by the Independent Examination Board (IEB). Whichever national exit examination is written in Grade 12 (IEB or DBE), the curriculum examined is based on the NCS and both examinations are governed by the quality assurance body, Umalusi (Umalusi, 2024).

The distribution of qualified teachers is as disparate as the distribution of physical resources, which compounds the problem of unequal education opportunities and reinforces the socio-economic divide (Reddy et al., 2022). The availability of resources, class size and teacher training (which may impact teacher confidence) often influences the teacher's pedagogical choices, with teachers in well-resourced schools choosing to use guided inquiry, while teachers in poorly resourced schools tend to use an 'active direct' approach (Ramnarain and Schuster, 2014). An active direct approach is when a concept is taught directly, but is followed by a practical task that verifies the concept. A guided inquiry approach allows students to engage with concepts and experience the scientific inquiry process, which teaches valuable skills, even though these are not assessed in most examinations. Teachers tend to choose guided inquiry with conscious scaffolding over open, unstructured inquiry, citing a lack of time to complete the large curriculum in the limited time available (Ramnarain and Schuster, 2014).

The independent schools at which I teach (which are the focus of this study) are well-resourced, elite institutions which offer education to a privileged minority who can afford the tuition fees or are awarded merit scholarships to attend. The experiences and expectations of my students are very different from those of students at the majority of South African schools.

### *1.2.3 Science education in South Africa*

In South Africa, all Grade 8 and 9 (ages 14-15) students study Natural Sciences, a subject which comprises topics from physics, chemistry and biology. In Grade 10, students choose the subjects that they will specialise in for the remainder of high school (Grades 10-12, ages 16-18). South African students write a national, externally set exit examination at the end of Grade 12, which is considered high stakes as it determines their eligibility to enter tertiary education. Students are required to offer[1] a minimum of seven subjects, which must include a first language, a second language, mathematics or mathematics literacy and life orientation. Physics and chemistry are examined as a single subject, Physical Sciences, comprising two papers: Paper I is physics and Paper II is chemistry. Teachers find it challenging to complete the Physical Sciences curriculum, due to the large volume of content that both physics and chemistry require and the limited time available.

The final (exit) physics examination assesses students based on their performance on traditional physics problems, their calculation skills and their application of conceptual understanding. Although research has shown that discovering content and building understanding yield better retention of knowledge (Hake, 1998), teachers have a responsibility to complete a very large curriculum over the three senior years of high school. The teachers are thus challenged to use methods that prepare students to pass a high-stakes exit examination that will determine their access to future study, while encouraging active learning and student participation to develop deep understanding and learning. With time, these two goals (deep learning and

[1] The term 'offer' is used in DBE circulars to mean 'take' or to write.

academic achievement) might be achieved by the same path, but with little time, efficiency needs to be considered.

The CAPS for Physical Sciences lists amongst its aims that Physical Sciences should equip students with skills for investigating, for “designing an investigation, drawing and evaluating conclusions”, for reflecting and for future learning, citizenship and holistic development (Department of Basic Education, 2012). The reality in South Africa is that these aims are aspirational and not always achieved, evidenced by the poor pass results (Department of Basic Education, 2024). The Trends in International Mathematics and Science Study (TIMSS) 2019 report differentiates between the intended curriculum (the NSC and CAPS), the implemented curriculum (classroom practice) and the attained curriculum (measured by student outcomes) (Reddy et al., 2022).

The 2019 TIMSS reported South Africa as the lowest performing country among the 39 countries who participated, although South Africa was the country that showed the most significant improvement since the 2015 study (Reddy et al., 2022). A concerning 64% of South African Grade 9 students did not demonstrate basic scientific knowledge in the Grade 9 TIMMS test, although 1% of the students achieved exceptional scores (Reddy et al., 2022). Students at fee-paying schools achieved better TIMMS results on the whole, while many at no-fee paying schools scored poorly (Reddy et al., 2022). The 2019 TIMSS reported that there was a significant difference in the achievement of students who are taught science by a teacher with a science specialisation and those taught science by a teacher whose specialisation is not science (for example, where a life sciences teacher steps in to teach physics) (Reddy et al., 2022). This points to the importance of the process of teaching science, the behaviours that are inculcated and the process of apprenticeship to develop scientific thinking (described in more detail in Section 2.3.2).

### 1.3 Problem statement

Previously, knowledge was produced within a defined discipline and often access to information and decision-making power was held in hierarchical management structures. Knowledge is now generated through greater collaboration among colleagues and between disciplines, where mutual learning occurs and plans emerge from discussion and shared ideas in a far more horizontal manner (Gibbons, 1994). We need to teach our students to communicate their scientific thinking, as well as teaching them to think scientifically (Ruibal-Villasenor et al., 2007).

Physics is perceived as a difficult subject and it is acknowledged to be cognitively challenging (Angell et al., 2004; Ekici, 2016). This may be attributed to the connections that have to be made between physical contexts and the abstract representations that are used to apply appropriate mathematics to solve problems. In addition to the challenges and complexities of physics itself, mathematical competency is needed and poor mathematical skill can hinder learning in physics (Meltzer, 2002; Angell et al., 2004). Meltzer and Otero (2015, p. 455) write about a "deep concern for improving access to and understanding of the principles and process of physics". One of the ways of 'improving access' is to change the way in which physics is taught at high school.

Traditionally, physics has been taught as a collection of facts and laws that students need to learn or that teachers need to 'deliver' or 'present' to transfer to their students (Etkina, Brookes and Planinšič, 2019). However, our understanding of how students learn has changed from this transmissive view of knowledge (Planinšič and Etkina, 2014). Knowledge is not an object that can be transferred from teacher to student or copied from a textbook or gained from visiting the library, despite the way that we talk about knowledge (Etkina, Brookes and Planinšič, 2019); for example, saying that the concepts are 'in the book'. Instead, we should think of physics as a process of thinking and so our classrooms need to provide opportunities for – and welcome – student participation in that process (Etkina, Brookes and Planinšič, 2019). Only once we change our view of knowledge from an object to a process, will we change the way that knowledge is constructed in our classrooms.

It is also important to think about knowledge construction and the learning process when designing material (Etkina et al., 2009b). Knowledge needs to be built on and connected to existing knowledge for cumulative knowledge-building (Maton, 2009) and brought together with knowledge from other sources through an integrative knowledge-building approach in order to solve problems (Maton and Howard, 2018). We expect students to learn physics (acquire knowledge) by becoming physics knowers, but often the emphasis in courses is on the knowledge, rather than on the approach of constructing or integrating the knowledge. The activities that I have introduced (many are from ISLE or are ISLE-inspired) intentionally validate particular knower characteristics so that these can be explicitly valued and developed and so that the basis of achievement can be made known.

In addition to preparing our students to be confident citizens of an uncertain world and evaluators of truth, it is important to teach them how to learn so that they can learn effectively in future (Etkina and Van Heuvelen, 2007). We are preparing students for a future where innovation, flexibility and independent and adaptable thinking is more important than conformity and declarative knowledge (Etkina, Brookes and Planinšič, 2019). We want students to be able to apply what they have learnt in new contexts, so being able to retain what they have learnt, is important. Students who have developed appropriate learning behaviours or habits are better prepared for life-long learning (Buckingham Shum and Crick, 2012). They should be self-directed in their learning, although at high-school level, they are still learning to take responsibility for their learning and require guidance as they gain independence (Shekhar et al., 2020).

Not all of our students will go on to study physics beyond school or even beyond Grade 9, and so it is important that what we teach them is broadly applicable. The critical-thinking skills that physics can develop, can be applied in many other contexts. For example, ‘knowledge’ is widely available to all through mass media, Artificial Intelligence and social media, and anyone can add to this knowledge repository, leading to ‘fake news’ and skewed truths. Modern citizens of the world should be equipped to be responsible consumers, evaluators and creators of knowledge, able to test the validity of an argument and discern truth from unproven or unlikely information. They should be able to form and justify an opinion based on facts, which they interrogate.

Far too often, a student’s experience of physics is that a teacher tells them something which is in conflict with their experience or understanding. If the teacher’s explanation of the conflict in understanding makes no sense, the student may take it as truth ‘because the teacher said so’ (on faith) and conclude that physics is often counter-intuitive and must just be believed (Etkina, Brookes and Planinšič, 2019). We need to equip our students with the skills to decide what is true (Etkina, Brookes and Planinšič, 2019). In this age where anyone can present information, students need to be able to identify truth. If I want to make an impact, my students should question, seek evidence, reason explanations and not believe everything that an authority figure tells them. Brookes, Etkina and Planinšič (2020) suggest that teachers must remember that they are not just transferring knowledge, but rather the intentional nature of teaching to create a transformative learning experience for students that will change their mindsets, their opinions and the way that they see the world.

## 1.4 Research goal and research questions

The Investigative Science Learning Environment (ISLE) approach has been used in college and high-school level physics teaching in the United States for the past 30 years. To my knowledge, few teachers in South African schools are aware of this approach, although it is being used as a physics teaching approach in at least one South African university (University of the Western Cape, 2024). To my knowledge, no research has been done on the implementation of ISLE in the South African context.

For this study, I implemented aspects of the ISLE approach, as well as ISLE-inspired activities, in a physics course in a South African independent high school. Not all aspects of the ISLE approach were incorporated due to our context and our constraints, but the goal of the research was to determine whether the ISLE approach and ISLE activities would develop the behaviours that we value in physics students.

The valued behaviours that are important in physics and that this study seeks to develop require students to

- actively engage with concepts while learning;
- transfer their knowledge to new contexts;
- make connections between the concrete, mathematical and conceptual representations of a concept (or problem), often aided by a visual representation;
- grapple with concepts.

In order to evaluate this goal, I posed the following research questions:

1. To what extent do ISLE activities legitimate the behaviours that we value in physics knowers?

2. How does the student experience of the ISLE approach demonstrate the development of behaviours that we value in physics knowers?

## 1.5 Significance of the research

Previous studies have shown that physics can be a difficult subject as it requires students to make connections between the abstract, mathematical and concrete aspects of the same problem (Greeno, 1989). Students also need to engage with the concepts and understand them well enough to be able to apply them in new contexts. Students need to be actively engaged in the learning process and grapple with the concepts to learn how to make connections and transfer their conceptual understanding to new contexts, as neither of these abilities is easy. Through grappling with concepts, they should develop tenacity to see the process through, even when it is difficult. These behaviours enhance success in the process of learning physics.

We need competent physics students who can go on to fill the shortage of doctors, health care professionals, engineers, scientists and science teachers in South Africa (George Philander, 2009). We also need critical citizens who think like physicists, considering the evidence available to them when drawing conclusions, and who have the courage to grapple with issues that may be uncomfortable.

The Investigative Science Learning Environment (ISLE) approach aims to develop the behaviours that we value and to encourage students to think like physicists. The approach focusses on the process of learning, rather than the outcomes of the learning process. There is a strong emphasis on student well-being, underpinning every pedagogical decision (Etkina, Brookes and Planinšič, 2019), which is also particularly pertinent, as we are conscious of the importance of students' mental health.

I have implemented aspects of the ISLE approach, which strives to be transformative. I hope to share what I have learnt about this approach in my context through the process by writing, and through future teacher development and mentorship initiatives. I hope to emphasize the learning process instead of the outcome and the importance of developing valued behaviours in our students rather than just imparting knowledge.

My contribution to the field of physics education focuses on the physics knower. The behaviours that we value in physicists and that need to be developed in the learning process, are often overlooked, in favour of a focus on the content knowledge that is taught. This study emphasizes the importance of an explicit focus on the learning process and the development of these valued behaviours. These behaviours are emphasized in the ISLE approach.

The ISLE approach has not been viewed through the analytical framework of Legitimation Code Theory (LCT) and I believe that LCT provides an appropriate lens to view ISLE. ISLE and LCT share fundamental outlooks, such as a view that all students should have equal access to learning and that the knower should be valued throughout the learning process (Brookes, Etkina and Planinšič, 2020; Ellery, 2021).

## 1.6 Personal motivation

Through the reading that I did for the research toward my Master of Science degree, it became clear that my often-didactic style of teaching needed to change and rather focus more on what – and how – students were learning. Having learnt more about how students learn, I could not continue teaching as I had in the past (Brookes et al., 2012). I was exposed to many different methods of teaching in my reading, but as I read more about the ISLE approach, it resonated with me for a number of reasons, particularly the value placed on:

- student well-being in this time when mental health is gaining consideration
- the process of learning, rather than the outcome

- the student: valuing who they are and what perspective they bring to the physics classroom and ensuring that they feel valued.
- the development of abilities that will be useful in the future
- developing critical citizens who have the confidence to challenge unfounded claims of truth.

When I read the passage below from Etkina's Millikan award lecture, it reminded me why I became a teacher: my hope to positively impact the lives of the students that I encounter:

Etkina quoted the principal, Zavelsky, of the school where she taught, who said: "Very few of your students will become professional physicists, so what should they *really* learn from you?" (Etkina, 2015, p. 669)

When I ask myself, "What do *I* want students to learn in *my* classroom?", I hope that my students will:

- value the process of learning and develop curiosity and a passion for learning.
- see learning as a transformative experience.
- develop tenacity and determination, and relish a challenge.
- take ownership of their learning and see themselves as capable and valued as students and human beings.
- value their peers and to be inclusive of others in their behaviour and their thinking.
- be motivated to bring about positive change both where they are and in the future.
- construct a good understanding of physics that will open doors to exciting future paths where they can find fulfilment, joy and have the opportunity to make a difference.
- develop the courage to challenge information that is represented as truth, but that has not been tested or substantiated with evidence,

particularly when that ‘truth’ is damaging to them, to others or to the environment.

Teaching physics is important, and it is an additional privilege helping young people to feel valued while challenging them to think about how they think and what they can do.

# CHAPTER 2: REVIEW OF LITERATURE

*"We have found that what students need the most is not self-esteem boosting or trait labelling; instead, they need mindsets that represent challenges as things that they can take on and overcome over time with effort, new strategies, learning, help from others, and patience. When we emphasize people's potential to change, we prepare our students to face life's challenges resiliently."*

(Yeager and Dweck, 2012, p. 312)

This chapter situates my study in the field of education research and specifically Physics Education Research. Applicable education research theory about learning is discussed before a brief history of Physics Education Research (PER) is given as background. I introduce some important themes in PER in more detail, such as transfer of concepts, scaffolding and the use of representations, before describing some theories of learning that are relevant to the field, and which are appropriate to my study. Lastly, I introduce the literature around formative assessment, reflection and student epistemology.

## 2.1 General education research on learning

Education research aims to understand how students learn and how, with improved teaching methods, learning can be improved. Physics Education Research (PER) investigates how physics learning can be enhanced through the use of research-informed teaching methods and the ISLE approach is an example of teaching approach that it informed by research. The Investigative Science Learning Environment (ISLE) approach to learning physics is described in detail in Chapter 3, but many of the principles of the ISLE approach are built on, or related to, general education theory and then, specifically, to PER. The ISLE approach values collaboration and the process through which students construct an understanding of concepts through active engagement and therefore sociocultural theory, collaborative learning and active learning are important underlying principles.

### 2.1.1 Sociocultural theory and collaborative learning

According to Vygotsky (1978), learning occurs first through cooperation and interaction with others and then individually. A consequence of this is that learning with others, which encourages dialogue and collaboration, is thought to improve learning (Sedlacek and Sedova, 2017). Sociocultural theory suggests that learning happens when students are in dialogue, taking them from what they can achieve on their own to what they can achieve with guidance (Applefield, Huber and Moallem, 2001). This progression may be scaffolded to assist students to move towards greater self-regulation and independence (Watson, 2001). *Constructivism* advocates that knowledge is constructed, rather than transmitted (Applefield, Huber and Moallem, 2001) and *social constructivism* contends that students learn through social interaction in a specific context (Adams, 2006). Adams (2006) summarises the ideals of social constructivism, which are:

- learning, rather than performance, should be the focus
- students construct their own knowledge and understanding.
- the teacher is present as a guide, not an imparter of knowledge.
- activities through which knowledge and understanding are built, should be seen as worthwhile.
- the student should be actively involved in the assessment process so that it becomes a dialogue to ensure understanding.

This emphasis on constructing knowledge shifts the focus of classroom activities from the *outcome* of learning to the *process* of learning. Students can follow individual paths to understanding and construct knowledge in different ways, but this is facilitated through social engagement with the teacher and their peers (Adams, 2006). Such a learning community, where students and teacher collaborate to construct knowledge and solve problems, needs to be established and managed through careful planning by the teacher (Applefield, Huber and Moallem, 2001). If students forge their own path to knowledge construction without dialogue or engagement with others, they run the risk of constructing knowledge that is inconsistent or incorrect and so learning environments need to provide opportunity for the negotiation of meaning (Etkina, Brookes and Planinšič, 2019). Active participation is vital in collaborating and engaging with others.

### *2.1.2 Active learning*

The constructivist view advocates active learning which is when students "deliberately take control of their own learning and construct knowledge rather than passively receiving it" (Schell and Butler, 2018, p. 2). This may involve any classroom activity which engages students in the learning process, whether through solving problems, answering questions, discussing concepts with peers in small groups, or teaching others (Nguyen et al., 2021). Students who are fully engaged in the learning process tend to learn more than those who are passive (McDermott, 1991; Singh, 2009). Students' assimilation of new knowledge into an existing knowledge structure is an active process (Egan and Greeno, 1973; Novak, 2006; Schell and Butler, 2018). Assimilating new knowledge requires a process of adjusting ideas and abstracting concepts based on observations and experience, so that concepts align with personal experience and with concepts accepted by the community (Otero, 2009).

While facts may be easily memorised, new processes (knowing *how* to do something) require much practice to master (Michael, 2006). It is important that students are exposed to opportunities to develop their skill in following these processes through practice and also that they are given feedback in their application and use of these processes (Michael, 2006).

Active learning means greater engagement – with content or with peers or with the teacher, or with all of the above (Ueckert and Gess-Newsome, 2006). Successful active learning requires an environment curated by the teacher to enable meaningful learning (Michael, 2006), while careful planning is needed to achieve this. Students need to actively engage with content through participation in learning activities under their control, based on an awareness of what they understand and do not understand, and they need to revisit concepts intentionally and thoughtfully. At the same time, students need to be given feedback on their understanding to facilitate effective learning (Ueckert and Gess-Newsome, 2006). Active learning requires students to take responsibility for their learning, but appropriate scaffolding is needed for students to develop the desired behaviours and approach, particularly initially (Shekhar et al., 2020). Scaffolding is discussed in Section 2.2.2.

Despite the benefits described, there is some opposition to active learning. For instance, Waldrop (2015) suggests that a badly taught active lesson is less effective than a lecture. On the one hand, teachers are reluctant to relinquish control of the classroom, particularly as the lesson could be unpredictable (Waldrop, 2015). Careful preparation and planning and guidance from the teacher, which includes walking round the classroom and monitoring student progress during the activities, are strategies that have been shown to assist successful implementation of active learning (Nguyen et al., 2021). On the other hand, studies have shown that students may respond negatively to an active learning approach, which discourages teachers from persevering with the approach (Shekhar et al., 2020; Nguyen et al., 2021), Students cite reasons for their negative experience of active learning such as the misalignment between the course outcomes assessed in examinations and the lessons learnt in active learning activities, the difficulty of the activities and consequent effort required, and the effect on their confidence (Shekhar et al., 2020). Emphasizing the purpose and benefits of active learning improves student buy-in and sufficient scaffolding helps to avoid cognitive overload (Shekhar et al., 2020).

Students do not spontaneously engage in active learning, particularly initially, so the scaffolding and guidance is important when implementing an approach that encourages active learning (King, 1993). Teachers can prompt active engagement through activities or instructions that call for particular behaviours (Chi and Wylie, 2014). Such activities might include asking students to reflect on how they learnt a concept or having them explain why they answered a question incorrectly in a test and how they have corrected their understanding to answer it correctly.

According to McDermott (1993), conceptual change requires active learning and intellectual engagement, and conceptual change results in learning. Thus, compared to traditional lecture-style teaching approaches, active learning methods, where the emphasis is on conceptual understanding, can improve the performance of students (Van Heuvelen, 1991b; Mazur, 1995; Hake, 1998). Teaching approaches that incorporate problem-based learning activities, demonstrations and practical investigations are discussed alongside the ISLE approach to practical work in Chapter 3.

## 2.2 Themes from Physics Education Research literature

In the 1980s, Physics Education Research (PER) was pioneered by Lillian McDermott, along with other academics who were invested in improving the teaching of physics at all levels. PER has gained status and credibility over the past few decades and provides valuable insight into how students learn (American Physical Society, 1999). As a result, research tools have been designed to measure the impact of teaching innovations on learning gains, confidence and conceptual understanding. These research tools are available from the PhysPort website (AAPT, 2019).

Approaches to instruction that are informed by PER are known as *reformed approaches* and they tend to emphasize physics learning over physics teaching. These include peer instruction (Mazur, 1995), an emphasis on using multiple representations and translating between them (Van Heuvelen, 1991a), self-explanation (Chi et al., 1994) and categorisation of problems (Mason and Singh, 2016a). PER often considers the effect of an intervention, perhaps on conceptual understanding or attitude to learning, but few studies focus on the process of learning (Etkina, Karelina and Ruibal-Villasenor, 2008). This study focusses on the learning process.

As a body of research, PER has developed themes and concepts that are used to explain observations and findings. This section introduces those that are relevant in this study. This conceptual framework includes the ideas of transfer, scaffolding and the use of representations. The concepts of expert and novice problem-solvers and the characterisation of problems based on their underlying physics are closely related.

### *2.2.1 Transfer of concepts*

It is evident that a student understands a physics concept when they are able to apply it in a new or similar context from the one in which they originally learnt the concept. This application of a concept in a different context is called 'transfer' and provides evidence of meaningful learning. Merely memorising a concept will not enable the student to apply it appropriately, so transfer is often used as a measure of conceptual understanding (Yerushalmi et al., 2009). This is an essential skill in physics and one of the behaviours that is valued in this study.

### *2.2.2 Scaffolding*

As students solve problems and learn new knowledge, scaffolding provides guidance, structure, and sometimes additional steps, in the process to help them, until they are able to perform tasks without the scaffolding (Dawkins, Hedgeland and Jordan, 2017). Importantly, scaffolding must align with, and be appropriate to, the students' prior knowledge and abilities to successfully support learning (Lin and Singh, 2015). The scaffolding used in building can provide a useful analogy: scaffolding is used in the construction process to provide access and support and, when the scaffolding is no longer required, it is removed, and the structure remains permanently in place. Scaffolding in learning temporarily provides an appropriate support that can be reduced and then removed once the new knowledge structures are in place. Physics teaching needs to provide scaffolded support to students as they construct a knowledge structure of physics concepts, which they need to learn to access and activate appropriately to analyse and solve problems (Van Heuvelen, 1991a).

While some scaffolding is vital for demanding tasks, such as ISLE design experiments, too much scaffolding can detract from learning as students need to be challenged and engaged to create their own understanding (Etkina et al., 2009b). The scaffolding can initially be constructed by the teacher or the task, but the learning process needs to empower the student to self-scaffold their own knowledge construction (Etkina et al., 2009b), enabling them to become independent learners.

Scaffolding can increase students' awareness of problem-solving processes (Etkina et al., 2009b) or it can assist with concept development and acquisition. If students are able to see the scaffolded steps, then they learn to ask themselves the right questions and learn to self-scaffold (Etkina et al., 2009b). Asking these questions can help students to connect concepts and domains and can assist as they grapple with concepts. It is thus important to make the scaffolding explicit and draw students' attention to the learning process, so that they can learn to self-scaffold, which will support the development of valued behaviours.

### 2.2.3 <u>Representations</u>

The ability to use representations is vital in problem solving and in developing a conceptual understanding of physics. Experts are able to seamlessly translate between different representations, as discussed in greater detail in Section 2.3.1. Novice students find it difficult to see the coherence of different representations and are not easily able to translate a scenario into representations that are different to the one that was provided (Van Heuvelen, 2001). When problem solving, we use both internal and external representations, created in our minds and drawn on paper, respectively (Larkin and Simon, 1987) and these internal and external representations need to be coherent. In this section, I will discuss the importance and relevance of visual representations, particularly diagrams and free-body diagrams, while the theory of representations is discussed in Section 2.3.1.

In physics, diagrams are a construction of a visual summary of the problem under consideration, showing the information relevant to the problem and a diagram can also show a change in the scenario or a sequence of events (Van Heuvelen, 1991a). The translation of words and verbal descriptions into a diagram requires deep engagement, which enhances learning (Scheiter, Schleinschok and Ainsworth, 2017). Drawing quality diagrams has been shown to support problem solving, particularly if these diagrams are detailed (Maries and Singh, 2017) and when free-body diagrams are drawn (Maries and Singh, 2018).

Despite the positive correlation between drawing a diagram and problem-solving success, students do not appear to appreciate the value of drawing a diagram and often do not spontaneously draw one, in the absence of an instruction (Larkin and Simon, 1987; Van Heuvelen, 1991a). It has been shown that prompting students to draw a diagram, may improve the frequency and quality of free-body diagrams (Heckler, 2009; Maries and

Singh, 2017). Consequently, students are encouraged to draw diagrams in many introductory physics courses (Maries and Singh, 2013; 2017).

The Examiner's report for the 2023 IEB Paper 1 stated,

> *"Candidates are encouraged to draw diagrams (even if just arrows and values) to help them visualise and solve problems". And "in future, more space will be provided for the multiple choice questions and candidates will be encouraged to use this space for rough work in order to answer the questions, as few multiple choice questions can be answered without some working." (IEB, 2024, pp. 1-2)*

Here the assessment is encouraging the drawing of diagrams, although no credit will be given for the diagram.

### *2.2.4 Expert vs novice characteristics*

The concepts and theory of physics fit together to form an interconnected structure. As students encounter new concepts, they need to organise their learning into a knowledge structure and 'file' the information appropriately. This allows them to recall the appropriate required information for future use (Greeno, 1989). In physics education literature, reference is often made to an expert approach and a novice approach to problem solving. Students usually display a novice approach when they first encounter physics (McDermott, 1993). In their knowledge structure, experts in physics have a large collection of subject knowledge that is structured in such a way that they can access the relevant knowledge and show that the connections and relationships between the knowledge is evident (Cahill et al., 2018). Novices find it difficult to access the information that is relevant to a particular problem, since they have less structure to their stored knowledge and are often unaware of the connections (Van Heuvelen, 1991a).

This comparison in knowledge structures is illustrated in Figure 2.1, which likens the novice's knowledge structure to a disordered pile of tools, while that of an expert is organised and ordered. It would be easier to find the appropriate tool in the expert's ordered tool collection, than in the novice's disorganised collection – everything has its place in the organised structure. This analogy implies that both the novice and the expert have the same number and quality of tools in their collections, which is not always the case.

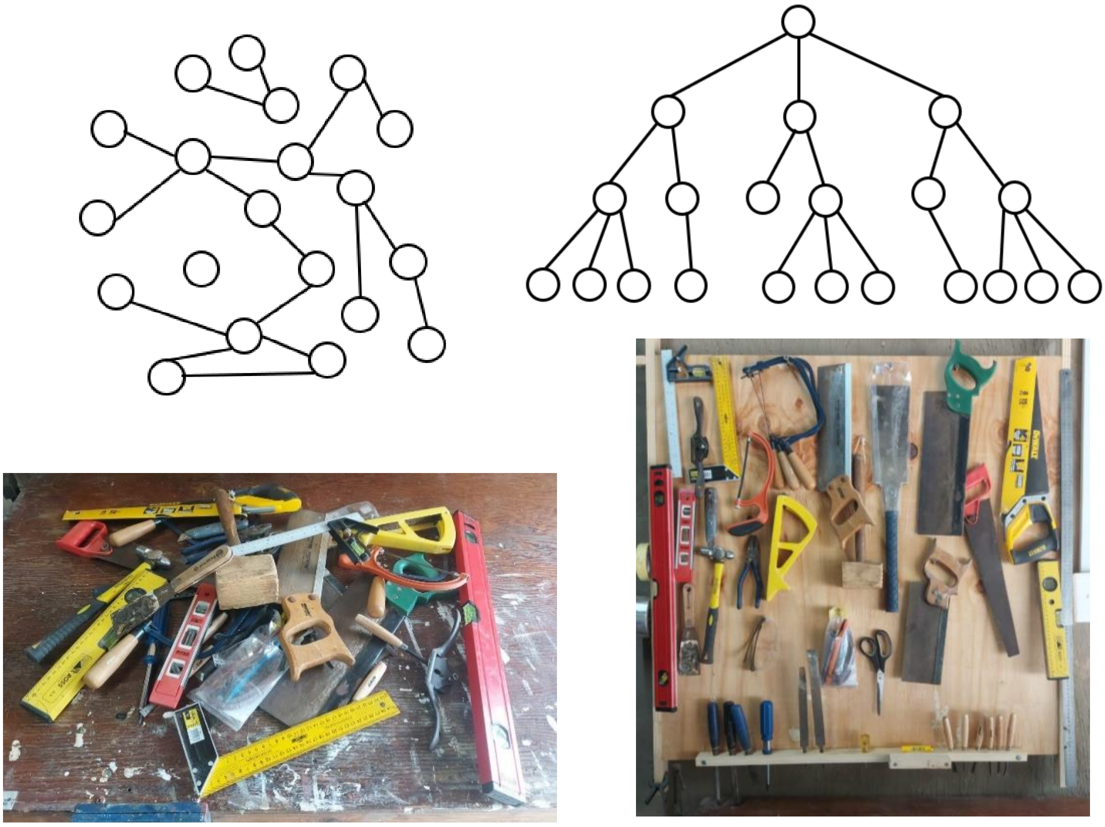


**Figure 2.1:** A diagram to illustrate the difference between the disordered knowledge structure of a novice physicist (left) and the organised knowledge structure of a physics expert (right).

When encountering an unseen problem, expert and novice problem-solvers often have different approaches. Expert problem solvers begin by analysing the problem to determine which principle or approach would be most appropriate in solving the problem, while novice students' problem-solving strategies are often guided by the surface features of a problem (Chi, Feltovich and Glaser, 1981; Kohl and Finkelstein, 2006). As mentioned, experts have a large collection of problem-solving sequences from which they can choose from when faced with an unseen problem (Larkin et al., 1980). Novices, on the other hand, tend to search for a formula, without necessarily understanding the connections between values or the concepts or the implications associated with the formula (Dhillon, 1998).

For example, when an expert is asked to find the acceleration of an object on an incline, the problem situation will prompt them to access their ‘object on an incline’ knowledge structure. They will consider the forces acting parallel and perpendicular to the incline and will most likely draw a free-body diagram including the perpendicular components of the weight. A novice may start with the formula $F_{NET} = ma$ and get stuck there, as they may not have an ‘object on an incline’ knowledge structure in place. Alternatively, they may have the ‘object on an incline’ knowledge structure, but it may not be obvious to them that this is the appropriate set of tools (or problem-solving procedures) that they should use. This may be because they are not correctly linking the concrete scenario to the appropriate abstract concept (this idea is elaborated further in Section 2.3.1). If the object on the incline was a box, and the novice had previously solved other questions with a box on a horizontal surface, they may be searching their knowledge structure for the ‘box’ tools rather than the ‘incline’ tools. This illustration shows that novice problem solvers struggle to see the similarities between problems with the same underlying physics, as they are looking at the symbols and surface features, rather than at the underlying physics concepts across similar problems (Sweller, 1988).

#### *2.2.5 Categorisation of problems: physics concepts vs surface features*

Experts categorise each physics problem according to the *physics concept* that needs to be applied to solve it, while novices see the *surface characteristics* of the problem. ‘Physics concepts’ refer to the principles or laws that apply, and the underlying physics knowledge that needs to be applied, in order to solve the problem. ‘Surface characteristics’ refer to the appearance of the scenario. In the example of the box on the incline, described in the previous paragraph, the physics concepts would include drawing a free-body diagram, resolving the weight into its perpendicular components and perhaps applying Newton's second law. The surface features of the problem would be what is seen or described; in this case, that is the box.

Surface characteristics do not necessarily define the physics, but describe the context of the problem. For example, in Figure 2.2, all the scenarios look different, but the object in each scenario is in equilibrium and the forces acting on the object could be resolved into their perpendicular components to solve a posed problem. The surface features (what is shown in the diagram, or the object involved) differ, but the applicable physics concept is the same in each of the four examples.

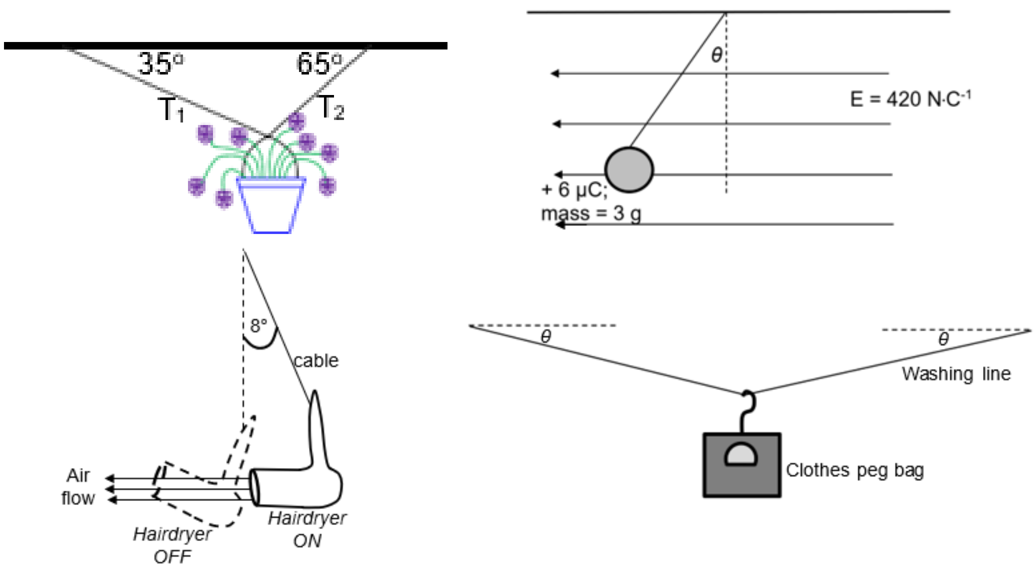



**Figure 2.2:** Examples of four diagrams from IEB examinations that have different surface characteristics, but require the application of the same physics concept.

Physics problems that require the application of the same physics concept to solve, even if their surface characteristics differ are called *isomorphic problems* (Singh, 2008a). Isomorphic problems are often used to test whether students are able to transfer their knowledge (see Section 2.2.1). The use of isomorphic problems, particularly with scaffolding that draws attention to the underlying physics patterns, may help students to see the characteristic features of the problems (Lin et al., 2010; Badeau et al., 2017). This categorisation of problems assists students to integrate new knowledge coherently with existing knowledge. Learning to recognise the underlying physics, rather than the surface features of a problem, takes practice and students need to be prompted to look beyond the surface features of a problem and to look for the underlying physics in order to start to see the patterns (Willingham, 2008; Berckley and Hattie, 2023).

The use of representations can assist students to see the underlying physics of a problem, as a free-body diagram or a sketch of the motion of an object that is thrown vertically upwards, represents the physics concepts, without the surface features. Translating problem scenarios into representations such as free-body diagrams or motion diagrams (or even just a sketch of the motion of an object) can help students to see that the physics concept applied in isomorphic problems is the same, even if the surface features change. This insight may help them to transfer knowledge across problems.

## 2.3 Theories of learning

In this section I will describe some of the theories of learning that are applied in PER to improve our understanding of how students learn. Although many of these were written decades ago, they remain relevant in explaining the challenges and successes that we see in student learning. I will give a brief overview of

- cognitive load theory,
- the theory of cognitive apprenticeship,
- the theory of conceptual change and
- Greeno’s model of problem solving and reasoning.

At the end of the section, I explain how each of these theories are relevant in my study.

### 2.3.1 *Cognitive load theory*

Cognitive load theory is often applied when students face tasks which have high cognitive demand (Paas, Renkl and Sweller, 2004) and so this theory is relevant in physics, which is perceived to be a difficult subject. Teachers should consider the cognitive load of a task when planning activities that they hope will build new knowledge. John Sweller's (1988) initial work on cognitive load revealed that, when faced with a challenging puzzle (or problem), subjects were unable to see the underlying patterns across the puzzles as all their mental resources were used to solve the puzzles. When cognitive load is too low or too high, learning is reduced (Paas, Renkl and Sweller, 2004) and so learning tasks should be designed to provide optimal cognitive load for learning and integration of new knowledge. The optimal cognitive load for a student depends on the capacity of their working memory (Van Gog, Paas and Sweller, 2010).

The working memory ('working space') is the component of the learning system where new information is integrated with prior knowledge through a process shown in Johnstone's (2009) model of learning in Figure 2.3. New information enters the working memory through a filter, which is particular to a person's experience, and is temporarily held while it is processed and possibly restructured (Johnstone, 2009). If the new knowledge can be linked to prior knowledge stored in long-term memory through a search and retrieve function, then the new knowledge can be assimilated and stored (Sweller and Chandler, 1991).

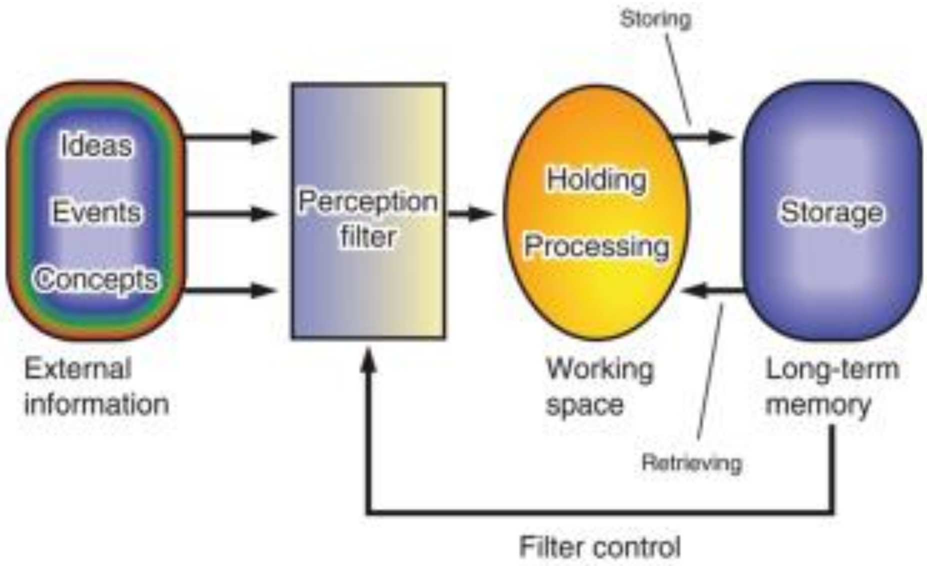



**Figure 2.3:** Johnstone's (2009) model of learning (Johnstone, 2009, p. 23).

The working memory has limited capacity. This means that while a large volume of information is held in the working memory, a limited amount of new information can be processed and integrated into long-term memory (Johnstone, 2009). The same is true for problem solving: if a significant portion of the working memory is holding information, there is diminished capacity for problem solving (Sweller, 1988). As a result of this, students should be encouraged to use visual representations (draw diagrams and write information down) so that less information has to be held in their working memory, freeing capacity for the problem-solving processes, as the paper acts as an extension of the working memory space (Larkin et al., 1980; Maries and Singh, 2013; 2017).

Scaffolding (see Section 2.2.2) the problem-solving process can also reduce cognitive load, which is particularly important when a concept is introduced, and the content is new. Limited working memory can hamper simultaneous processing of a new concept and the acquisition of appropriate problem-solving skills (Etkina, Karelina and Ruibal-Villasenor, 2008). The repeated retrieval and processing of knowledge from long-term memory, achieved through practice and repetition, reduces the cognitive load of these processes, as they become unconscious or automated (Paas, Renkl and Sweller, 2004; Schell and Butler, 2018). This is why practising routine problems and calculations is important in physics: if these basics become automated, then more space in the working memory can be devoted to conceptual reasoning and problem solving.

Characterising problems can reduce cognitive load when problem solving, as the problem-solving pathway will be a familiar one, if the student has practised similar problems (Sweller and Chandler, 1991). In contrast, students who do not see beyond the surface features of a problem (Section 2.2.4) will see every problem as different, requiring a different approach, and this results in cognitive overload (Sweller and Chandler, 1991). Worked examples can help students to characterise problems in order to reduce cognitive load (Sweller and Chandler, 1991) and also to provide the platform for cognitive apprenticeship.

### *2.3.2 The theory of cognitive apprenticeship*

The theory of cognitive apprenticeship supports the idea that students construct conceptual knowledge by social participation and following the approach of experts (Collins, Brown and Newman, 1987). This approach involves ‘modelling’, ‘coaching’, ‘scaffolding’, ‘articulating’, ‘reflection’, ‘weaning’ and ‘exploring’. A process or behaviour is *modelled* by an expert, who is explicit about their actions or thinking. Students then attempt the process themselves, with guidance or *coaching*, where the expert offers guidance, feedback and scaffolding to support and assist students to gain the skills required. *Scaffolding* provides the students with the necessary structure and prompts to support them as they develop the skills to carry out the process on their own. As they learn, students are encouraged to *articulate* their understanding, as well as their thinking, which allows the expert to guide and adjust and, at the same time, compels students to structure their thinking and interrogate coherence. Alongside this scaffolded learning and articulation of knowledge, students are prompted to *reflect* on their learning and their approach, often through comparing their approach to that of an expert or to their peers. As students gain knowledge, competence in the process and confidence, scaffolding and guidance is gradually withdrawn (*weaning*) until students are able to follow the process independently, with the input from the expert reduced to refinements. Students are then able to test and strengthen their application of the process or new knowledge through *exploring* new problems or contexts (Collins, Brown and Newman, 1987; Singh, 2008b; Mason and Singh, 2016b).

Expert physicists model the process of problem solving or behaviour, as well as modelling the characterisation of problems as they approach different problems in particular ways, based on the physics concepts that are relevant to the problem (see Section 2.2.5). Such modelling and characterisation can help students to correctly structure their new knowledge, linking concepts to the appropriate 'section' (Collins, Brown and Newman, 1987), which can assist with the transfer of concepts (see Section 2.2.1). Teachers may also model the use of representations (see Section 2.2.3) as they approach a problem and are likely to scaffold the process of problem solving, particularly when a concept is introduced (see Section 2.2.2). Ideally, students adopt the processes that have been modelled for them, asking themselves the guiding questions that they were asked during the modelling or coaching phases of the apprenticeship process and, thus, being empowered to direct their own learning (Collins, Brown and Newman, 1987). When students question and interrogate their understanding, they create an opportunity for learning through conceptual change.

### *2.3.3 The theory of conceptual change*

In the 1970's Piaget described learning as a process of integration of new knowledge into an existing knowledge structure. An adjustment of understanding may be required when there is a misalignment between the new knowledge and the existing knowledge. Piaget used the analogy of eating food, as the food is processed and absorbed, rather than just being taken up as it is, which is unlike water being absorbed by a sponge (Sutherland, 1992).

Posner et al. (1982) offered a theory of conceptual change to explain the learning process and perhaps account for student misconceptions. As mentioned, new knowledge is constructed on the foundation of prior knowledge, but needs to align with the existing knowledge to be accepted (Kural and Kocakülah, 2016). This acceptance of information that fits, is called *assimilation* (Posner et al., 1982). If there is *conflict* between the student's existing knowledge and the new knowledge, the student has to grapple with the concepts and reorganise their existing knowledge, through a process of *accommodation* (Posner et al., 1982). Once the new knowledge is assimilated and accommodation has taken place, the student reaches a new *equilibrium,* with new conceptual understanding (Sutherland, 1992; Kural and Kocakülah, 2016).

Learning occurs through this process of assimilation and accommodation, but it is not a passive process and students need tasks that challenge their current understanding in order to seek accommodation of new ideas (Posner et al., 1982). For successful learning, teaching needs to be based on the student's existing knowledge (Sutherland, 1992), which supports the idea that learning is a unique pathway for each student. However, sometimes students' existing knowledge needs to be challenged and corrected. Exposing students to problems and posing conceptually challenging questions, may induce conflict, which could prompt them to grapple with their understanding to accommodate new understanding (Applefield, Huber and Moallem, 2001).

Students need to be convinced of the new concept, often through demonstration or investigation, and given the opportunity to connect their new knowledge to existing knowledge (Kural and Kocakülah, 2016). Teaching alone is often unsuccessful in changing student misconceptions, particularly as students' real world experience is often in conflict with the Newtonian physics that we teach at high school (Nersessian, 1989). Tasks should engineer situations of conceptual conflict to offer students the opportunity to address misconceptions and to make robust connections between the newly constructed knowledge and their existing knowledge.

### *2.3.1 Greeno's model of problem solving and reasoning*

Connections are important in learning. As previously described, new knowledge needs to be connected to prior knowledge for effective learning. For effective reasoning and problem solving in physics, connections need to be made between the physical, symbolic, model and abstract representations of a concept (Gaigher, Rogan and Braun, 2007). Greeno used the term *domain*, rather than *representation* and so I use the term domain in explaining his model (Greeno, 1989). Greeno's domains are facets of physics, including the abstract, concrete, symbolic and model domains. Specific representations in physics are likely to be found in each domain. For example, equations are in the abstract domain and diagrams or visual representations are in the model domain.

Each system or problem has *objects* that interact or can be manipulated into a *structure* and this terminology is best illustrated through a common physics example, as described below and shown in Figure 2.4 (Gaigher, Rogan and Braun, 2007).

Figure 2.4 shows a crane that is lifting a load. The load, the cable and the crane are *concrete objects*, which are part of the physical domain (bottom right of Figure 2.4). These concrete objects can be manipulated into a *concrete structure*. The forces that the objects experience and the masses of the objects are *abstract entities*, which can be manipulated into concepts or laws, which are *abstract structures* (top right of Figure 2.4). These abstract entities can be represented with *symbolic notations* (objects), which can be manipulated into *symbolic structures* (top left of Figure 2.4). The system can be represented as a *structured model* of objects by a free-body diagram (bottom left of Figure 2.4).

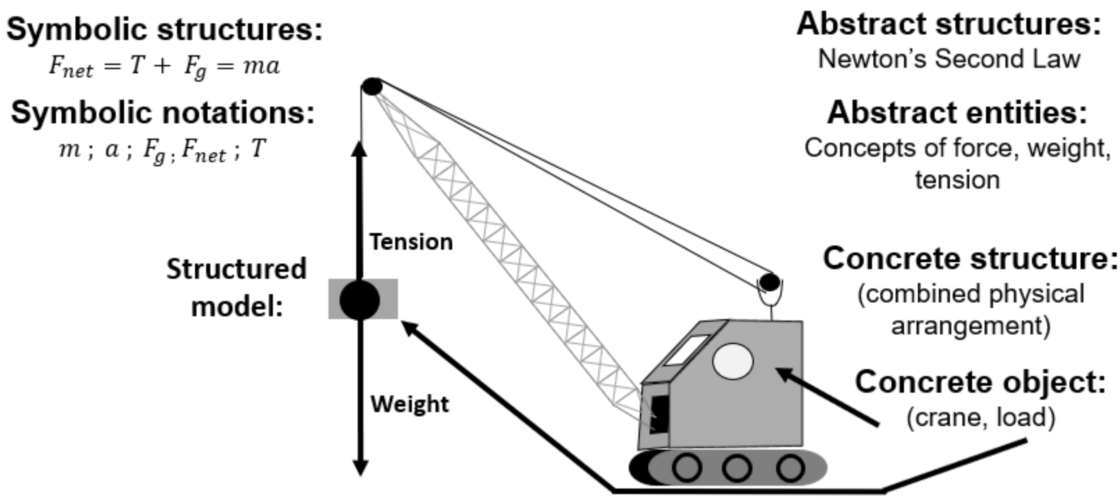



**Figure 2.4:** The multiple representations of a typical physics context, which illustrates Greeno's model of problem solving and reasoning (Cobbing, 2019, p. 20).

When experts (see Section 2.2.4) approach a physics problem or scenario, they are able to translate the problem from one representation to another, maintaining coherence in their translation (Savinainen and Viiri, 2008). Students (or novices) are often unable to make the connections between these domains and this leads to superficial - or even incorrect - application of concepts (Greeno, 1989).

Connecting the physical or concrete domain and the associated abstract concepts is particularly difficult for students, and usually requires scaffolding and guidance (Maries and Singh, 2017). Models can assist students in connecting these domains and making sense of changes in a dynamic system. Students can more easily develop meaning when they link abstract concepts and language to the real, through observation of demonstrations or visual stimuli (Van Heuvelen, 2001).

In my MSc, I proposed that the model domain could serve as a useful 'translation scaffold' to make the translation between representations more accessible for students. The model domain can include visual models and physical models such as diagrams and demonstrations, which support understanding and building connections between the other, more challenging representations, such as the symbolic or abstract (Cobbing, 2019). I used a triangular prism to represent the different representations and possible translations between them, which I adapted from Johnstone (2009) who represented the three ways in which chemical phenomena could be described with the idea of a triangle.

My triangular prism (Figure 2.5) had different representations of physics problems and scenarios at each of the vertices: physical and contextual, conceptual and abstract, and symbolic and mathematical. Each physics problem could be represented at some location in the triangle, perhaps with a more physical representation or a symbolic representation. Experts can shift between representations, and students may find it difficult to follow the teacher's translations between representations in explanations, unless these are made explicit and scaffolded (Johnstone, 2009).

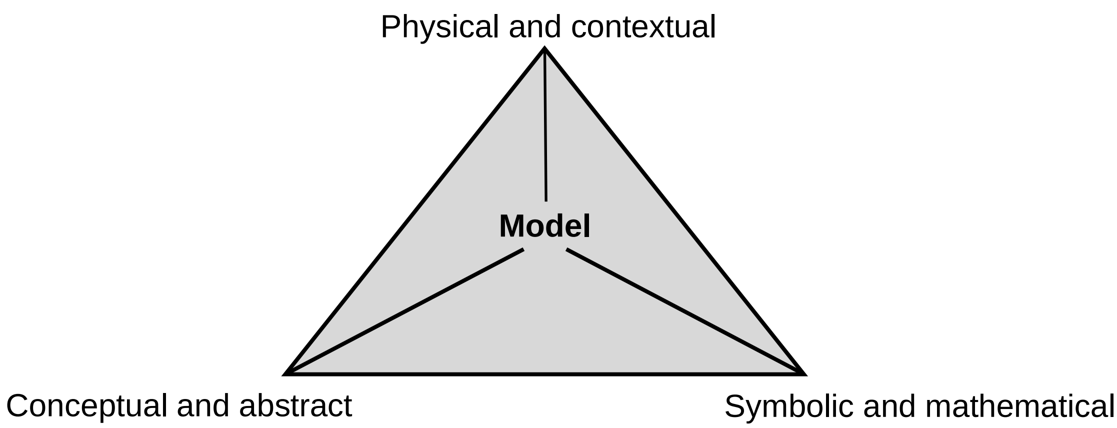



**Figure 2.5:** Four representations of a physics problem (Cobbing, 2019, p. 102).

Using the example from Figure 2.4 to illustrate the use of the triangular prism shown in Figure 2.5, a teacher may describe a crane lifting a load (physical domain), write the formula for Newton's second law on the board (symbolic domain) and ask students to determine the acceleration of the load, if the relevant forces are known (abstract domain). The teacher is able to connect these three representations, recognising that they are all representations of the same scenario. However, many students (novices) may struggle to see the connections and the coherence. By drawing a sketch (if not provided) and a free-body diagram of the forces acting on the load (using the model domain) as a 'translation scaffold', the teacher can help students to see the coherence between the representations, and students may learn to translate and move between the representations more easily. Learning to translate between representations requires students to engage and to grapple with their understanding of the connections between the representations. The model can assist students in visualising problems and making connections and also reduces cognitive load, as described in Section 2.3.1.

We value particular behaviours in the physics classroom and, in this study, I introduced activities which I hope will develop these behaviours. Cognitive load theory supports the behaviour of drawing a diagram to reduce cognitive load and structure students' thinking. The cognitive apprenticeship model explains how students are trained as physics students through scaffolded learning, modelling and coaching. Students need to experience conceptual conflict in order to change their understanding of a concept, according to the theory of conceptual change and the ISLE approach engineers such conflict so that students interrogate their understanding of a concept and correct it, where appropriate. Greeno's model of problem solving and reasoning describes the valued behaviour of connecting the different representations of a problem coherently. In this way, the students can become experts, learning how to make connections between concepts to construct a coherent knowledge structure, which allows then to transfer this knowledge to new contexts, particularly if their learning has been scaffolded. Reflection on their understanding will aid students in their transformation from novice to expert.

## 2.4 Reflection and learning

The focus of this study is on the process of learning, rather than on the outcome of the learning process, but it is nonetheless important for both students and teachers to be able to gauge the progress of learning and its success. Almost all our formal assessment tasks are summative, which focus on the outcomes of the learning process, rather than on the process of learning itself. On the other hand, the emphasis of formative assessment tasks is often on the process, and, as such, the tasks legitimate valued behaviour. Formative assessment can show both teachers and students what is known and understood and what is not yet fully understood. The assessment can be used by students to improve their learning, but also by teachers to adapt their teaching or adjust the learning environment through their own self-assessment (Etkina et al., 2006; 2009b). Formative assessment has been shown to have more significant learning gains than any other intervention (Etkina et al., 2006), although it has a greater positive impact on the academic achievement of low achievers (Black and Wiliam, 1998).

Good formative assessment provides students with feedback on their practice and on their performance to help them learn to apply knowledge through appropriate procedures (Michael, 2006). 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.” A study by Willson-Conrad and Kowalske (2018) showed that those students who demonstrated academic success, pursued feedback to improve their performance in the next assessment, which also improved their self-efficacy. Learning from feedback is not passive: students need to engage with the feedback to change their practice (behaviour).

Encouraging students to reflect on their learning and on their problem-solving approach, may strengthen the coherence of their knowledge structure and their epistemology, which, in turn, affects their study methods and improvement in understanding (May and Etkina, 2002). This may be done through having students look over work that has been corrected by the teacher, with or without feedback or by having them evaluate their own work with guidance (scaffolding). As students become more independent in their learning approach, they become more self-reliant and can learn to self-assess their own work, to self-diagnose mistakes and inconsistencies in applying concepts, and to self-explain concepts.

Self-assessment has been shown to improve student learning, particularly if students are trained or guided to self-assess (McDonald and Boud, 2003; Sadler and Good, 2006). Self-assessment should become part of the learning process and is valuable in preparing students for future learning so that they can evaluate, correct and adjust their understanding. Involving students in the assessment process also enables them to understand the purpose and process of assessment, helping them to see assessment as part of their learning (Sadler and Good, 2006). Evaluating a solution and looking for coherence and for inconsistencies requires a high level of engagement and mental processing, which can result in deep learning (Mason and Singh, 2016b), assisting the construction of a robust and coherent knowledge structure.

Self-diagnosis can be encouraged through a structured evaluation of the student's solution, when they work through a previous task to identify where they went wrong and to explain their mistakes (Yerushalmi et al., 2009). This can help them to gauge their understanding and to determine any gaps in their knowledge (Schell and Butler, 2018). A guided process of self-diagnosis, prompting students to think about how they solved a problem, can help students to make connections, add to their knowledge structure and to develop metacognitive skills (Singh, 2004). In this study, students were encouraged to reflect, to think about how they learn and how they think and to learn from their mistakes through a guided process.

Unfortunately, even though a guided process of self-diagnosis may foster habits that help students learn from their mistakes, students do not easily transfer these lessons when solving similar problems (Cohen et al., 2008; Yerushalmi et al., 2009). Students who struggle with physics, struggle to self-diagnose, as they are often unable to diagnose their errors or conceptual inconsistencies in order to learn from them. These students require specific guidance to self-diagnose, but too much guidance reduces the opportunity for learning as reflection and integration of knowledge becomes superficial (Mason et al., 2009). Hence, there is a fine balance between providing sufficient guidance for students to learn to self-diagnose their mistakes and providing too much guidance, so that they are not challenged to think about the problems independently (appropriate scaffolding by the teacher is required).

Self-explanation can also assist learning and deepen understanding as it requires students to explain their thinking (Chi et al., 1994). If prompted to identify key concepts and principles, students can improve the quality of their self-assessment and this increases the learning benefit of the task, as well as the transfer of concepts to new contexts (Van Gog et al., 2009). Students' ability to self-explain is closely related to their performance on subsequent tasks applying the same concepts (transfer): students who were able to generate better quality self-explanations were more successful in applying their understanding in future tasks, but those who had a poor understanding of the concepts to begin with, could not self-explain (Chi et al., 1989).

This chapter has described the concepts that are relevant in the context of Physics Education Research, as well as the learning theories that are pertinent to this study. Many of these are applicable in explaining pedagogical choices in the Investigative Science Learning Environment (ISLE) approach.

An understanding of these concepts and theories can offer insight into the pedagogical choices made when implementing the ISLE approach to develop physics knowers with the behaviours that we value. Active learning and the principles of constructivism (Adams, 2006) underpin the ISLE approach. Learning experiences facilitate conceptual change and are scaffolded to encourage the construction of a coherent and ordered knowledge structure (through modelling and coaching) to facilitate the transfer of understanding to new contexts. The use of representations is encouraged, to reduce cognitive load when solving problems, to help students connect the domains of a problem and to see the underlying physics concepts in a problem, rather than the surface features.

# CHAPTER 3: THE INVESTIGATIVE SCIENCE LEARNING ENVIRONMENT (ISLE) APPROACH: AN OVERVIEW

*The ISLE process allows students to "see how new physics ideas develop naturally from the need to explain something that is currently not understood, dispelling the myth that new ideas can only be created by a few brilliant and creative geniuses"*
(Brookes, Etkina and Planinšič, 2020, p. 5).

Against the background of the concepts and theories covered in the previous chapter, the Investigative Science Learning Environment (ISLE) approach is described in detail. The ISLE approach has two intentional objectives: (i) to provide activities and an environment where students can learn physics through *doing* physics and (ii) where all aspects of the learning experience seek to enhance student well-being. I will give an overview of the approach in general and then discuss the features of the approach that pertain to learning physics, while student well-being emerges as a thread through every aspect of the ISLE approach.

## 3.1 Introduction to Investigative Science Learning Environment (ISLE) approach

The Investigative Science Learning Environment (ISLE) is an approach developed by Eugenia Etkina to provide structures and activities which empower students to learn physics by emulating the actions of physicists (Etkina, 2015). The approach was first introduced almost 30 years ago at College level in America (Etkina and Van Heuvelen, 2007) and has gained traction at this level in multiple countries and, more recently, at high-school level.

Etkina was inspired as a high-school physics teacher to shift her emphasis from what she taught to what her students learnt. She pioneered the Investigative Science Learning Environment (ISLE), which is an approach where the teacher engages students in active learning and models a way of thinking about physics, in particular, and science in general (Etkina, Brookes and Planinšič, 2019). ISLE is based on Physics Education Research (PER) and provides a structure which allows students to develop scientific abilities and appropriate learning behaviours while they learn physics through curated activities, which have been developed by Etkina and her team at Rutgers University (Etkina, 2015).

The ISLE approach has two main principles which underpin the development and use of all activities. The first is that students learn physics through doing physics or mimicking the process by which physicists construct laws and concepts. The second is an emphasis on student well-being, which is critical to learning (Brookes, Etkina and Planinšič, 2020). All ISLE activities, assessments and curriculum design are based on these two underlying principles. In this study, I did not investigate the effect of the approach on well-being as my focus was on the behaviours that facilitate and support physics learning, but an awareness of student well-being and concern for improving it, underpinned all pedagogical decisions.

The sections that follow will elaborate on activities that have been developed and used as part of the ISLE approach. This approach influences the design of learning activities, classroom management and approach to assessment (Brookes, Etkina and Planinšič, 2020). A summary of the main tenets of the ISLE approach is shown in Figure 3.1 and these will be discussed through this chapter.

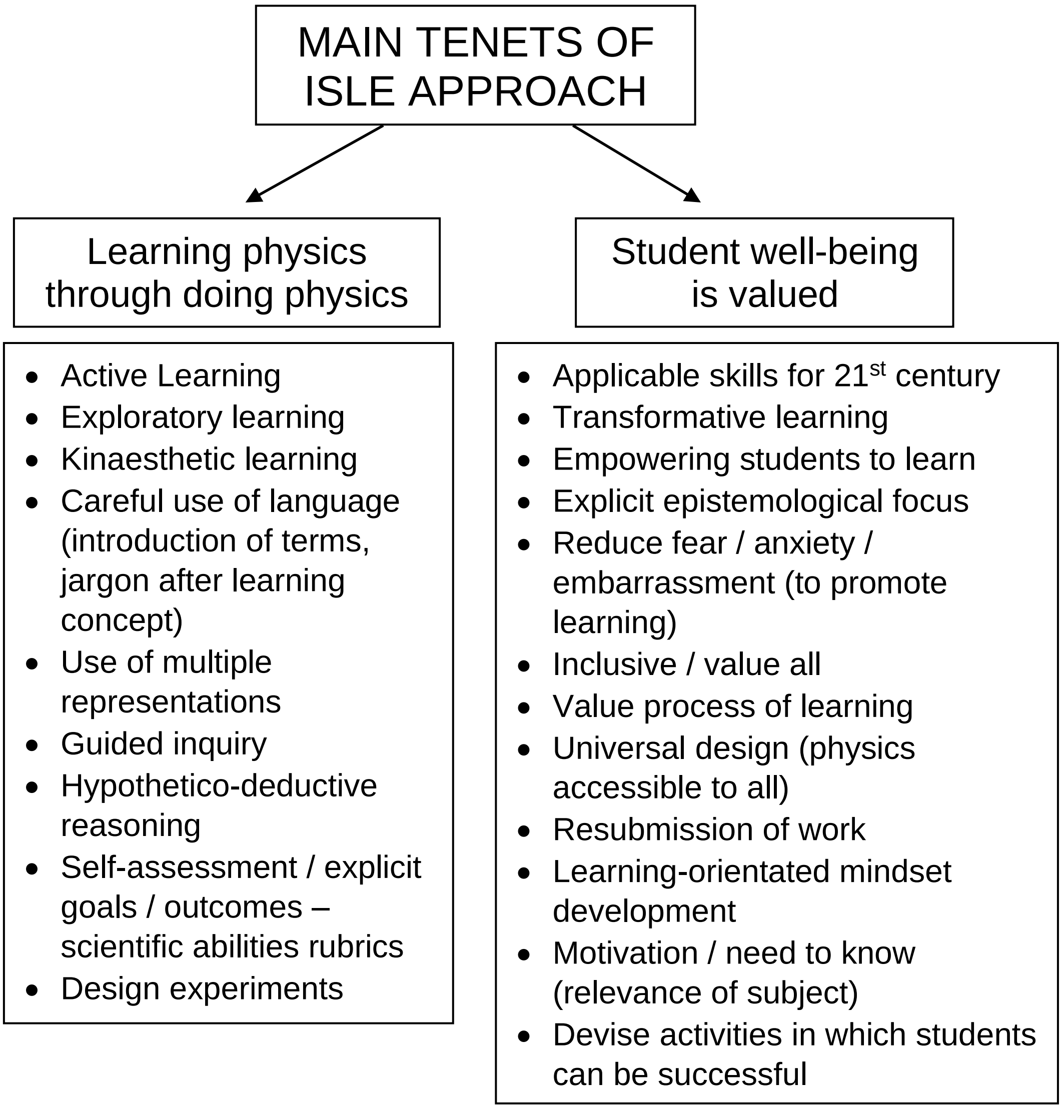



**Figure 3.1:** The main tenets of the ISLE approach (Etkina and Van Heuvelen, 2007; Etkina, Brookes and Planinšič, 2019)

The ISLE approach is underpinned by the epistemological stance that learning requires physical and social engagement, but is also individual and should prepare students for “a productive life in society” (Etkina, Brookes and Planinšič, 2019, p. 3-1). In this approach, students intentionally and regularly engage in active learning that mirrors the practice of scientists (Etkina, 2015). As described in Section 2.1.2, learning is more effective when students are actively engaged (Singh, 2009). Every student brings their own experience of the world to the classroom, and this experience is their unique platform for learning (Sutherland, 1992; Etkina and Planinšič, 2014b). Learning occurs in the brain of each student, through the formation of new connections to existing knowledge (Etkina and Planinšič, 2014b; Larison, 2022). This means that each student needs to experience the physics to internalise the concepts through kinaesthetic experiences and engagement (Etkina, Brookes and Planinšič, 2019). Kinaesthetic experiences involve physical movement to improve learning (Richards and Etkina, 2013). The concept of embodied cognition proposes that learning and understanding is rooted in our real-world experience of the environment and, even when we are later disconnected from this real-world context, we retain the pathways which were formed through interactions with the environment (Wilson, 2002).

When teachers demonstrate or tell students something, the connections are not made as effectively as when students actively experience the phenomenon for themselves (Sedlacek and Sedova, 2017; Etkina, Brookes and Planinšič, 2019). In the ISLE approach, teachers curate learning activities and engineer an environment that supports students in the construction of their own physics knowledge. Importantly, students are not left to play and discover concepts by chance, but are guided through carefully curated activities that are scaffolded and designed to create opportunities for students to discover a concept or link a new understanding to existing knowledge or even correct a prior understanding.

Although learning happens in the mind of each student, it is also a social process, aided by collaborative learning through discussion and debate (Vygotsky, 1978; Etkina and Planinšič, 2014b; Etkina, Brookes and Planinšič, 2019). The negotiation of meaning is critical to ensure that students fully understand a concept (Brookes and Etkina, 2009; Etkina, Brookes and Planinšič, 2019). The ISLE classroom is also intended to be a learning environment where the well-being of students is enhanced and it is an important ISLE underpinning that each student is included and empowered as part of a learning community and never excluded (Brookes, Etkina and Planinšič, 2020).

In most traditional teaching methods, even ‘reformed’ methods (informed by PER), knowledge comes from authority: either from the teacher or from the text book (Etkina, Brookes and Planinšič, 2019). The subliminal message that a teacher is communicating when telling their students about findings from previous centuries, is that knowledge can be passively accepted (Brookes, Etkina and Planinšič, 2020). Every physics concept and idea was developed through experiment (Etkina, Brookes and Planinšič, 2019) and just being introduced to the final product without knowing how the authority came to that knowledge, is in conflict with the ISLE approach, which challenges students to question the process. The ISLE approach puts intentional emphasis and value on the process of learning, as well as the actual learning outcome (Etkina, Brookes and Planinšič, 2019).

We want students to be ‘critical’ citizens, who can reason, and who do not believe everything that they read or are told. They should question the validity of information that is presented to them and not simply accept others’ opinions at face value. They must ask questions such as “how do you know this?” and independently evaluate the answers that they are given to form their own opinions. Being mindful of assumptions and the difference between evidence and inference can help students to become critical and independent thinkers (Etkina, 2015). It is then the hope that students will “approach life outside of the classroom with the same questioning attitude that we have tried to cultivate in the classroom” (Brookes and Lin, 2010, p. 2).

## 3.2 Description of the ISLE approach

### *3.2.1 <u>Introduction to the ISLE approach</u>*

The ISLE approach is an approach to teaching and learning physics that guides classroom practice, activities, assessment and feedback. This approach offers a set of resources and tools that enables the teacher to intentionally curate a learning experience to assist students as they become physicists (Etkina, Brookes and Planinšič, 2019; 2022). Physicists, as scientists, revise existing explanations ("anomalous data") or create new theories ("puzzling data") (Etkina and Van Heuvelen, 2007, p. 22). With the ISLE approach, students replicate how discoveries were made by observing something, trying to explain it, testing their ideas and rejecting those that fail. All aspects of the ISLE approach place equal value on the *process of knowledge construction* as on the *content knowledge that is developed* (Etkina, 2015). This echoes the aim of this study: to draw attention to the process of knowledge construction (and the role of the student's behaviour in this), alongside the knowledge.

The ISLE approach (Etkina, Brookes and Planinšič, 2019) aims to develop students (or knowers) who:

- think like scientists.
- question the source and validity of knowledge and the assumptions made when information is presented, looking for evidence.
- are able to say how they know something.
- collaborate.
- are able to communicate their reasoning.
- are prepared for a productive life.
- work independently and take ownership of their learning.
- view learning as a transformative process that might be uncomfortable.
- are actively engaged in the learning process, rather than passive observers of teaching.
- learn from their mistakes and are willing to make mistakes while learning.
- are able to identify, correct and learn from their mistakes with guidance.
- use multiple representations.
- are motivated by learning goals, rather than performance goals
- evaluate their answer.

- are mindful of the assumptions that they have made in their approach to solving a problem or conducting an experiment.

Each activity is carefully chosen or designed for reasons which will be described throughout this chapter. Broadly, the activities engage students in active learning where they answer questions and engage in group discussions and report back to the class, before the teacher clarifies and adjusts understanding (Etkina, Brookes and Planinšič, 2019). There are three main "types" of experiments: observational, testing and application, which are shown in Figure 3.2 and will be explained in the following section. In brief, observational experiments "are used to generate explanations"; testing experiments are "used to test explanations" and application experiments are "problems to solve for which one needs to synthesize multiple explanations and/or relations" (Brookes and Etkina, 2010, p. 605).

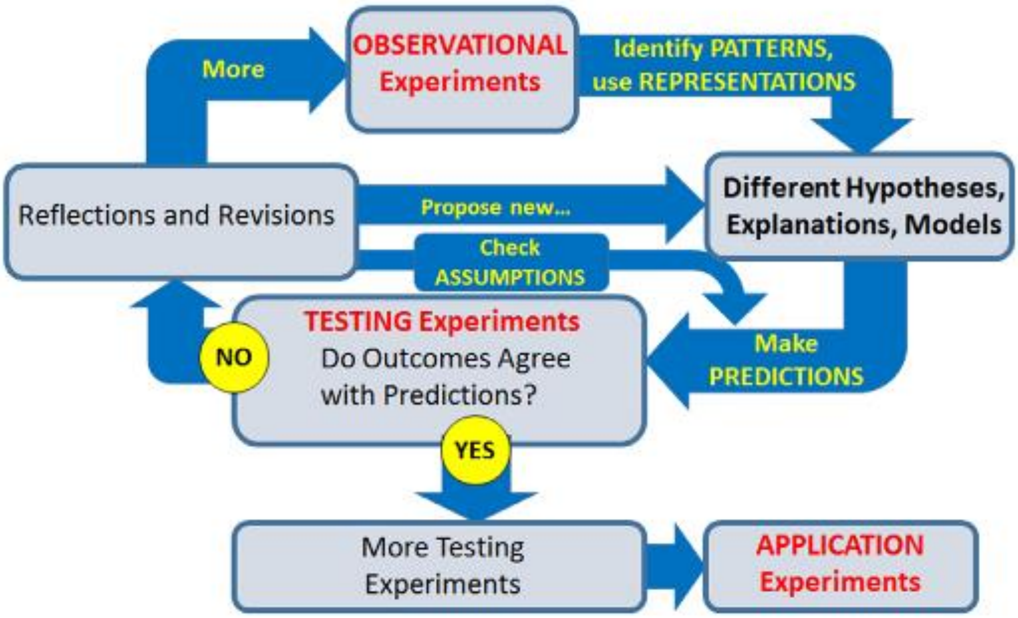



**Figure 3.2:** A schematic diagram of the ISLE process (Etkina, Brookes and Planinšič, 2019, p. 1-7).

The cyclical ISLE process is shown in Figure 3.2, illustrating how observational experiments begin the cycle of investigation before students propose a hypothesis or explanation and design experiments to test their ideas. This process is described in detail in the section that follows.

### *3.2.2 The ISLE approach to investigations*

Before the ISLE approach is described in detail, some key differences between the ISLE approach and other approaches are outlined. Laboratory work is considered essential in modern science teaching, but the purpose of these laboratory-based activities needs to be clearly defined and model real experimental practices (Holmes and Wieman, 2018), so that students can be apprenticed or trained as scientists. Many practical lessons are designed to lead students through a process and so much of the decision-making is removed for the student (Osborne, 2015). Despite good intentions of the activity, this often means that the students do not have to think about the physics principles that are being applied. The person who designed the practical had worked through the relevant physics and the student is often able to (almost mindlessly) follow the stipulated steps (or 'recipe') to achieve the desired results. The ISLE approach requires that students gradually refine their understanding of a concept through experimentation and evaluation, as evident in the ISLE process shown in Figure 3.2 rather than a rigid process of 'scientific method' (Etkina et al., 2009b).

Conventional teaching may look like active learning, but practical lessons are often just 'cookbook' exercises (Waldrop, 2015). Traditional practical lessons with 'cookbook' or 'recipe' instructions usually just have students confirm a concept that is already known, rather than discovering a concept in order to be convinced (Etkina et al., 2002; Etkina, Brookes and Planinšič, 2019). Such experiments, where students are told what steps to follow, might discourage 'sense-making' as students develop the habit of not thinking for themselves (Etkina et al., 2010, p. 71). During an ISLE lesson, handouts do not contain instructions for how to conduct the experiment or what to measure, although they do have questions that focus students' attention on important aspects of the design (Etkina et al., 2010). These questions provide scaffolding that supports students as they grow in their thinking through the process. The questions prompt reflection and connections to prior knowledge (Etkina et al., 2010).

Many 'reformed' approaches suggest that students predict what will happen in an experiment before it is conducted, and then reconcile their predictions and thus hope to modify their understanding once the phenomenon is observed (Etkina et al., 2002). Such teaching approaches prompt students to engage and to take part in the learning process, and they scaffold the connection of new knowledge to existing knowledge. Approaches such as problem-based learning and inquiry-based learning offer students a relatively open-ended experimental experience, where they can pose a question, design an experiment, collect and analyse data, formulate an argument based on evidence and present their findings (Ramnarain, 2023).

Prior knowledge is an important part of the construction of new knowledge as it provides the platform onto which new knowledge is connected (Kural and Kocakülah, 2016), but at the same time, prior knowledge can hinder learning, if a student's previous understanding was wrong (Etkina, Brookes and Planinšič, 2019). This should be addressed through a problem or activity that challenges the student's concept and brings about conceptual change (Posner et al., 1982). However, even addressing cognitive errors and engaging with misunderstandings is sometimes not enough to change understanding (Nersessian, 1989; Etkina and Van Heuvelen, 2007). Rather, repeated experiences of cognitive conflict may have a negative effect on student attitude (Etkina, Brookes and Planinšič, 2019). For this reason, the ISLE approach does not require students to guess what they will see based on their prior knowledge or 'ability' (Etkina, Brookes and Planinšič, 2019). Students are simply asked to make observations, which allows all to be successful and to feel equally capable, so that those who may have more knowledge or more exposure to science are not advantaged (Etkina, 2023).

### 3.2.3 *Sparking curiosity with the 'need to know'*

Each chapter in the ISLE textbook (Etkina, Planinšič and Van Heuvelen, 2019), begins with a 'need to know' segment, which is a story, a video or an application which introduces the section (Etkina, Brookes and Planinšič, 2019). Creating a 'need to know' question is a motivational tool and provides a coherent link through the section. A conceptual unit may be introduced with a question that students set out to answer ('need to know' is from (Knowles, 1980) cited in (Brookes, Etkina and Planinšič, 2020)). For example, at the start of an observational experiment on waves (Appendix 1: Waves investigation, p. 323), students are challenged to think about how noise-cancelling earphones work (Brookes, Etkina and Planinšič, 2020). By the end of the activity, they have learnt the physics that they need to explain how these earphones work. This is perhaps particularly useful in high-school context where interesting, exciting and relevant questions can be asked, or videos chosen to engage students and capture their attention. It empowers students to discover what is relevant and important to them and prompts buy-in and motivation (Brookes, Etkina and Planinšič, 2020).

### 3.2.4 *Observational experiments*

Each module or concept of the ISLE approach starts with a very simple, concrete experience for students to observe, which can be represented (perhaps in multiple ways), which is called an *observational experiment* (Etkina and Planinšič, 2014b). Working in groups, students describe what is observed with familiar, simple language, avoiding scientific terminology or equations (Brookes, Etkina and Planinšič, 2020). Encouraging simple language and avoiding jargon or scientific terms allows all students equal access to the knowledge building process (Brookes, Etkina and Planinšič,

2020) – one might say that it ‘levels the playing fields’. It also communicates to students that anyone can develop knowledge in physics and thus improves motivation, as it dispels the myth that only those who use fancy (or ‘the right’) words and already know all the answers, can be successful physics knowers (Brookes, Etkina and Planinšič, 2020). Using language that is familiar also helps students to connect and integrate new ideas with their existing knowledge structure (Etkina, Brookes and Planinšič, 2019).

Once students have made their observations, they come up with as many explanations as possible for the observation, again using simple language. These explanations suggest the reasons for the observations. Students are encouraged to come up with multiple possible explanations or “crazy ideas”, with an emphasis on creative, rather than correct explanations (Etkina and Planinšič, 2015; Etkina, Brookes and Planinšič, 2019). By referring to the possible explanations as “crazy” ideas, all students can contribute with confidence, no matter their prior knowledge or previous exposure to physics, as there are no ‘wrong’ answers and students are not putting their understanding up for scrutiny (Etkina, 2015; Etkina and Planinšič, 2015; Brookes, Etkina and Planinšič, 2020). All explanations are deemed equally likely / of equal value until tested (Etkina, 2015). The only restriction on these explanations is that each one must be testable.

Using simple, accessible language also avoids confusion or misunderstandings. When experts use a term, they have a picture of what that term means in their mind, with all the connections that their knowledge construct has associated with those terms. Unless the teacher engages in discussion with their students and hears feedback from them, we cannot be sure that they have the same picture with the (correct) associations (Etkina, Brookes and Planinšič, 2019). The teacher needs to create opportunities for this two-way communication between student and teacher to resolve any discrepancies in understanding or application of terms (Brookes and Etkina, 2009; Brookes, Etkina and Planinšič, 2020).

Using simple language and limiting jargon to explain and describe phenomena avoids some problems with the use of language, particularly when terms are nuanced and need to be used with care. Experts use language with understanding of the limitations and restrictions of scientific terms, which students might not consider (Brookes and Etkina, 2015). Students may have sound conceptual understanding, but express this in an inappropriate way, suggesting misconceptions that they do not have (Brookes and Etkina, 2009). This is particularly relevant in South Africa where English is the language of teaching and learning at school, but is not the home language for many students. Expressing ideas in a second or even third language is already a challenge, compounded when using scientific language.

The conflict between the ISLE approach and other reformed approaches in terms of their view on prior knowledge needs to be interrogated. In observational experiments, when students are being introduced to a phenomenon, they are instructed to approach the scenario with an open mind and simply observe. They are then asked to come up with ‘crazy ideas’, rather than ideas based on prior knowledge or experience. This means that they are not accessing potentially incorrect existing knowledge, but the ISLE activity can curate a learning moment where conceptual change can occur. All too often when students observe something that does not match their experience, they see physics as not applicable to the real world or they struggle to change their entrenched prior knowledge. Constructing new knowledge does require connections to prior knowledge, but these observational experiments encourage the construction of the concept before it is connected to correct(ed) existing knowledge. Once these existing knowledge structures are correctly in place, the ISLE approach shares the idea that new knowledge is connected to the knowledge already in place (Etkina et al., 2010).

In this study, I used observational experiments to develop the concepts of force, Newton’s third law and relative motion (described in detail in Chapter 5).

### 3.2.5 *Testing experiments*

Having made observations and come up with multiple explanations for these observations, students must devise experiments to test these explanations. While no predictions were made prior to the observations, predictions are made for testing experiments, based on the explanations being tested (Etkina and Van Heuvelen, 2007), although these explanations are hypothetical until tested (Etkina, Brookes and Planinšič, 2019). For each testing experiment, students predict the outcome that would confirm or reject each prediction, being mindful of the assumptions that have been made (Etkina, Brookes and Planinšič, 2019).

The terms ‘prediction’ and ‘hypothesis’ are often used to mean the same thing in everyday language and it is important to emphasize the difference: a hypothesis is a general statement that explains a relationship or outcome, while a prediction describes the outcome of a particular (specific) experiment, assuming that the hypothesis is true (Etkina, Murthy and Zou, 2006; Etkina, Karelina and Villasenor, 2007; Etkina and Planinšič, 2015). Predictions need to be made based on the hypothesis under test, and not based on any prior knowledge or intuition, thus producing a non-threatening environment where all students feel that their ideas are valued and can be safely explored (Etkina and Van Heuvelen, 2007; Brookes, Etkina and Planinšič, 2020).

Although it has been strongly emphasized that learning is built on a foundation of prior knowledge, students are told to disregard their intuition and prior knowledge, when coming up with explanations for observations, and to base their predictions only on the hypothesis. This also paves the way for the activity to change the student's prior understanding, if new knowledge is found to be in conflict with their original understanding (see Section 2.3.3).

ISLE activities do not include detailed or specific instructions, as students have to design their own experiments – plan, evaluate and reflect on their choices – to test their explanations (Etkina, Murthy and Zou, 2006). This is considered a substantial factor in the benefit of the ISLE approach for a number of reasons. When students design their own investigations, without specific instructions, they are often unsure about the method to choose, the design decisions, and how to approach the design process. This uncertainty results in significant reflection, metacognitive thinking and deep engagement as they try to make sense of the task, which also results in students taking more ownership of their learning (Etkina et al., 2010). Students who design experiments become accustomed to justifying their actions and procedures (Etkina et al., 2010).

The process of devising and testing multiple explanations for observed phenomena can improve critical thinking (Etkina and Planinšič, 2015). On the other hand, students who are not exposed to tasks that require them to design experiments do not show the same reasoning or the quality of explanations and justification. This is perhaps because this mimics their experience of investigations where they were not required to engage in 'sense-making' (Karelina et al., 2007) or because they are used to following instructions without questioning them (Etkina et al., 2010).

The goal of testing experiments is to rule out an explanation rather than prove it (Brookes and Etkina, 2010). When the outcome of the testing experiment does not match the prediction for the experiment, that explanation is rejected, but an outcome that matches the prediction does not prove the explanation; it merely fails to disprove it (Etkina and Van Heuvelen, 2007; Brookes and Etkina, 2010; Etkina, 2015). This falsification strategy may also help to counter 'confirmation bias' (Etkina, Karelina and Ruibal-Villasenor, 2008), which is a psychological tendency to look for or favour evidence that supports an existing belief or hypothesis (Nickerson, 1998). Falsification is a useful thought process to develop, as the ability to justify why a hypothesis is not valid in the era of overwhelming social media and uninformed ‘knowledge’ on topics, may be as important as being able to convey the idea that you believe to be true (Faletic and Planinšič, 2020). This process of rejecting explanations that are shown to be untrue is one of the most important aspects of the ISLE process as it mimics real science practice (Brookes, Etkina and Planinšič, 2020).

Through this approach, students learn to reassess their understanding of a concept or their reasoning based on the outcomes of testing experiments. Because their predictions are based on the ‘crazy’ explanations that they came up with, rather than their personal input, students can volunteer answers without feeling that their understanding is being judged (Etkina, Brookes and Planinšič, 2019). Comparing the results of these testing experiments to their previous understanding, can result in meaningful changes in understanding (Etkina and Van Heuvelen, 2007; Etkina and Planinšič, 2015).

I used the ‘water in a glass’ experiment (Activity VI, described in Section 5.3.2) to introduce the process of coming up with ‘crazy’ ideas to account for an observation. This provided the opportunity to discuss the difference between a hypothesis and a prediction and to have students design testing experiments and predicting the outcome for each experiment based on the hypothesis under test. Our students designed testing experiments to determine where the water on the outside of a glass of cold water comes from, to test whether they walk at constant velocity and to test ‘a friend’s’ hypothesis about current in a circuit.

Ideally, students do the experiments themselves, collecting data and looking for patterns in that data. These experiments need to be simple enough and produce clear results from which students can easily discern a pattern (Etkina, 2015; Etkina, Brookes and Planinšič, 2019). Students need to decide what data to collect in their subsequent testing experiments and how to collect it (Etkina, 2015). Sometimes they are told what to observe, measure or what data to collect, but are still able to make these design decisions themselves (Brookes and Etkina, 2010).

Testing experiments are supposed to teach students to collaborate as they design a suitable method to test their ideas, to evaluate the assumptions that they made in their design and to represent their model and their findings in different ways, which they are able to communicate and evaluate (Etkina, 2015). Throughout the process, students should be reflecting and asking the questions “how do we know that?”, just as scientists would (Etkina and Van Heuvelen, 2007; Etkina, Brookes and Planinšič, 2019).

An unexpected outcome from a testing experiment prompts students to conduct further testing experiments, either to examine their explanation or to evaluate their assumptions or the experimental design (Planinšič, Gregorcic and Etkina, 2014). Unexpected outcomes can trigger another iteration of the ISLE cycle (Etkina and Planinšič, 2014a). Sometimes this process is curated by supplying students with a set of unexpected data (these activities are called ‘surprising data’ experiments) so that students are forced to examine their assumptions (Brookes and Etkina, 2010) or can learn to analyse or explain the data and revise their original predictions (Etkina et al., 2006).

#### *3.2.6 Alternative approaches to experiments*

Instead of performing the experiment themselves, students might observe an experiment, but use data provided for analysis (Etkina and Van Heuvelen, 2007). They might use data or observations from a video of the experiment, photographs, a demonstration, or even be provided with a set of data that was collected previously (Etkina, Brookes and Planinšič, 2019). This approach can save time and may eliminate cost or danger for some experiments. Using such resources also make experiments accessible even in poorly resourced environments or where equipment is limited or unavailable (Brookes and Etkina, 2010). Using videos can be useful, even when time and equipment are available, as this method facilitates data collection as students can observe phenomena in slow motion (Brookes and Etkina, 2010). Collecting data from a video can also allow students to focus on specific tasks, without the distractions of a real set-up (Brookes and Etkina, 2010).

Another approach is to give students ‘someone else’s’ explanation to evaluate (or that of an ‘friend’) (Etkina et al., 2006), particularly when alternative conceptions are common. Not only does this provide the opportunity to rule out some explanations through tests, but such activities also help the student to learn the process of evaluation (Etkina, Brookes and Planinšič, 2019). Students are then more confident and better equipped to evaluate and correct their own work, which is an important part of the learning process (Etkina, Brookes and Planinšič, 2019). Activity VIII in Section 5.3.2 uses this approach, as the activity tells the students that their ‘friend’ says that current is used up around a circuit. This approach of disproving ‘someone else’s’ concept provides students with the opportunity to engage with and correct previous incorrect understanding without damage to confidence, as they do not have a personal stake in the outcome (Etkina and Van Heuvelen, 2007).

### *3.2.7 ‘Time for telling’*

Once some explanations have been rejected through testing experiments, and students have had a chance to develop and explore an idea, the ‘time for telling’ (Schwartz and Bransford, 1998) can be used to clarify, correct and tie together the concepts that have been discovered. Although the teacher has guided the process through the activity, this is a curated summary of the concept that has been explored and the teacher introduces the concept and associated terms (Etkina, 2015). This may be achieved through a summary of various groups' contributions, or a clarification by the teacher, but is valuable in bringing a concept together with emphasis on particularly important points (Brookes, Etkina and Planinšič, 2020). The students can then go on to apply this concept in application experiments.

#### *3.2.8 Application experiments*

Once they have been introduced to a concept, students go on to apply the newly-learned concept through application experiments, which use the knowledge that they have constructed to solve practical problems or to determine a physical quantity (Etkina, Murthy and Zou, 2006; Etkina, Karelina and Ruibal-Villasenor, 2008). These experiments may expose students to the practical applications of the ideas that they tested (Etkina, Brookes and Planinšič, 2019). Students may also be encouraged to design multiple experiments, choose those for which they have the equipment and then compare the answers or results that the different methods give (Etkina, Murthy and Zou, 2006). I did not use any specific ISLE application experiments, but the practical experiments that we complete as part of our usual teaching would likely fall into this category, where a concept is investigated or a question is answered through an experiment that the students design.

#### *3.2.9 Fostering of reasoning skills*

As students learn physics through the ISLE approach, they practice inductive reasoning and hypothetico-deductive reasoning (Etkina, Brookes and Planinšič, 2019), which are common reasoning patterns in experimental physics and in science in general (Etkina and Planinšič, 2014a). Inductive reasoning involves identifying patterns in the data and deducing explanations for these patterns (Etkina, Brookes and Planinšič, 2019). Etkina, Karelina and Villasenor (2007, p. 1) explain that hypothetico-deductive reasoning

> *“involves devising a hypothesis to explain some observational facts, designing an experiment whose outcome can be predicted using the hypothesis, using* if, then *logic to predict the outcome of the testing experiment based on the hypothesis, carrying out the experiment, comparing the outcome with the prediction, and rejecting the hypothesis if there is a mismatch of the outcome and the prediction”.*

The ISLE-approach activities offer students the opportunity to develop this reasoning skill as they find patterns in data and invent mechanistic or causal explanations for the patterns, as well as using these explanations to predict the outcomes of testing experiments (Etkina, Brookes and Planinšič, 2019). All of these practices require engagement, connection between and transfer of concepts and grappling with concepts, so it appears that the behaviours that we value should be developed through these ISLE activities.

## 3.3 Justification of the ISLE approach

In many teaching practices, when conducting an experiment, the teacher may demonstrate a physics principle or give instructions for students to follow. However, demonstrations alone do not probe student understanding or offer an appropriate tool for an expert to provide feedback on the understanding of a concept that students express (Roth et al., 1997). Demonstrations as well as experiments in which students follow a ‘recipe’ have been reported to be ineffective (Osborne, 2015) and so another approach is necessary (Etkina et al., 2002). The ISLE approach does not include demonstrations or experiments that seek merely to verify a known outcome (Brookes, Etkina and Planinšič, 2020). Instead, the approach encourages hands-on practical work where the students themselves investigate a phenomenon through a guided process. While the teacher might demonstrate a phenomenon or have the students observe an experiment, they then require the students to explain their observations.

In summary, the main differences in pedagogical approach between other reformed approaches and the ISLE approach are that:

- concepts are not first encountered or ‘introduced’ by a demonstration that is explained or discussed up front. Students observe a phenomenon and grapple with the explanation themselves.
- when a demonstration is done, no predictions of outcomes is expected. The ISLE approach requires that observations are made and then explained.
- courses often require the textbook to be read in preparation for the lecture. The ISLE approach requires the textbook to be read only once the concept has been uncovered (Etkina and Van Heuvelen, 2007).

Etkina and Van Heuvelen (2007) explain how each step in the ISLE process is intentional and can be justified by what the process is trying to achieve. Some of the features of the ISLE approach are shown in Table 3.1.

**Table 3.1:** Justifications for some of the features of the ISLE approach (Etkina and Van Heuvelen, 2007; Etkina, Brookes and Planinšič, 2019)

| ISLE approach | Justification |
|---|---|
| Observations of experiments are described in simple language. | Links to prior knowledge are made more easily when simple language is used and lack of jargon means all students have equal opportunity for success, regardless of prior knowledge. |
| No predictions are expected for observational experiments – predictions for testing experiments are made on the hypothesis for an experiment. | All students can be successful, and no students are advantaged. Every student has an equal opportunity to predict an outcome based on the hypothesis. |
| Concepts begin with concrete experiences and, if observations do not match prior understanding, students need to examine their prior understanding, test their understanding, and possibly change their understanding. | The opportunity for conflict according to the theory of conceptual change is created through the experiments. |
| Representations are encouraged. | Representations offer connections between concrete scenarios and mathematical and conceptual methods. |

ISLE experiments result in students spending more time planning, discussing and evaluating the merit of design decisions, based on assumptions (and uncertainties), which they needed to consider in their experiment design (Karelina and Etkina, 2007). The ISLE process makes “students pose questions and answer them”, resulting in “self-triggered sense-making” (Karelina and Etkina, 2007, p. 3). Students are prompted to behave like scientists, as they are required to carefully plan each experiment that they design, paying attention to the details and considering assumptions (Karelina and Etkina, 2007).

## 3.4 Scientific abilities, rubrics and self-assessment

There are certain practices and reasoning processes that scientists use when “constructing knowledge or solving experimental problems”, which the ISLE community refers to as ‘scientific abilities’ (Etkina et al., 2006, p. 1). These are called scientific ‘abilities’ rather than ‘skills’ because a skill can be automated, like knitting or riding a bicycle, and abilities should be used with cognitive engagement and reflection (Etkina et al., 2006; Etkina, Brookes and Planinšič, 2019; Faletic and Planinšič, 2020). The ISLE approach develops scientific abilities alongside content knowledge and understanding, and students need to use the processes that demonstrate their scientific abilities with metacognitive reflection (Etkina et al., 2010).

These scientific abilities are broken into sub-abilities to cover the various aspects of scientific knowledge building and experimentation (Etkina et al., 2006) including:

- Ability to represent information in multiple ways
- Ability to design and conduct an observational experiment
- Ability to design and conduct an experiment to test an idea / hypothesis / explanation or mathematical relation
- Ability to design and conduct an application experiment
- Ability to communicate scientific ideas

- Ability to collect and analyze experimental data
- Ability to evaluate experimental predictions and outcomes
- Ability to evaluate models, equations, solutions, and claims

In this study, I focused on the first three of these abilities. We also expect students to collect and analyse experimental data in our course, but this was not a focus of this study. I specifically wanted to introduce or emphasize observational experiments because I want students to be convinced of concepts through their observations. I introduced testing experiments because these require students to develop a different way of thinking that is not emphasized in our NSC curriculum at all: that of falsification. Using multiple representations is one of the valued behaviours that I have sought to emphasize.

ISLE activities engage students in appropriate tasks to prompt processes which develop these scientific abilities (Etkina, Brookes and Planinšič, 2019). These activities use scaffolded questions to assist students in developing these abilities and are accompanied by a set of self-assessment rubrics (Etkina, Brookes and Planinšič, 2019). The rubrics are a set of descriptors that articulate the learning goals of a particular task (Faletic and Planinšič, 2020). They make the learning outcomes of the task explicit to students and detail what is expected of a student to demonstrate that they have developed the scientific abilities or sub-abilities.

Rubrics provide scaffolding for learning that allows students to learn independently, be able to assess their own abilities against the criteria provided and adjust their own thinking guided by the rubrics without external assessment (Etkina et al., 2006; Etkina, Brookes and Planinšič, 2019). The ISLE rubrics have been extensively tested and validated (Etkina et al., 2006). A full set of scientific ability rubrics is available from the ISLE website (Etkina, Brookes and Planinšič, 2022). A set of rubrics modified for use at high-school level, called PUMRubrics (Rutgers University, 2022).

Table 3.2 shows an example of one of the rubrics.

**Table 3.2:** The rubric for hypothesis-prediction-testing (used for testing experiments), an example of an ISLE scientific abilities rubric, taken from PUMRubrics (Rutgers University, 2022).

| Scientific Ability | Missing | An attempt | Needs some improvement | Acceptable |
|---|---|---|---|---|
| **Is able to distinguish between a hypothesis and a prediction** | No prediction is made. The experiment is not treated as a testing experiment. | A prediction is made but it is identical to the hypothesis. | A prediction is made and is distinct from the hypothesis but does not describe the outcome of the designed experiment. | A prediction is made, is distinct from the hypothesis, and describes the outcome of the designed experiment |
| **Is able to make a reasonable prediction based on a hypothesis** | No attempt to make a prediction is made. | A prediction is made that is distinct from the hypothesis but is not based on it. | A prediction is made that follows from the hypothesis but does not have if-and-then structure | A prediction is made that is based on the hypothesis and has if-and-then structure. |
| **Is able to make a reasonable judgment about the hypothesis** | No judgment is made about the hypothesis. | A judgment is made but is not consistent with the outcome of the experiment. | A judgment is made and is consistent with the outcome of the experiment but assumptions are not taken into account. | A reasonable judgment is made and assumptions are taken into account. |

In terms of the cognitive apprenticeship model (Collins, Brown and Newman, 1987) of learning, the rubrics fulfil the modelling and coaching aspects as students self-assess, while making expert practices explicit (Etkina et al., 2010). Rubrics empower the student to self-assess, transferring evaluation from an authority figure to the student themselves, which teaches them that they can learn from their mistakes without authority input (Etkina et al., 2006). In this way, teachers empower the students, share the responsibility for their learning and expecting them to take action to improve, after descriptive feedback (Etkina et al., 2006; Etkina, Brookes and Planinšič, 2019). Scaffolding can improve or speed up the development of scientific abilities, but multiple cycles of tasks may be needed to master the ability (Etkina, Karelina and Ruibal-Villasenor, 2008; Etkina and Planinšič, 2015).

The rubrics focus on scientific abilities, not content (Faletic and Planinšič, 2020). They help students to focus on the reasoning and learning process, rather than the end result, which values learning goals over performance goals. As the rubrics do not give every single step or detailed instructions as to what to do, students still need to reflect on what it is that they did wrong, if they do not achieve a full score, and this prompts reflection, which is valuable for learning (Faletic and Planinšič, 2020). Students' use of rubrics for self-assessment have also been shown to improve the transfer of abilities from one task or context to another (Faletic and Planinšič, 2020). Students are encouraged to refer to the rubrics continuously as the criteria described should draw attention to important aspects of each scientific process (Etkina, Brookes and Planinšič, 2019). They are expected to use these rubrics to "identify, correct, and learn from their mistakes", guided by their teacher when required (Etkina, Brookes and Planinšič, 2019, p. 4-21). Rubrics encourage self-assessment (Faletic and Planinšič, 2020), which can improve student learning, if students are trained to self-assess (Sadler and Good, 2006) and if the objectives that they are aiming for, are made explicit (Black and Wiliam, 1998). Rubrics also encourage reflection and improve metacognitive thinking skills through self-assessment.

Assessment is a necessary part of learning. It promotes student learning by giving an account of what students are able to do and identifies gaps in their knowledge for teachers and students themselves (Etkina et al., 2009b). It also draws the attention of students to what we value (Etkina and Van Heuvelen, 2007, p. 10).

Rubrics can be used by the teacher for both formative and summative assessment purposes and they provide a scaffold for feedback as the extent to which the scientific ability has been developed is articulated in detail (Etkina et al., 2006). Teachers' use of rubrics assists the learning process as these rubrics focus their attention on important goals and allow them to choose particular tasks or testing experiments to develop specific scientific abilities (Faletic and Planinšič, 2020). The assessment of investigation write-ups using a rubric has also been shown to be less time-consuming for teachers (Faletic and Planinšič, 2020).

The inclusion of rubrics for each activity is a significant part of the ISLE approach. However, I chose not to use rubrics for the ISLE activities that we used, as the language was unfamiliar to our students and the use of rubrics is not common in our science curriculum and tasks. The rubrics would have required regular use for students (and teachers) to learn to use them confidently enough that they would fulfil their purpose in assisting students to self-assess and to know what is required in their answers.

## 3.5 Resubmission of work

At schools, a greater diversity in student learning needs and language competence requires greater diversity in teaching approaches (Scott, McGuire and Foley, 2003). In South Africa, diversity is a defining feature and students are diverse in their educational, social and cultural backgrounds (Ramnarain, 2023), as well as their language proficiency and prior knowledge. Universal design is an idea that came from the world of architecture where buildings and environments are designed to be accessible and usable by all people, as far as possible, including those with specific needs. For example, someone in a wheelchair is accommodated by a ramp or a lift or lower switches and door handles. This concept has been adopted in education spheres and Universal Design for Learning (UDL) strives to be

more inclusive to all students (Almeqdad et al., 2023), offering diverse means of engagement, representation and expression of knowledge which enables all students to develop and thrive, promoting equity (Dalton et al., 2019).
The principles of Universal Design translated to Universal Design for Instruction (UDI) principles which are applied to instructional design to allow access and inclusion of all students without differential treatment (Scott, McGuire and Foley, 2003). There are nine principles of UDI (Scott, Mcguire and Shaw, 2003), which include:

- equitable use (instruction should be accessible to all, for example through providing access to class materials online),
- flexible in use (a variety of instructional approaches should be used),
- tolerance for error (recognising that students learn at different paces and providing practice exercises, formative assessment opportunities and feedback that allows improvement) and
- a community of learners (where group work and inclusivity are encouraged)

In physics learning, applying the principles of UDI might mean multiple opportunities to learn a concept or allowing students to work at their own pace (Brookes, Etkina and Planinšič, 2020).

Etkina, Brookes and Planinšič (2019) argue that opportunities to provide students with feedback should be part of the learning process and that students should not be punished for not getting physics right on their first attempt. Rather, they should be given multiple opportunities to improve their understanding through further engagement and be allowed to resubmit work with no penalty (Etkina, Brookes and Planinšič, 2019). This reiterates the point that everyone can learn physics if given enough time (Brookes, Etkina and Planinšič, 2020). The challenge in our context (Section 1.2.3), is that time is very limited and external pressures, such as a national curriculum, an external assessment and two subjects taught together, constrain the physics-learning process.

The idea is that physics learning should more closely resemble real-life learning. For any skill that is learnt, a person needs to practise and practise – and often fail many times in the process – before they have mastered that skill. They are assessed on their most recent attempt. For example, someone learning to solve the Rubik's cube might practise and practise and then time themselves. and practise some more, to improve their time. They will only keep track of their best attempt. Similarly, within the ISLE context, students who rewrite an assessment or resubmit work are allowed to use this new assessment opportunity to show what they now know and are thus given full credit for it, as this is the evidence of their understanding (Etkina, Brookes and Planinšič, 2019). Allowing students the opportunity to improve, promotes a learning-orientated mindset, which is discussed in more detail in Section 3.9 (Brookes, Etkina and Planinšič, 2020).

In a study on the effect of re-test opportunities, Covington and Omelich (1984) showed that re-test opportunities improved motivation and enhanced learning gains. The UDI principle of 'tolerance for error' is employed here, recognising that students learn at different paces and that formative assessment and feedback play important roles in learning. Under non-competitive conditions, students focus on self-improvement and are motivated by their achievement of mastery or improvement, rather than being deflated by failure along the way (Covington and Omelich, 1984). In this study, I began by implementing a resubmission policy similar to that of the ISLE-approach practitioners (Blackman, 2022), but then I adapted this method to suit our context and still retain the benefits. Resubmission of work requires students to reflect on the work that they have done and consider how to improve on it.

## 3.6 Reflection

The activities that I introduced, valued and encouraged reflection on learning, and this is also an important aspect of the ISLE approach. May & Etkina (2002) found a correlation between reflection and learning gains on learning. They found that the quality of the reflection impacted student learning significantly. Students' learning gains may be assessed over the duration of a course, usually using pre- and post-tests, which indicate how the students' understanding has changed through the course. Students with high learning gains on a course reflected more appropriately on the process of their construction of new knowledge and were able to link new concepts to their existing knowledge structure. Meanwhile, students who showed low gains referred to rote learning or the delivery of content from an authority figure in their reflections on their learning process (May and Etkina, 2002). Reflection needs to be seen as an integral part of doing science. May and Etkina (2002) suggest that the inclusion of reflection tasks as part of assignments may emphasize the value of reflection in learning science.

Etkina (2000) introduced weekly reflection for students in which they were asked to reflect on: what they had learnt; what still remained unclear to them; and what questions they thought the instructor would ask to determine their understanding of the concepts. This process provided the students with an opportunity to reflect on their own learning and to anticipate questions by identifying potential questions that would test the concepts covered (Etkina, 2000). It also offered the instructor insight into the students' thinking about learning (epistemology), misunderstandings and areas of concern (Etkina, 2000).

### 3.7 Group work

In the workplace, students are likely to work with people from diverse backgrounds as our societies become more diverse. They need to learn to collaborate with others and value and respect each person’s views and contribution (Bielaczyc and Collins, 2013). ISLE-approach activities encourage students to work together in small groups so that they can benefit from one another’s different expertise, to be exposed to others’ ideas and to learn to negotiate meaning and shared understanding (Etkina and Planinšič, 2014b; Brookes, Etkina and Planinšič, 2020). This resonates with Vygotsky’s sociocultural theory ((Vygotsky, 1978). An ISLE classroom is noisier than those where teacher is delivering content and students raise hands to ask questions (Etkina, 2015), but if learning is considered a social process (Adams, 2006), then it is important that students participate. Fostering a sense of team or camaraderie encourages students to work and study (Brookes and Lin, 2012).

In some group activities, these small groups cluster around whiteboards, so that each person can contribute and so that shared ideas are visible to all. This helps to make knowledge equitably shared and distributed between the individuals of the group to enable all to progress and improve their understanding together (Etkina, Brookes and Planinšič, 2019; Brookes, Etkina and Planinšič, 2020). Teachers monitor this process to ensure that all students have a voice and that no voice dominates, so that all can participate in a knowledge building community (Scardamalia and Bereiter, 1993). This requires teacher engagement and careful management of the classroom dynamic, particularly before the students have learnt that everyone is part of the learning community and should be included. The teacher should also model inclusivity by listening to all and bringing attention to good ideas from unexpected places (Etkina, Brookes and Planinšič, 2019). Once the students have discussed and debated their ideas within their small groups, they then share their results as the consensus of the group (Brookes, Etkina and Planinšič, 2020).

As mutual trust and reliance is important in a learning environment where students are a learning community, it may be helpful to implement activities and tasks that promote communication and interaction. A number of such activities are detailed in the literature (Brookes and Lin, 2012). As students discuss problems in groups, they may articulate their understanding as they disagree and try to convince their peers that their answer is correct, which offers the teacher insight into their understanding of the concept, which may not come through in other, more formal interactions (Redish, 2014). Group work has the dual advantage of supporting the development of communication skills and similar skills that will benefit them in future work, as well as assisting their physics learning (Van Heuvelen, 2001).

In this study, students worked together during many of the ISLE activities and also work together more informally on a regular basis in lessons, discussing questions and explaining questions to one another.

## 3.8 Representations in ISLE

The confident use and translation of multiple representations is an important ability in physics (see Section 2.2.3). Representations help students to see the relationships between physical quantities and to connect them to their current understanding, which can help them make sense of a concept (Etkina, 2015; Scheiter, Schleinschok and Ainsworth, 2017). It is particularly helpful to use multiple representations to connect the concept and the mathematics for those who struggle with the mathematical aspect of physics (Greeno, 1989; Brookes, Etkina and Planinšič, 2020).

Physics students are required to integrate, match and translate between different representations to build understanding (Van Meter and Garner, 2005; Brookes and Etkina, 2007). They need to be able to navigate between the various representations of a problem to assist their construction of knowledge and understanding: the physical set-up, the words or verbal description, the visual representation using diagrams and pictures, and the equations (Greeno, 1989; Brookes, Etkina and Planinšič, 2020).

In a course where the use of – and translation between – multiple representations is emphasized, students may see the value of drawing diagrams or develop the habit of drawing diagrams and draw them spontaneously when evaluating a problem statement or solving a problem (Rosengrant, Van Heuvelen and Etkina, 2009; Maries and Singh, 2017). They can also use representations to determine patterns (Brookes and Etkina, 2010). There is research to show that there is a correlation between the quality of a diagram drawn by a student and the student's performance (Maries and Singh, 2017).

The ISLE approach encourages the use of multiple representations throughout the process of observation and testing. This may include drawing apparatus, constructing tables of data and graphical representations or making use of reasoning tools such as mathematical representations (Etkina and Van Heuvelen, 2007). Teachers might suggest the appropriate representations to use or students may need to identify the appropriate or useful representations that will help them (Etkina and Van Heuvelen, 2007; Chen et al., 2017). As the use of representations is so important (as described in Section 2.2.3), the ISLE approach incorporates the use of multiple different representations into the learning activities to help students learn how to use them and develop the habit of using them, even when unprompted (Rosengrant, Van Heuvelen and Etkina, 2009).

## 3.9 Student epistemology

May and Etkina (2002, p. 1) describe student epistemology as students' "beliefs or views about how knowledge is constructed and evaluated". As the ISLE approach is concerned with the process of knowledge construction, student epistemology is an important consideration (Etkina et al., 2009b), particularly as encouraging an appropriate epistemology can enhance content learning (May and Etkina, 2002). I am interested in the epistemology of the students I teach, so that I can prompt students to think about learning in a way that will encourage the construction of a coherent knowledge structure.

Students who believe that knowledge is a collection of unrelated, undisputed facts and formulae presented by experts, find it more difficult to develop a coherent, integrated knowledge structure (Qian and Alvermann, 2000; May and Etkina, 2002). The students believe that they learn by reading and listening to experts (Villasenor and Etkina, 2007). Still others believe that rearranging equations or memorising problems, rather than understanding concepts, will equip them to do physics (Bransford, Brown and Cocking, 2000; Willson-Conrad and Kowalske, 2018). The ISLE approach encourages the epistemology that knowledge is gained by personal construction, rather than handed out by an authority figure (Etkina and Planinšič, 2014b), to be memorised. ISLE activities model this epistemological view, prompting students to construct their own knowledge (Etkina and Van Heuvelen, 2007) and to connect concepts. While these tasks demonstrate a constructivist epistemology, this also needs to be clearly articulated to students, to shift their epistemologies (Brookes, Etkina and Planinšič, 2020).

Depending on their view of knowledge and learning, students approach learning and problem solving in different ways. This influences how they react to learning opportunities. Students are thought to have either predominantly learning-orientated goals or predominantly performance-orientated goals. Those who approach learning activities with goals that are orientated around performance or marks, tend to believe that intelligence is a fixed quality and see tasks as opportunities to demonstrate their ability (Dweck and Leggett, 1988). This often results in a negative response to a poor result in an assessment, as this seems to them to be a final evaluation of their ability and the importance of the negative result is thus inflated (Dweck and Leggett, 1988). Because they feel that their competence is being measured, their mistakes show them to be lacking (Yeager and Dweck, 2012). This is counter to the philosophy of the ISLE approach, which seeks to foster a "mistake-rich environment" (Etkina, Brookes and Planinšič, 2019, p. 7-1) as a breeding ground for deep learning.

These performance-orientated students view difficult problems as a threat because they are concerned about not achieving the correct result. Thus, such students often avoid challenging tasks, opting for easier ones, or are adversely affected by anxiety when faced by difficult tasks because the stakes are high (Yeager and Dweck, 2012). They may also hold the view that multiple attempts at a solution or needing to work hard to reach a goal indicates low ability. This discourages them from perseverance in the face of difficulty and results in them abandoning the task and missing the learning opportunities that it offers, rather than grappling with it (Dweck and Leggett, 1988). They also experience greater fluctuations in confidence than those with a learning-goal orientation, as each task is perceived to define their ability or give a measure of their adequacy (Dweck and Leggett, 1988). This performance-orientated viewpoint is likely to clash with many constructivist or active learning approaches where students are given challenging problems (albeit with scaffolding) to develop integrated new knowledge (Applefield, Huber and Moallem, 2001).

Students who engage with content to improve their understanding or their competence have learning goals, which motivates them to grapple with concepts in physics, intent on mastering them. Such students often believe that intelligence is not fixed, but can change and grow over time (Dweck and

Leggett, 1988; Yeager and Dweck, 2012). They approach challenges as opportunities to increase their intelligence or competence, increasing their effort when confronted with a difficult problem and often showing innovative problem-solving strategies (Dweck and Leggett, 1988; Yeager and Dweck, 2012). The ISLE approach encourages grappling, and mistakes are viewed as learning opportunities and so it is necessary to change students' view of learning so that students' mindsets become orientated to value learning over performance.

A more learning-orientated mindset can be developed with positive impact (Yeager and Dweck, 2012). Students who are taught that they have the potential to change their academic trajectory are able to use the other academic skills that they are taught to better effect than those who believe they are unable to overcome their challenges (Yeager and Dweck, 2012). Students who are taught that the brain can change, and that intelligence is not a fixed entity, have been shown to be able to change their view of difficult tasks from insurmountable challenges to opportunities for growing their brains (Yeager and Dweck, 2012).

An understanding of these mindsets can affect the nature of feedback and encouragement given to students. For example, an emphasis on developing better strategies when a student does not perform well (Yeager and Dweck, 2012), rather than a comment on a result, can help students to shift their mindset from performance to learning. Being able to reason that a poor result on an assessment was due to a misapplied formula or concept (that can be addressed and correctly applied in future) leads to a far more positive outlook and greater motivation than believing that a poor result is due to fixed ability or limitations that cannot be changed (Zimmerman, 2002). In this study, this was a consideration in designing the examination reflection tool that the Grade 10-12 students used to identify patterns in their examination performance. They were able to identify the types of questions that they struggled with and the types of mistakes they made, to avoid making the same errors in future.

This mindset pattern extends beyond an approach to learning. Those whose view is that nothing is fixed, see their environment as malleable and can be changemakers as they believe that things can be improved, while those with a fixed view may tend to be helpless or feel that there is no way that a situation can be improved when faced with a problem (Dweck and Leggett, 1988). This means that changing the way that students think about their learning in the classroom can have far-reaching implications. The ISLE approach seeks to be transformative and change the way in which students view learning and the truth, and encouraging a learning-orientated mindset can empower students to a more positive and proactive outlook. As I strive to enhance students' well-being and epistemology, changing their mindset is a valuable goal.

Students who learn to adopt a learning-goal orientation, believing that ability and performance can be improved with effort and help over time, are more resilient when faced with challenges (Yeager and Dweck, 2012). Resilient students respond constructively and positively to challenges. Students are more resilient in the face of difficulties when they believe that good strategy, effort and help from others can enable them to develop their intellectual ability (Yeager and Dweck, 2012). As student well-being and self-perception are important in an ISLE classroom, there are benefits to encouraging a learning-orientated mindset in students.

Villasenor and Etkina (2007) found that students' ideas about their own learning influenced how readily they embraced reforms in learning, with those who believe that knowledge comes from authority and needs to be conveyed, being less likely to accept the new approach. Van Heuvelen and Zou (2001) proposed that explaining why reform approaches are thought to be effective may make students more receptive to the new approach. Similarly, explicitly communicating the goals and process of a course or activity and explaining why these goals are important or useful might help students to meet these goals by improving motivation, investment and engagement (Etkina, 2006; Villasenor and Etkina, 2007). This highlights the importance of teaching epistemology, so that students are more open to teaching reforms that will improve their learning.

### 3.10 Student perception

Learning through the ISLE approach is initially unfamiliar and difficult, as students are accustomed to having knowledge presented to them and are now expected to take responsibility for the construction of their own knowledge (May and Etkina, 2002; Villasenor and Etkina, 2007). They are used to following clear instructions and conducting neat experiments that are usually tried and tested and initially tend to find the design process frustrating and complain particularly about the difficulty of the task (Murthy and Etkina, 2005; Karelina and Etkina, 2007). Students who are unfamiliar with the ISLE approach, may find the language and the questions daunting and may question the importance of reflection (Etkina, Karelina and Villasenor, 2007), although reflection has been used with success in other contexts (Dounas-Frazer and Reinholz, 2015). In most cases, once students have adjusted to the new expectations, and engaged repeatedly with the scientific abilities, they are able to succeed and thrive (Etkina et al., 2009b). In time, students may learn to appreciate active learning and acknowledge the benefits. Again, explicitly explaining the reasons for change and citing evidence in support of the effectiveness of active learning might help students to be more positive about it sooner (Deslauriers et al., 2019).

Students often prefer teacher authority and find the responsibility for their own learning demanding. As mentioned previously, teachers are also sometimes reluctant to relinquish authority, However, in a setting where all students and their ideas are respected, students quickly adopt expert physics behaviour (see Section 2.2.4), suggesting explanations, devising and conducting testing experiments and eliminating those that they do not prove to be true (Čančula, Planinšič and Etkina, 2015).

Students in classes where interactive, reformed methods are used, have also responded to indicate that they felt they learnt less, even when learning gains showed otherwise (Deslauriers et al., 2019). This may be because of poor metacognition or their epistemology (see Section 3.9) that they do not recognise learning when it happens or because the learning is obscured by the cognitive load of active learning (Paas, Renkl and Sweller, 2004; Deslauriers et al., 2019). Students prefer passive learning and recognise and applaud a 'good' teacher, assuming that they will learn more when they are 'told' than when they construct the knowledge themselves (Deslauriers et al., 2019).

### 3.11 Cultivating an Investigative Science Learning Environment

The ISLE approach strives to encourage learning goals rather than performance goals for students (Yeager and Dweck, 2012), and to curate a learning environment where each student feels like a member of a learning community (Applefield, Huber and Moallem, 2001; Bielaczyc and Collins, 2013; Etkina, Brookes and Planinšič, 2019), as described in Sections 3.9 and 3.7. In the spirit of community, learning is done together in small groups and the consensus of the group is reported. There is little emphasis on individual brilliance, as this hampers motivation (Brookes, Etkina and Planinšič, 2020).

The ISLE experience is inclusive as it offers all students the opportunity to be successful in some tasks, such as describing observations in simple terms and coming up with 'crazy' explanations (Etkina and Planinšič, 2014b). It also values the contribution of all, not just those who know the answers before they begin. This fosters an inclusive and fair learning environment where all students feel that they are valued. Shifting the emphasis from the ‘right answer’ to the ‘right process’ changes the way that teachers respond to questions and how learning is managed (Brookes, Etkina and Planinšič, 2020). Although physics is being taught, the teacher also has the opportunity to model inclusion and equity (Brookes, Etkina and Planinšič, 2020).

Recognition that science is shaped by people and their thinking will encourage placing value in diversity (Hlatshwayo et al., 2022). During class discussions and debates, questions and student ideas are valued as part of the process of creating and evaluating new knowledge (Brookes, Etkina and Planinšič, 2020). Teachers can also help marginalised voices by foregrounding good ideas from unexpected places (Brookes, Etkina and Planinšič, 2020).

It is important for the teacher to avoid provoking negative emotions, (Etkina, Brookes and Planinšič, 2019) as negative emotions hamper learning. When the amygdala, the ‘fear centre’ in our brain, is activated, even subconsciously, our brains cannot focus on the current problem or learning opportunity, as the activated amygdala sends ‘fight or flight’ responses to our body (Zull, 2002). Thus, fear reduces learning (Etkina and Van Heuvelen, 2007). Focussing on solving a problem does seem to suppress the amygdala, however (Zull, 2002), so a balance needs to be achieved between ‘keeping the student busy and distracted’ and creating an environment that is safe and where the student does not feel anxious.

Learning from mistakes through feedback and repeated engagement is a critical aspect of the learning process (Etkina, Brookes and Planinšič, 2019). However, students need to feel safe to make mistakes in an environment where this is not seen as a weakness and where learning is prioritised over performance (see Section 3.9). Buggé and Etkina (2020, p. 67) note that

> *“because the course provided opportunities for students to challenge themselves in a safe space, … they were able to focus on growing*

*their metacognitive abilities instead of worrying about how failure would impact their performance."*

Teachers 'set the tone', establishing the boundaries of acceptable and applauded social behaviour and curating an environment where students can discuss their understanding safely and debate meaning, ideas and explanations comfortably (Brookes, Etkina and Planinšič, 2020). Teachers are like the referees of the classroom, allowing the game of learning to go ahead with as few disruptions as possible and ensuring fair play without advantage to anyone. As we want students to grapple and ask questions and debate ideas amongst themselves, the classroom environment needs to encourage this behaviour and ensure that students feel safe to 'be brave' to face their mistakes, ask questions and thus benefit from learning moments (Etkina and Planinšič, 2015).

Etkina, Brookes and Planinšič (2019) emphasize that a transformative, active learning experience, even in a safe space, is not comfortable. Being explicit and open about the goals and the process of the learning experience can assist students as they are challenged by an environment where they are not allowed to sit passively, but are required to grapple with concepts and to think deeply. However, the ISLE process also communicates to students that their instructor believes them capable of learning physics and trusts them to manage (Etkina, Brookes and Planinšič, 2019).

I have watched my own children as they grappled through the learning process. Solving the Rubik's cube required hours of practice, repeating steps, having to start again, persevering, until – finally – the cube was solved! And then they had to retain that knowledge by solving it again and again until the process was ingrained. Learning to do a backwards dive meant hours at the pool, trying again and again, until at last they could do it! And then they practised the dive again and again until the process was ingrained. The joy and sense of confidence when they mastered what they were trying to do was uplifting and empowering and transferred to a shift in demeanour and a confidence in other activities. The ISLE approach strives to make the learning process look more like this than students sitting in their desks while the teacher (through some assessment) declares whether learning was successful or not (Etkina, Brookes and Planinšič, 2019). But competence and mastery require deliberate practice, motivation and tolerance of failure, just like real-life learning (Etkina, Brookes and Planinšič, 2019).

Motivation is particularly important in an inquiry-based course as students are expected to grapple with concepts, which can be challenging and uncomfortable, as they are not told what to think or what the answer is (Etkina, Brookes and Planinšič, 2019). Without motivation, students are less likely to persevere through such challenges. Students who feel invested in the learning process tend to be motivated (Brookes, Etkina and Planinšič, 2020). As motivation supports grappling, which is important in learning physics, it is important that students are encouraged to develop a learning-orientated mindset, which strengthens motivation. The ISLE classroom offers an environment in which students can feel supported to develop an appropriate mindset and valued behaviours under the guidance of the teacher.

### 3.12 The role of the teacher

The ISLE approach is a good example of apprenticeship (see Section 2.3.2), where the teacher is imparting their craft (Etkina, 2015). The teacher is the curator of the precious contact time with a class where they can guide the learning process so that students have the opportunity to "learn to think like physicists" (Etkina, Brookes and Planinšič, 2019, p. 2-15). Etkina, Brookes and Planinšič (2019) advocate that this should be through a process of guided inquiry, but the learning process will be determined by the goals and the abilities that need to be developed (Etkina et al., 2009b).

Effective teaching encompasses “on-the-spot judgments about how best to facilitate his or her learning in the specific activity setting in which he or she is engaged.” (Wells, 1999, p. 329). This can be challenging for the teacher, as well as uncomfortable at times, requiring experience, solid knowledge of the subject matter, and plenty of confidence.

As the teacher curates the learning environment, their role is to provide opportunities for students to engage with concepts and negotiate meaning (Brookes, Etkina and Planinšič, 2020). During the observation phase of the learning experience, they should encourage students to take time and make an effort in their observation of the initial phenomenon, as this forms the foundation on which the concept is developed (Etkina and Planinšič, 2015). They then need to ensure that all explanations are viewed as equally valid before testing and that students are testing predictions based on their hypotheses and not their intuition (Etkina and Planinšič, 2015). The teacher circulates and guides the small groups so that there is not too much repetition of ideas between the groups and so that all possibilities are addressed (Etkina, Planinšič and Vollmer, 2013). In all engagements with students, teachers should challenge the students in their thinking so that students extend themselves, and teachers should engage with them through ‘Socratic dialogues’, rather than merely providing answers or ideas (Etkina, Murthy and Zou, 2006).

“Students are expected to identify, correct, and learn from their mistakes with the help of an instructor.” (Etkina, Brookes and Planinšič, 2019, p. 4-21). This shift in responsibility from external evaluation to self-evaluation empowers the student to recognise their autonomy in their learning (Etkina, Brookes and Planinšič, 2019).

The teacher needs to circulate through the discussions to be familiar with each group’s testing experiments and explanations so that they can coordinate the presentations. Useful strategies include having groups present in order of increasing sophistication to avoid a group being ‘a hard act to follow’, and, to avoid repetition, encouraging each group to share a unique idea (Etkina, Planinšič and Vollmer, 2013).

Once students have had the opportunity to be creative and test their ideas, the teacher’s role is to help them make sense of their observations and findings (Brookes, Etkina and Planinšič, 2020). Part of this is the ‘time for telling’ when the teacher summarises the explanations and discusses the concepts that have been investigated (Etkina, Planinšič and Vollmer, 2013). This offers students the opportunity to check their understanding (Etkina, Planinšič and Vollmer, 2013), and teachers can use this to make links to prior knowledge and decode meaning from the class discussions (Brookes and Etkina, 2007).

The teacher in a classroom where the approach is being implemented, needs to be excited about the lesson and to convey the message that they believe their students are capable of learning physics. They need to include relevant, interesting problems that the students can relate to and then be comfortable when students propose unexpected hypotheses (Etkina and Planinšič, 2015). The teacher’s role is certainly not passive, even though they are not at the front of the class sharing their knowledge. This role requires constant evaluation of concepts and process, and previous literature cites teachers’ familiarity with the ISLE approach as an advantage in successfully implementing it (Etkina, Murthy and Zou, 2006; Buggé et al., 2023).

### 3.13 Other studies using the ISLE approach

Since the ISLE approach was introduced, research has been conducted on its impact in a learning environment, predominantly at American college or introductory level at university. Some of the findings of this research are summarised in this section, although this is by no means an exhaustive overview. Zou conducted a study in a calculus-based introductory physics course at university level in the United States of America and found that many students embrace an approach based on qualitative reasoning more readily and apply it more effectively if this approach precedes a formula-based, mathematical approach (Van Heuvelen and Zou, 2001).

In an algebra-based physics course following the ISLE approach, Etkina et al. (2010) found that students who designed their own investigations (rather than following instructions to solve the same problem) developed better scientific abilities than those who did not design their own investigations (Etkina et al., 2010). The students who designed their own investigations were also able to identify and evaluate the effect of their assumptions and communicate effectively. Their study found that students were able to transfer the scientific abilities developed to other content areas and contexts. "*Students who engage in experimental design and reflection learn more than those who do not.*" (Etkina et al., 2010, p. 89). This supports previous work on experimental design (Hmelo, Holton and Kolodner, 2000).

Ruibal-Villasenor et al. (2007) used the context of a biology problem to assess students' transfer of abilities from an introductory physics course taught using the ISLE approach. They also found that students who designed their own experiments spent more time on sense-making and were better able to transfer their scientific abilities to new content areas. They suggested that a design approach "promotes a more profound and meaningful approach toward laboratory investigations" (Ruibal-Villasenor et al., 2007, p. 4).

Buggé and Etkina (2016) showed that the majority of students in a high-school physics classroom setting in the United States of America were able to develop scientific abilities associated with identifying and evaluating assumptions through repeated exposure to tasks which were designed to develop them. They also surveyed and interviewed former students, who had been taught physics using the ISLE approach, and found that they still felt confident in most of the scientific abilities that had been the focus of the course, and many still embodied a learning-orientated mindset (Buggé and Etkina, 2020).

### 3.14 Key elements of ISLE

One of the goals of the ISLE process is to prepare students for future learning, which means that it is important that they are able to transfer learning and scientific abilities into other contexts and content (Etkina et al., 2010). Another vital outcome for future learning is that students are able to learn on their own (Etkina et al., 2009b). It is also important that our classroom learning environments develop independent learners, as there is so much that students need to learn on their own outside of the classroom (Etkina et al., 2009a). When students construct their own understanding through active engagement and experimental design, it is not possible to teach the same breadth of content or the same number of topics, but students retain more of what they do encounter (Waldrop, 2015; Etkina, Brookes and Planinšič, 2019).

Etkina et al. (2009a) found that students who engaged in the innovative process of designing experiments were able to learn more from a text than those who followed instructions when conducting experiments, suggesting that experimental design prepared them for better learning in future (Etkina et al., 2009a). Designing experiments also requires students to use prior knowledge and accessing this prior knowledge helps them to connect new content with stored knowledge (Etkina et al., 2010). Even if the rest of the learning programme is not changed, students can benefit if the investigations in the curriculum are changed to ones that require design (Rutberg, Malysheva and Etkina, 2020).

The ISLE approach also helps students to learn to take risks in their thinking and to develop a learning-orientated mindset, as they are encouraged to persevere when faced with a challenge (Etkina, Brookes and Planinšič, 2019; Buggé and Etkina, 2020). Students who no longer fear physics, who know that their participation in the physics classroom is valued and who can successfully grapple with a physics concept, should experience enhanced well-being.

The ISLE approach aims to empower students to think like physicists (Brookes, Etkina and Planinšič, 2020). This approach is a good example of the cognitive apprenticeship model (Collins, Brown and Newman, 1987) where the entire process models the behaviour of scientists, in the way that students enact the scientific process, how they design and conduct experiments, evaluate the process, reflect on their findings and collaborate with others (Etkina et al., 2010). This introduces students to the practices of scientists (Ruibal-Villasenor et al., 2007).

# CHAPTER 4: AN INTRODUCTION TO LEGITIMATION CODE THEORY (LCT)

*"… making explicit the basis of achievement in curricula, is inherently transformative".*
*(Hlatshwayo et al., 2022, p. 6)*

This chapter provides a brief introduction to Legitimation Code Theory (LCT) and describes those aspects of this multifaceted theory that are applicable to my study. I have used the dimension of Specialization to consider the extent to which the ISLE activities develop knowers and legitimate the behaviours that we value in these knowers. This chapter introduces and describes the concepts of hierarchical and horizontal knowledge and knower structures, gazes, a translation device and cumulative learning.

## 4.1 Introduction to Legitimation Code Theory (LCT)

In today's world of readily accessible knowledge, the opportunity to both access and create knowledge is available to much of the population. However, accessing knowledge, but not knowing how to use it or repurpose it in relevant contexts, is unproductive. Our students are expected to navigate a knowledge-centred physics course and they need the appropriate dispositions and attitudes to assimilate the physics knowledge they encounter and then apply it in new contexts. Most of our students study further after school and will be expected to be independent and autonomous learners in fast-paced, content-laden courses (Ellery, 2021). We expect students to acquire and master scientific concepts, but there is also a need to induct them into the ways of being a scientist (Blackie, Adendorff and Mouton, 2022). Often in science courses, we focus on the knowledge and the knowledge-related skills required, but expect students to adopt practices that are necessary for success in science, which are rarely explicitly taught. For example, it is valuable for a student to learn to self-assess their work, but this is rarely explicitly taught, despite the evidence that self-assessment improves learning and that training in self-assessment improves the quality of the learning (McDonald and Boud, 2003; Sadler and Good, 2006). In the sciences, legitimacy is usually related to knowledge practices, but the “social elements of this practice cannot be ignored” (Adendorff and Blackie, 2022, p. 87). It is important that we consider not only knowledge, but also the “practices for socializing or cultivating knowers” (Maton, 2014, p. 14).

This study uses the analytical tools and explanatory potential of Legitimation Code Theory (LCT) to examine the ISLE and ISLE-inspired activities that were introduced in my classes, and to explore the student responses to these activities. LCT is an explanatory framework that enables the visualization of knowledge and knowledge practices, as well as exposing the organizing principles of these practices so that their effects can be examined (Maton, 2014). LCT explores the way in which ‘social actors’ interact and make meaning through practice (Doran, Maton and Martin, 2021).

As an important part of the ISLE approach, students work together on experiments and problem-solving tasks and students and teachers are in dialogue to negotiate meaning (Brookes, Etkina and Planinšič, 2020). In these interactions, there are accepted or ‘legitimate’ ways of being and behaviours, which the actors (or participants) adopt to move towards what is perceived as success in that field (Doran, Maton and Martin, 2021). Making these paths to success explicit, potentially allows all participants to be successful. In the classroom, and in this study, this means making known the behaviours that allow participants or knowers to successfully access the knowledge that is required in a field.

## 4.2 Hierarchical and horizontal knowledge and knower structures

Knowledge structures can be hierarchical or horizontal. A hierarchical knowledge structure is one in which knowledge is coherently built on a broad base of principles and becomes increasingly specialized. Such knowledge structures are common in the sciences, broadening the base as they develop to integrate new knowledge (Maton, 2014). Such a knowledge structure can be represented by a triangle, as shown in Figure 4.1 (left). On the other hand, a horizontal knowledge structure allows knowledge to develop alongside one another, without hierarchical ordering in the structure of the knowledge. This is more commonly found in the humanities and these knowledge structures develop as new knowledge is added with equal status alongside existing knowledge, which can be represented by the structure shown in Figure 4.1 (right) (Maton, 2014).

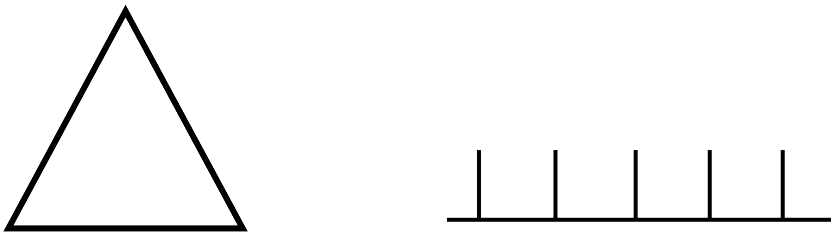


**Figure 4.1:** Depiction of hierarchical structure (left) and horizontal structure (right) which could be applicable to practices with knowledge structures or knower structures (Maton, 2014, p. 70).

Just as *knowledge* structures can be hierarchical or horizontal, so can *knower* structures be hierarchical or horizontal, with humanities often displaying a hierarchical knower structure where knowers with particular dispositions are legitimated (Maton, 2014). Knower structures that are hierarchical grow as new knowers are integrated into the base of the structure and aspire to be the kind of knower that is legitimated in that structure (the apex of the triangle), which is determined by the legitimation code of that practice (Maton, 2014). The sciences tend to display horizontal knower structures as the (often diverse) participants in scientific practices have equal legitimacy based on their personal dispositions, as these are downplayed and it is their specialized knowledge, or the scientific claims that they make that are legitimated (Maton, 2014). The legitimation codes are often more clearly articulated and visible in hierarchical knowledge structures, such as the sciences, where the knowledge is defined and specific, than in knower structures where the legitimation codes may be more tacit (Maton, 2014).

Although physics (as a science) is usually considered to have a horizontal knower structure, as described above, I argue that students who apply behaviours that are valued in physics, achieve greater success in accessing and applying physics knowledge. In this study, I want to emphasize these valued behaviours and make their importance explicit, as they are more influential in students' success in learning than the traditional view of science as a horizontal knower structure suggests. The knower's behaviour and the role that this plays in the process of constructing knowledge is often overlooked, but is significant. The ISLE approach emphasizes the value of certain behaviours, which makes LCT an appropriate theoretical lens to use to explore the ISLE approach.

The ISLE approach seeks to make the codes that legitimate a practice explicit, so that all participants can access the learning opportunities.

## 4.3 The dimension of Specialization

LCT is a dynamic and evolving field, with a number of *legitimation codes* that have been used to analyze the organizing principles of practice. In every field of practice, there are '*practices*' (or *languages of legitimation*), which are the actions and approaches that enable success (or legitimacy) in a field. These practices which determine legitimacy are called *legitimation codes* (Maton, 2014). These codes can be explored through a series of *dimensions* which allow practitioners and critics to view and interrogate the organizing principles of a set of practices (Maton, 2014). This study employed the dimension of S*pecialization*, which is briefly described below. In Chapter 6, I will expand on the insights that this dimension can generate and how it can offer a means to articulate what is legitimated in this study.

Specialization is concerned with the interaction of knowledge and knowers and explores the relations between them in particular disciplines, studies and tasks. *Epistemic relations* focus on interactions between "practices and their object or focus" and "*social relations* between practices and their subject, author or actor" (Maton, 2014, p. 29). Examination of these relations brings to light "*what* can be legitimately described as knowledge (epistemic relations)" and "*who* can claim to be a legitimate knower (social relations)" (Maton, 2014, p. 29) so that these can be made explicit and therefore accessible. To ensure that all students in our physics classes have equal opportunity to be successful and to access knowledge, we need to be aware of what knowledge we legitimate and who we legitimate. For example, we need to question whether our activities legitimate all students or only those who have studied physics before and have established prior knowledge.

Practices can be evaluated as stronger in their social relations (SR+) where the behaviours (or 'attributes') of the knower are responsible for success in that practice, or weaker in their social relations (SR–) where the behaviours of the knower are inconsequential to their ability to succeed or be legitimated in the practice. For example, in teaching, a teacher who is unapproachable, shy and does not willingly engage with students, may struggle to manage a class, to build rapport and to guide the students in their learning. The attributes of such teachers minimise their success in the practice of teaching. Similarly, where the focus in a practice is on specialized knowledge, the practice is considered to have stronger epistemic relations (ER+), while practices with little focus on specialized knowledge have weaker epistemic relations (ER–) (Maton, 2014). To extend the example of the teacher, a language or social science teacher would find it very difficult to teach physics successfully without the specialised knowledge required to guide students to an understanding of physics concepts, even if they have the legitimated knower attributes of a 'good' teacher. So, teaching requires both stronger social relations and stronger epistemic relations in the specific subject area to be taught.

Practices of and interactions between actors can be 'mapped' on a Cartesian plane, with a continuum on each axis, representing epistemic relations and social relations, as shown in Figure 4.2 below. Rather than defining strong or weak epistemic relations and strong or weak social relations, LCT allows observers to note strengthening or weakening processes along these continua (Maton, 2014).

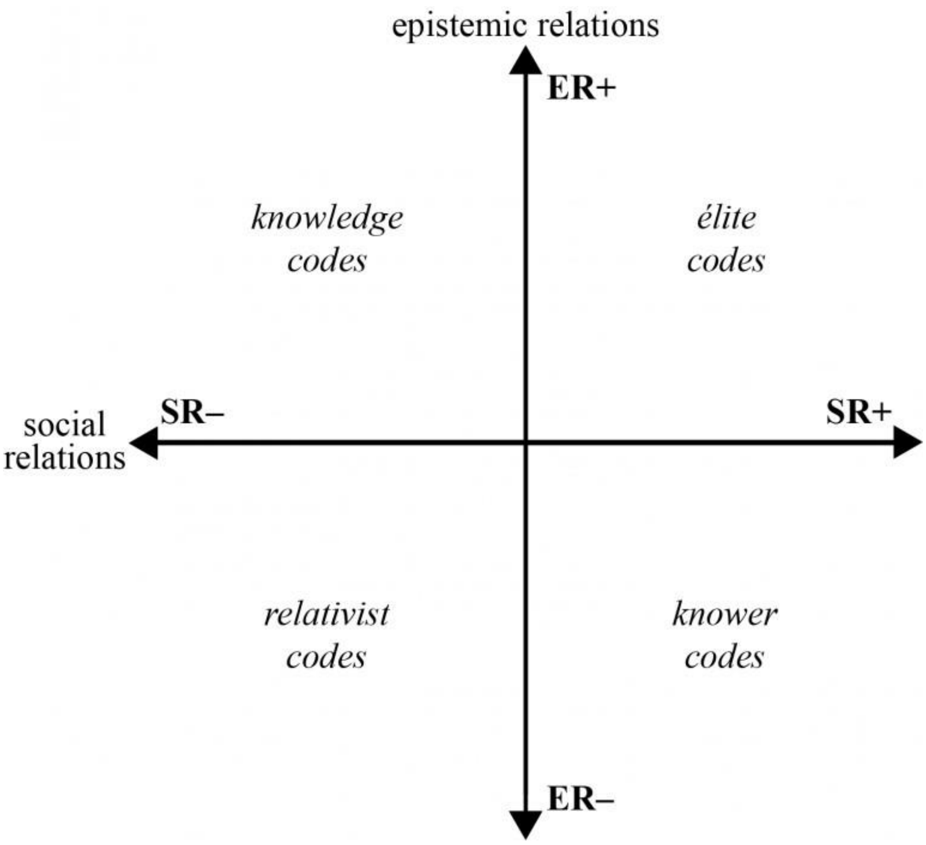



**Figure 4.2:** The Specialization plane, showing Specialization codes (Maton, 2014, p. 30).

Practices with a *knowledge code* (ER+, SR–) are characterized by an emphasis on specialized knowledge or the study of specific objects (ER+), where the role and the disposition of the knower is not considered significant (SR–). In contrast, practices with a *knower code* (ER–, SR+) legitimate knowledge claims based on *who* made them (SR+) (Maton, 2014). Practices with *élite codes* (ER+, SR+) require the knower to possess specialized knowledge (ER+) and also to have the dispositions of a legitimate knower (SR+), while practices with *relativist codes* (ER–, SR–) require neither specialist knowledge (ER–) nor particular attributes (SR–) for legitimacy (Maton, 2014). For example, being a physicist requires specific knowledge and the knowledge legitimates the practice, so this would be an example of a practice with a knowledge code. Physics teaching would be an example of a practice with an élite code, where the behaviour or disposition of the teacher has a bearing on the practice, as well as the teacher's specialist knowledge.

Science is usually considered to be a practice with a knowledge code, as success is determined by a knower's possession of specialized knowledge (ER+), rather than who they are (Maton, 2014; Adendorff and Blackie, 2022). Physics is a tightly defined subject in which students cannot create their own meaning and understanding, but need to assimilate and understand a defined set of knowledge, where personal interpretation is limited (Maton, 2014). However, to successfully access the specialised knowledge, students need particular behaviours. Such behaviours are not all specific to physics, but are valued in the physics context. I have chosen to focus on the valued behaviours that require students to

- actively engage with concepts while learning;
- transfer their knowledge to new contexts;
- make connections between the concrete, mathematical and conceptual representations of a concept (or problem), often aided by a visual representation;
- grapple with concepts.

These behaviours are not physics-specific, but are ‘ways of being’ or behaviours in the physics classroom that will enable access to the physics knowledge. In writing about access to science education, Ellery (2021) distinguishes between “a science-related knowledge code and an academic practices-related knower code” (Ellery, 2021, p. 192). The academic practices-related knower code recognizes the importance of the skills and dispositions that students need to develop and become independent and self-regulated in enabling the science-related knowledge code (Ellery, 2021). Students studying science need to be the right kind of learners, adopting the right (valued) behaviours, in order to access the science-related knowledge (Ellery, 2018). The ISLE approach may offer a means to develop these knower attributes that give access to knowledge in science.

LCT literature refers to the ‘dispositions’ or ‘attributes’ of a legitimate knower to describe what is valued. The Oxford English Dictionary defines an ‘attribute’ as a “quality or character considered to belong to or be inherent in a person or thing” (Oxford English Dictionary, 2024a), while a ‘disposition’ is defined as the “natural tendency or bent of the mind, esp. in relation to moral or social qualities; mental constitution or temperament; turn of mind.” (Oxford English Dictionary, 2024b) These definitions suggest that both an attribute and a disposition are inherent or ‘natural’ and I argue that productive ways of being or habits can be developed. A person’s disposition and attributes are often part of who they are, and it is difficult to measure this. It is also difficult for a teaching approach to change the nature of the person, but behaviours (perhaps the result of a disposition) can be modified or adopted through training or inculcation. ‘Trained attributes’ may be seen as an oxymoron if an attribute is inherent. I argue that students can be trained to adopt particular valued behaviours, which may not always be inherent, and so I have chosen to use the term ‘valued behaviours’ instead of attributes or dispositions.

It may be helpful to think of these ‘valued behaviours’ as the evidence or outcome of the attributes of a specific kind of knower. It may be that someone can adopt particular behaviours to conform (having been trained, apprenticed or inculcated), even if they do not possess certain personal attributes. However, the behaviours displayed by students may be evidence that particular attributes have been developed.

Maton (2014) describes attributes of knowers as “innate or natural (such as notions of genius), inculcated (such as an artistic or literary sensibility cultivated through prolonged immersion in great works) or resulting from the knower’s social position (such as standpoint theory)” (Maton, 2014, p. 76). This suggests that the term ‘attributes’ is an umbrella term for knower dispositions that are natural, inculcated or social in nature. In this study, I am not looking at all attributes, but am specifically concerned with trained or inculcated attributes, which I will term ‘valued behaviours’, in order to differentiate them from natural or social attributes.

As the basis of legitimation in a practice with a knower code can be subjective and not universal, it is helpful to consider gazes, which offer a view of what is considered genuine. Those with the right *gaze* are legitimated (Maton, 2014). A knower with a *born gaze* may be described as being talented or have the appropriate genetic or ‘natural’ attributes to legitimate them in a particular field. This would represent stronger social relations (SR+), where their knower disposition legitimates them. A knower would have a *social gaze* if their social category made them a legitimate knower, while a knower could develop a *cultivated gaze* after extensive immersion in the practice to cultivate legitimacy (Maton, 2014). For example, a South African teacher will have a social gaze enabling comment on teaching in South African schools, while a visiting teacher from a foreign country could only develop a cultivated gaze in time, with extensive experience of teaching in a South African school.

A *trained gaze* can be acquired by any knower who is trained in “specialised principles and procedures” and so anyone can become a legitimate knower as this gaze illustrates weaker social relations (SR–) (Maton, 2014, p. 95).

Knowers in the sciences are usually regarded as having a trained gaze and this is the most accessible gaze, as anyone can be trained to become a 'good' scientist, while a born gaze is available only to a select group. A social gaze is also restricted by the knower's social categorisation and the cultivated gaze requires extensive inculcation (Maton, 2014). A trained gaze aligns with the theory of cognitive apprenticeship (Section 2.3.2), which describes how students are apprenticed into a practice through modelling, coaching, scaffolding, articulating, reflection and exploring (Collins, Brown and Newman, 1987).

This study introduced ISLE activities to develop the behaviours that we value in physics knowers through repeated exposure to activities that legitimate these valued behaviours. This was intended to train the students' gaze to gain access to physics knowledge. Many of the ISLE activities served a dual purpose of providing the opportunity for students to construct physics knowledge, as well as legitimating valued behaviours, but both of these outcomes were not always explicit in the basis for success or the focus of the task.

A practice or task is categorized by the *basis* for success, rather than the *focus* of the task (Ellery, 2021). For example, the focus of most experiments in physics is a practical task, such as making observations, connecting a circuit or taking measurements, but the basis of success in ISLE is whether students are able to learn or improve their understanding of a concept from the experiment. This usually requires that they connect their experience during the experiment in the concrete domain (see Section 2.3.1) (Greeno, 1989) to the physics theory in the abstract domain[2].

In the ISLE activities that I tried, there were examples of activities where the basis for success and the focus of the activity were the same, such as the

[2] In LCT, the term 'domain' refers to the field of practice in the Specialization dimension and reference to 'abstract' and concrete' is usually made when using the Semantics dimension, which I have not used in this study.

observational experiment where students were required to draw ‘dot diagrams’ from a video showing bean bags dropped at regular time intervals. Students who drew dot diagrams had achieved the goal of the activity. In contrast, the focus of other activities, such as the students’ reflections on their learning after a lesson, did not illustrate the basis of success of the activity. Students were focused on the knowledge that they had learnt while the basis for the success of the activity was their ability to reflect on their learning.

Codes, which are the ‘rules of the game’ or legitimated practices in a field, are not always explicitly visible to all participants, hampering the success of those who do not know what is required for success in a particular field or practice (Maton, 2014). Students need to recognize the dominant code of a practice and “be able to realize and enact practices that match that code” to be successful in that context (Ellery, 2021, p. 190). Elucidating the codes and expectations and making them explicit to students may help them in this regard. For example, telling students that we expect them to draw diagrams, validating this behaviour through activities and modelling this behaviour, make this legitimated practice explicit to students.

Sometimes there is a *code shift* within a context when the dominant code changes, for example how the knower code enacted by a certain practice may shift to a knowledge code within a subject as students progress through school (Lamont and Maton, 2008). There may also be an instance of a *code clash* where there is a misalignment or even conflict of the code that is dominant in a practice and the code perceived to be dominant by participants (Maton, 2014). An example of a code clash might be the perception of students that physics has a knowledge code and so they believe that memorisation will be sufficient for success, but physics requires engagement and the application of a knower code.

LCT emphasizes the value of looking at **both** *what* students are learning and *how* they learn it (Maton, 2014; Doran, Maton and Martin, 2021). Valuing particular knowledge in teaching determines what is emphasized in a discipline and the thinking and practice of those who are learning in this discipline (Jacobs and Van Schalkwyk, 2022). However, in teaching, *how* we teach is as important as *what* we teach, as the approach that we choose sends a message as to what we value (Maton and Chen, 2019; Martin, Maton and Doran, 2020; Doran, Maton and Martin, 2021). For example, guiding students to discover a concept through investigations, rather than simply imparting the concept, implicitly validates learning through exploration, as well as sending the implicit message that the teacher believes that the students are capable of developing an understanding of the concept. Drawing attention to such decisions in pedagogy and revealing the implicit messages, equips teachers to be more mindful of what they are emphasizing and to consciously curate lessons that align with their intentions. Education is introducing or inducting students into the organising principles of a knowledge structure as much as providing the knowledge, because the structure of the knowledge is as important as the knowledge itself (Georgiou, 2016). The dimension of Specialization in LCT offers the means to examine relations between the practices related to the knowledge and the practices related to the knower.

## 4.4 The role of a translation device

As the interaction of data and theory can be subjective, a translation device (or ‘external language of description’) is often developed through an iterative process of moving back and forth between the data and theory to allow translation between them (Maton and Chen, 2015; Ellery, 2021). The translation device is a means to conceptualise what was observed in the data and provides a decoding key for the results so that they are accessible and interpretable by others (Maton and Chen, 2015). This assists in improving the trustworthiness of the interpretations (Schwandt, Lincoln and Guba, 2007).

Table 4.1 below shows how examples of epistemic relations and social relations can be found in curriculum, pedagogy and assessment. Specific features about each item could be categorised on a continuum of strengths to describe the features observed in a particular examination of practice.

**Table 4.1:** The structure of the translation device used to translate between data and theory, taken from (Maton and Tsai-Hung Chen, 2015, p. 44).

| | **Curriculum** | **Pedagogy** | **Assessment** |
|---|---|---|---|
| **Epistemic relations** | Content knowledge | Teaching of content knowledge | Explicit criteria |
| **Social relations** | Students' personal experience | Personal dimensions of learning | Students' self-evaluation |

The ISLE approach values the student and their well-being and so stronger social relations are legitimated by the underpinning philosophy of the ISLE approach. Both ISLE and LCT want the 'rules of the game' to be explicit to students so that students have a fair chance of success (Etkina, 2006; Maton, 2014). Being intentionally explicit about criteria ensures that we do not 'assume' anything is obvious or allow hidden expectations to limit students.

## 4.5 Cumulative learning

For meaningful learning to take place, new knowledge needs to be integrated and anchored to existing knowledge (Egan and Greeno, 1973). This requires links between new knowledge and existing knowledge to secure the integration. Segmented knowledge is tightly bound to the context in which it is learnt to the extent that it has little meaning beyond that context (Maton, 2014). 'Segmented knowledge-building', or segmented learning, inhibits the transfer of knowledge to new contexts (Maton, 2009; 2014). In contrast, cumulative learning enables the transfer of knowledge from one context to another (Steenkamp and Rootman-le Grange, 2022, p. 872). Cumulative learning in physics

> *“means that students know (have understood and memorised) the core concepts in each section of the curriculum and are able to transfer this knowledge to analyse phenomena and solve problems in different real-world contexts by identifying the relevant core concepts and applying these (either conceptually or by calculation).”*

In Physics Education Research (PER), cumulative learning results in transfer (see Section 2.2.1), is critical to learning, and is one of the behaviours that is valued in physics knowers. The studies that have looked at cumulative learning (Steenkamp, Rootman-le Grange and Müller-Nedebock, 2021; Steenkamp and Rootman-le Grange, 2022) have been in the context of Semantics, which was not applied in this study. However, cumulative learning is necessary for students to construct a hierarchical knowledge structure and so is relevant in this study, even though ISLE was explored within the dimension of Specialization.

The Specialization dimension of Legitimation Code Theory (LCT) (Maton, 2014) offers an analytical framework to explore the legitimation of knowers and knowledge in activities and in practices. Physics knowledge is the focus in most physics classrooms, as students need to develop a hierarchical knowledge structure. However, I argue that there should be an explicit focus on legitimating and developing the behaviours that we value in the students that we teach, recognising that the right kind of knower will have greater success in accessing physics knowledge. The next chapter details the activities that were used to develop the trained gaze of the knowers in this study.

# CHAPTER 5: RESEARCH METHODOLOGY

*"The student's traditional role is that of a passive note-taker and regurgitator of factual information. What is urgently needed is an educational program in which students become interested in actively knowing, rather than passively believing."*

(Michael, 2006, p. 159)

This chapter describes the process of the research design to explore the introduction of the ISLE approach to teaching physics in a South African high school. The first section outlines and justifies the action-research methodology and the mixed methods approach that were adopted. A description of the setting and sample and the resulting ethical considerations is given in the second section. The third section provides an overview of the exposure of students to the ISLE approach and descriptions of each of the ISLE-approach activities that were introduced. This includes a description of the tasks and activities that were developed in our context, using the underpinning philosophies of the ISLE approach. The tools of data collection are detailed in the fourth section and, lastly, in the fifth section, the methods of data analysis are described.

## 5.1 Introduction to the research design used in this study

During this study, the ISLE approach was introduced in a South African high school. Surveys, interviews and focus-group discussions, as well as student responses and reflections on tests and activities, were used to explore the impact of this approach on students. The 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.

As an experienced physics teacher, I had done a lot of reading about different approaches to teaching my subject. I came across the Investigative Science Learning Environment (ISLE) approach, which resonated with me. As I was introducing this new approach, I was unsure initially what would and what would not work in our context, so I tried a range of activities, some straight from ISLE resources and some 'ISLE-inspired' or adapted activities. Although some of these were soon disregarded, all are included in the section that follows as they were all part of the process of determining which activities develop valued behaviours in our context. As this is, to my knowledge, one of the first applications of the ISLE approach in a South African context, I have included descriptions of every activity that I tried, in case colleagues wish to try them in their classrooms.

### *5.1.1 Action research*

Action research has its roots in critical theory, which encourages self-reflection to improve practice and address problems, through a combination of the relevant aspects of a scientific approach, theory and practical experience (Carr and Kemmis, 1986; Koshy, 2010). Action research is an iterative process and is a commonly-used approach when research is focused on a social practice, as the participants play a key role (Grundy and Kemmis, 1982), making it applicable in education research. The teacher is instrumental in action research as they usually identify the problem to be investigated, and their critical reflection and analysis facilitates transformation through action (Carr and Kemmis, 1986).

The intention of this study was to improve practice through the introduction of an approach to teaching physics which I hoped would develop valued behaviours in our students. Using the action-research method of iterative cycles of activities, with reflection and refinement between cycles, I critically considered both the theory and the practical reality. The refinement of the activities required self-reflection with the intention of improving practice.

### *5.1.2 Mixed methods*

Since the 1990's, there has been a growing trend to use both quantitative and qualitative methods in one study, either in combination or in turn, taking advantage of the merits of each form of analysis (Creswell and Creswell, 2017). Mixed methods research has been described by Johnson, Onwuegbuzie and Turner (2007) as:

> *"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 of analysis offer researchers access to diverse means of analysis and it facilitates triangulation which enables "the confirmation of results from one approach by those of another approach" (Flick, 2018, p. 5). Triangulation can be applied to reduce bias or broaden perspective when considering data, theory, investigations, or methods. It aims to find an agreement in findings to improve their validity.

In this study, interviews, focus-group discussions and surveys provided rich qualitative data, while test, pre-test and re-test scores were methods used to collect quantitative data. Both qualitative and quantitative means of analysis were applied, often to the same data. For example, survey responses were coded and tallied, and quotes from the surveys were used to clarify and deepen perspectives that emerged from the broader quantitative analysis (Johnson, Onwuegbuzie and Turner, 2007).

## 5.2 Description of research site, sample and ethical considerations

As a full-time teacher, it was convenient to use the students in my classes and in colleagues' classes as my study sample. In our department, we share resources so that all students have access to the same learning experiences and materials, no matter which class they are in or who their teacher is. I shared the activities based on the ISLE approach, as well as a basic introduction to the ISLE philosophy, with my colleagues. However, I was conscious of my position of power, both as a Head of Department and as a teacher. I emphasized that my colleagues should only implement aspects with which they were comfortable, and I did not pressurise students to complete surveys or participate in focus groups.

This may have impacted my data collection as not all students completed all activities. This also meant that some classes, taught by colleagues, did fewer of the ISLE activities than my classes, although I drew from all classes for interviews, focus groups and survey responses.

I am mindful of a potential conflict of interest as I am conducting a study using the students in my classes as the subjects, but I have been very explicit and open about the research activities, telling students that I want to evaluate the activities objectively and to see whether they are worth pursuing. A potential threat to the validity of this study is students answering what they think I want to hear, rather than answering honestly. Using Google Forms for the surveys, I sought to distance myself from the students when they completed the survey and, in the focus groups, I often reminded students that I was looking for genuine, honest answers, rather than what they thought was the 'right' answer or something they thought I was hoping to hear.

I do also need to acknowledge that my employer funded my studies from the Staff Professional Development Fund. This could be seen as a conflict of interest, but, for reporting purposes, my school will remain anonymous. The benefit to my employer has been my deeper understanding of physics teaching, as well as the introduction of a different approach to teaching physics in our schools.

### *5.2.1 Sample selection and description*

I teach physics at a pair of well-resourced, independent schools in a small town in the Eastern Cape, South Africa. The schools, one for boys and one for girls, cater for students from ages 14 to 18 and for most subjects the boys and girls are taught together from Grade 10 to 12 (ages 16 to 18). Each of the schools has approximately 430 students, and both are independent, meaning that they are privately governed, rather than public schools. This means that such schools have greater flexibility than public schools in how they teach content and what they teach. The schools in this study follow the syllabus that is examined by the Independent Examinations Board (IEB), which is subtly different in approach and content from the Department of Basic Education (DBE) syllabus. All students write an exit examination, at the end of Grade 12, the National Senior Certificate (NSC), which is set either by the DBE or the IEB.

The school fees for both the schools in this study are extremely high, and the majority of students are from high- to medium-income families, although some students are from low-income families and attend the schools on bursaries and scholarships. Students are mostly South African, although there are international students from other African countries and other continents. There is no entrance examination to enrol at either school, and students of a wide academic range attend the schools.

As in all South African schools, students in Grade 8 and 9 (ages 14 to 15) study Natural Sciences, which comprises physics, chemistry and biology. At most schools, modules from these subjects are taught by one teacher, in a sequence determined nationally. However, at our schools, the academic year is broken into three terms and students study modules related to biology, chemistry and physics, each in a separate term. This ensures that all classes have a similar exposure to each subject, which also informs a less biased subject choice in Grade 10. There are eight Natural Sciences classes (four classes of boys and four of girls) in each of Grade 8 and 9, with 18-26 students in each class.

A consequence of teaching all three subjects under the umbrella of Natural Sciences is that each class only studies physics for a total of about 26 lessons each year. We try to limit the mathematical rigour and cognitive complexity of the physics course in Grade 8 and 9 to make it accessible to all students, regardless of their mathematical aptitude.

At the start of their Grade 10 year, students choose five subjects which they take for their Grade 10 to 12 years. In South Africa, Physical Sciences is reported as one subject, with physics (Paper 1) and chemistry (Paper 2) each counting 50% towards the result. Students who choose to take Physical Sciences, have to take Mathematics. The uptake of Physical Sciences at the two schools is around 43%, while the national uptake for Physical Sciences is around 29% (calculated from number of students taking Physical Sciences, stated in the DBE Annual Report (Department of Basic Education, 2024)).

At these schools, physics and chemistry are taught by specialist teachers (who teach only physics or only chemistry). There are usually four Physical Sciences classes per grade with 20-25 students in each class. In 2020, we were required to teach the boys and girls separately while under Covid-19 restrictions, as no student movement was allowed between the campuses of the two schools. We noticed a marked increase in confidence and engagement from many students when the boys and girls were separate and a short survey confirmed that many students at the time saw academic benefit in Physical Sciences, so we continued to teach the boys and girls separately in Physical Sciences, even after the restrictions were lifted. This means that for the duration of this study, we taught single-gender classes, except for one class where the boys' class and girls' class were merged from September to December 2023, due to numbers.

Students are placed in a class at the start of their Grade 10 year, based on an average of their year mark for mathematics in Grade 9 and their test marks for the physics and chemistry components of Natural Sciences in Grade 9. During almost the entire period of the study, physics and chemistry were taught in alternate weeks, so that, for example, students would study physics for a week with Teacher A and then chemistry for a week with Teacher D before going back to physics with Teacher A again. Physical Sciences is allocated eight 45-minute lessons in a 2-week timetable cycle, so each class would have four lessons of physics and four lessons of chemistry each cycle. Near the end of 2023, we changed this model so that each class has a half term of physics and a half term of chemistry, instead of alternating through the term. In total, each class has approximately 40 45-minute physics lessons in a year, equating to about 30 hours of physics teaching time a year. Although this study began in 2021 when many schools were still affected by Covid-19 restrictions, as a boarding school, classroom contact time was unaffected by the pandemic during the period of study.

The teachers at these schools have written and collated a set of notes for each Natural Sciences component (physics, chemistry and biology) and also for the syllabus covered by Physical Sciences. These notes are printed for students to work through in class and are the basis of the teaching, with no additional textbook used, although sometimes additional worksheets and tasks may be used. Concepts which were introduced in Grade 9 are revisited in the senior grades in more detail and with greater mathematical emphasis. Concepts are cumulative and are examined internally (with papers set, moderated and marked by the teachers at the schools) in July and November each year, with the exit examination in November of the Grade 12 year, which is nationally set, and marked.

The teachers each have their own style and approach, but the predominant style of teaching these subjects is traditional, with content delivery and problem solving (practising examples) taking up the majority of class time. Prior to the introduction of the ISLE approach, demonstrations and experiments were woven into the teaching schedule when possible, but not in all sections and there was certainly more regular practical work in the chemistry component.

Once a week, teachers are available in their classrooms in the afternoon, for “Support” when students come to work, bring questions or ask for individual help with a concept. In addition to the help available during these times, students can send questions to teachers via email or other school-sanctioned communication platforms. In the lead-up to examinations, there are many additional hours of ‘Support’.

This study involved students from Grade 9 to 12 (with one activity used with a Grade 8 class) over a period of three years (2021 to 2023). As mentioned above, I have used the students in my classes, as well as those in colleagues’ classes as the sample for this study.

### *5.2.2 Ethics clearance and introduction of study to classes*

I was granted ethical clearance for this study by the Rhodes University Ethics Standards Committee (RUESC) (2021-5074-6199; 2022-5074-6932; see Appendix 2**:** Ethical clearance 2.1 on p. 324 and Appendix 2**:** Ethical clearance 2.2 on p. 325). The students involved in this study range in age from 13 to 18 and so consent was required from their parents for them to participate. The Heads of both schools involved in the study gave permission for the study and the consent was sought by email from the parents of all science students in Grades 8-12 (Appendix 2**:** Ethical clearance 2.3 on p. 326).

In addition to parental consent, I requested assent from students to participate (Appendix 2**:** Ethical clearance 2.5 on p. 332). The project was introduced to students in class by their teachers. I prepared a document to introduce my research, which I read to my classes and shared with the other physics teachers for them to read to their classes, so that all classes would receive the same introduction (Appendix 2**:** Ethical clearance 2.4 on p. 331).

This introduction explicitly stated that participation in the research was voluntary and that I would only use the responses of students who assented to participate. Students were informed that there was no pressure to participate, no benefit, or disadvantage, nor any extra work in participating and that they could choose to withdraw from the research at any time. Reading the instructions to all classes was also so that I could reduce my position of authority as the teacher and distance myself from the process in the hope that students felt more comfortable to choose freely whether to participate or not, as reading is less personal than me asking them to participate. I emphasised that the purpose of this study was to evaluate the learning materials and approach and that their frank participation would help us to do this. As all classes were addressed and no individuals were approached, I hope that students did not feel pressure to participate. I also regularly emphasized the purpose of my research in my classes. On each survey, I asked again for permission to use the data and so students had the opportunity to opt out each time. Some did, which suggests that students did feel comfortable declining assent, which supports the validity of the study.

### *5.2.3 Considerations of validity, authenticity and trustworthiness*

Unlike a scientific experiment, where variables can be controlled and the experiment can be repeated under the same conditions and an average result found, education research involves people, and different considerations are needed to gauge the rigour and validity of the research. Valid research methods produce consistent results each time they are applied to the same set of data (Bertram and Christiansen, 2020). Lincoln and Guba (1986) suggest that consideration of the trustworthiness of research can give insight into the rigour of the research (Lincoln and Guba, 1986).

*Trustworthiness* incorporates credibility, transferability, dependability and confirmability (Lincoln and Guba, 1986). The *credibility* of a study is strengthened by long-term engagement and recurrent observation, the triangulation of data, the engagement with neutral outsiders who critique the interpretations made and the research process, as well as engagement with participants to cross-check information (Lincoln and Guba, 1986). This study was conducted over a period of three years, with repeated engagement with each activity and each cohort. Data were triangulated and were discussed with others to guard against biased interpretations. 'Thick' descriptive data which tells the story of the context can assist those who wish to compare their findings as a means of establishing *transferability*. The process of the study gives an indication of *dependability* and an examination of the data itself and the interpretation speaks to the *confirmability* of the study (Lincoln and Guba, 1986). Comments on variations in the study from one cohort to another, or one year to another, improve the dependability of the study and recording the process of the study in sufficient detail that the research process is transparent, improved the confirmability of the study (Bertram and Christiansen, 2020).

This study was conducted over a period of three years, with regular data collection in the form of reflections, corrections, formal assessments (tests) and surveys, discussions and observations, which were triangulated. The extensive quotes taken from focus-group discussions, interviews and surveys provide insight into the context of the study and offer a strong student voice in the narrative of the findings. The process of data collection is extensively documented in detail in the section to follow, as is the process of analysis in the subsequent section. Participants were informed of the research process and the purpose of the research and were asked whether they agreed to participate in each survey, as well as in the initial consent process. As the research developed, I shared preliminary findings and experience of the process with the students and discussed these in groups and in class. Students were given opportunities to give input on activities and we asked their opinion on various aspects of the ISLE approach as it was implemented. I also adjusted the activities, based on feedback from the students, so they could see the impact of their input.

## 5.3 The research process and research tools

The research process was designed to answer the research questions:

1. To what extent do ISLE activities legitimate the behaviours that we value in physics knowers?

2. How does the student experience of the ISLE approach demonstrate the development of behaviours that we value in physics knowers?

The section that follows describes the research process and the exposure of each cohort to the ISLE approach. The details of all the ISLE and ISLE-inspired activities that we tried or introduced are given in sufficient detail that teachers who wish to use them can refer to this study. This section goes on to describe the research tools that were used to gather data, including the surveys, interviews and focus groups.

The activities described in Section 5.3.2 provided the data from which I developed a translation device to answer the research question: To what extent do ISLE activities legitimate the behaviours that we value in physics knowers?

Student responses in surveys, interviews and focus groups provided the data to answer the research question: How does the student experience of the

ISLE approach demonstrate the development of behaviours that we value in physics knowers? Coding the student responses in the surveys provided quantitative data, which could be substantiated and enriched with qualitative data supplied by the students in surveys, reflections, interviews and focus groups. Evidence was also gathered from studying student assessments, including their re-tests, pre-tests, tests and examinations.

**Table 5.1:** A summary of the research questions that were answered in this study and the data that was used to answer these research questions.

| **Research question** | **Research question answered** | **Data used to answer research question** |
|---|---|---|
| **1** | To what extent do ISLE activities legitimate the behaviours that we value in physics knowers? | Analysis of ISLE activities using a translation device<br>*(Chapter 6)* |
| **2** | How does the student experience of the ISLE approach demonstrate the development of behaviours that we value in physics knowers? | • Survey responses<br>• Student reflections<br>• Interviews<br>• Focus-group discussions<br>• Student assessments<br>*(Chapter 7)* |

### *5.3.1 Overview of research process*

As mentioned in Section 5.2.2, the study was introduced to each class by their teacher. After the study and the process had been explained, students were sent a link to a Google Form, which they completed during the lesson. This included an opportunity to give or decline assent for participating in the research (Appendix 2**:** Ethical clearance 2.5 on p. 332), and then to complete the questions that form the Colorado Learning Attitudes about Science Survey (CLASS) (Appendix 4: Data collection and analysis tools, p. 374). This survey is a research-validated pre- and post-test to assess attitudes and beliefs about learning physics to see whether they change over a period of time or with a change in approach. CLASS is described in more detail in Section 5.3.3 below.

All students completed all forms and surveys, regardless of whether or not they or their parents had given permission for me to use their responses. This meant that no students missed out on the opportunity for reflection and only I would know who was participating in the research and who was not, so that no one felt excluded. This was particularly pertinent where students had given assent, but their parents had not responded to my request for consent. However, when it came to the analysis of my data, I only used the responses of those students whose parents had given consent and who had, themselves, given me permission to use their responses. In 2021 I only asked the students for consent to participate in the initial consent survey, but, from 2022, I included a confirmation of their assent in every survey and reflection, to ensure that students were comfortable to withdraw their consent at any time. No students were named in any of the data analysis to ensure their anonymity.

As the data collection for this study spanned a period of three years, the students moved through the grades and changed classes from Natural Sciences to Physical Sciences, if they chose Physical Sciences as a subject in Grade 10. I did not teach all the physics over this period and my colleagues did not all adopt the ISLE approach from the start of my study or to the same extent. However, many of the activities and approaches were introduced to all the classes, particularly in 2023. Table 5.2 gives a summary of the number of participants in each cohort and the years during which they were exposed to the ISLE approach.

**Table 5.2:** A summary of the number of participants, shown by cohort.

| Cohort names | Grades of participation | Data collection year(s) | Number of girls | Number of boys | Total number of participants[3] |
|---|---|---|---|---|---|
| Pilot | 11 - 12 | 2021 - 2022 | 21 | 24 | 45 |
| Trailblazers | 11 – 12 | 2022 – 2023 | 29 | 28 | 57 |
| Pioneers | 9 – 11 | 2021 – 2023 | 21 | 28 | 49 |
| Explorers | 8 – 10 | 2021 – 2023 | 29 | 30 | 59 |
| Last Chance | 9 | 2023 | 36 | 41 | 77 |
| Total: | | | 136 | 151 | 287 |

Data were collected from surveys, post-lesson reflection tasks, semi-structured focus-group discussions and interviews, tests, pre-tests and re-test applications. As this was an action-research investigation, there were some adjustments to the surveys over the period of the study, as the method and tools were fine-tuned.

### *5.3.2 ISLE and ISLE-inspired activities*

This section provides an overview of the ISLE resources that were used or adapted, as well as the ISLE-inspired activities that were developed. The first section indicates which tasks and activities each cohort was exposed to and then, in the second section, each activity that was used in this study is described.

The ISLE community have created and shared a large number of resources which are available through the ISLE website (Etkina, Brookes and Planinšič, 2022). ISLE developers generously share their resources with all interested teachers (Hrvoje Miloloža, 2022) and monthly online workshops are available for anyone interested in using the ISLE approach in their classroom, building a community of practice. Most of these resources are aimed at introductory

[3] This was the number of participants who gave assent and whose parents gave consent for me to use their responses and who were in classes that participated in the activities.

physics courses at an American college or university level, although it is stated that they are suitable for any level (Etkina, Brookes and Planinšič, 2019).

Most of the courses where the ISLE approach is implemented have six hours or more per week for the course (May and Etkina, 2002; Buggé, 2020), while we have an average of just 90 minutes per week of physics in our school system. Many of the introductory physics courses in which the ISLE approach was used, have the autonomy to choose the content to be taught as well as nature, style and content of the assessment. We are constrained by a defined syllabus and an externally set, high-stakes exit examination. For these reasons, I introduced a selection of activities which suited our curriculum and the time available.

Many of the activities that we have implemented, have been adapted from the activities that were shared. As these activities were all new to our context and untested for our students, I tried some and then stopped using them. I adapted some of the activities over the course of this study and I also introduced some of our own ISLE-inspired activities later in the study. Table 5.3 and Table 5.4 provide a more detailed view of the extent to which each group experienced ISLE activities. As evident in the table, not all cohorts experienced exactly the same set of activities. Table 5.3 shows the activities that each cohort experienced.

The activities to prompt the use of representations, the observational experiments, the testing experiments and the expertise activity, all listed below, were taken from Physics Union Mathematics (PUM) (Rutgers University, 2022) or the Active Learning Guide (Van Heuvelen and Etkina, 2005) or adapted from ISLE community papers or workshops. Two of the activities which model behaviour were adapted (in the case of the post lesson reflection task and re-tests), but the rest were developed during this study.

The survey questions and focus-group discussions asked participants to reflect and comment on their experience of the ISLE approach, which included a range of activities. So, although data were not collected for each activity explicitly, the students' responses would consider all the activities that they had been exposed to. All these activities share the same underpinning philosophy and goals, contributing to the learning experience. Similarly, although the effect of the activities and approach on student well-being was not explicitly explored in this study, each aspect of the ISLE approach considers the well-being of the students, and so valuing their well-being undergirds the entire approach.

**Table 5.3:** ISLE and ISLE-inspired activities that were used, showing the cohort and the year.

**KEY:** 2021 2022 2023

| **Activity** | **Pilot** | **Trailblazers** | **Pioneers** | **Explorers** | **Last Chance** |
|---|---|---|---|---|---|
| I. Representations: introduction to motion (bean bags) | | | X | X | |
| II. Representations: motion diagrams | | | X | | |
| III. Observational experiment: relative motion | | | X | X | |
| IV. Observational experiment: introduction to forces | | X | X | X | X |
| V. Observational experiment: Newton's third law | | | X | X | X |
| VI. Testing experiment: water in a glass | | | X (not all) | X | X X |
| VII. Testing experiment: How fast do you walk? | | | X | | |
| VIII. Testing experiment: current in a circuit | | X | X | X | |
| IX. Modelling behaviour: our physics workbooks | | X | X | X | |
| X. Modelling behaviour: post lesson reflection | X | X | X | | |
| XI. Modelling behaviour: examination reflection task | | X | X | X | |
| XII. Well-being: Expertise Activity | X | X | X (not all) | | |
| XIII. Well-being & modelling behaviour: re-tests | X | X | X | X | |
| XIV. Well-being & modelling behaviour: take-home tests | | X | X | | |
| XV. Well-being & modelling behaviour: pre-tests | | X | X | X | X |

Each of the ISLE and ISLE-inspired activities is described in turn below.

### Activity I: Representations: introduction to motion (bean bags)

Motion diagrams are one of the representations included in Explore and Apply (Etkina, Planinšič and Van Heuvelen, 2019) and in the PUM resources (Rutgers University, 2022). These are useful as they allow students to visualise and conceptualise motion when solving a physics problem.

When acceleration was introduced in Grade 9 and Grade 10, students worked through an activity which had them draw “dot diagrams” from a series of videos shared on the ISLE Resources website (Etkina, Brookes and Planinšič, 2022), which can be found in Appendix 3 on p. 338. A bowling ball is rolled first slowly, then faster, then on a carpet (so that it slows down) and finally while being pushed by a plank (so that it speeds up). Bean bags are dropped alongside the ball at regular time intervals to visualise the motion of the ball. The task is to draw the positions of the bean bags and to observe the pattern between the distance between the bean bags (or dot representations of the bean bags) and the motion of the bowling ball.

This visual introduction to motion provided a useful link to the concept of acceleration. As students are taught how to calculate acceleration using the pattern of dots produced by a ticker timer, this was a particularly useful exercise to see the distance covered by an object in equal time intervals.

### Activity II: Representations: motion diagrams

This activity was taken directly from the PUM resources (Rutgers University, 2022). We used it with the Grade 10 classes in 2022. Students were expected to work through a guided worksheet in groups, with little input from the teacher. The guided worksheet can be found in Appendix 3: ISLE approach and ISLE-inspired activities. Activity I (as described above and provided in the

Appendix p. 338) and Activity II (learning to draw motion diagrams; Appendix p. 339) were completed with peers and little teacher input.

### Activity III: Observational experiment: relative motion

This concept exploration from PUM resources (Rutgers University, 2022) uses two observational experiments, both of which introduce the concept of relative motion (see Appendix 3: ISLE approach and ISLE-inspired activities; p. 344). In the first experiment, each student is handed a tube (the inner cardboard tube from a toilet paper roll). They are told that this is their 'telescope' and instructed to follow an object (I use a red ball). They need to keep the red ball in sight through the telescope. As the teacher stands in front of them, holding the object stationary, they must take note of the original orientation of the telescope.

The teacher then moves across the classroom and each student should follow the object, taking note of the direction in which their telescope is pointing, if they keep the object in sight. The teacher then uses their own 'telescope' to observe the object that they are holding as they walk across the classroom again. Students are asked to observe the orientation of the teacher's telescope as the teacher walks and comment on how it differs to what they observed about their telescopes when they followed the object. They are asked to consider whether they can tell whether an object is moving, by regarding the orientation of the telescope. The teacher then moves while keeping one of the students in the sight of their telescope and students are asked whether the idea that they came up with still holds true. The teacher is then able to guide students to the concept of relative motion.

In the second experiment, a number of student volunteers hold cardboard signs towards the class. The signs match the objects in the description in the students' books (see Appendix 3: ISLE approach and ISLE-inspired activities;

p. 344) so that the class can make observations as we follow the sequence of instructions. There is a moving blue car with two passengers (one in the front seat and the other in the back seat), a red car that travels in the same direction as the blue car and is overtaking the blue car and there is a pedestrian standing on the pavement ('pavement' in South Africa, rather than the American 'sidewalk') alongside the road as the cars pass.

As the students (slowly) act this out, the class observes the motion of the passenger in the front seat of the blue car from the perspective of each of the other role players. This is followed by two questions: do any of the role players or observers say that this passenger in the front seat is moving and do any say that they are not moving. Students are then asked to articulate what it means when we say an object is moving.

We have incorporated this activity into our Grade 10 workbook and use it as a visual introduction to relative motion.

### Activity IV: Observational experiment: introduction to forces

We introduce the concept of a force in Grade 9 and students learn to identify the interactions between objects that are in contact with one another and learn to calculate the weight of an object. They learn to draw free-body diagrams and encounter Newton's first, second and third laws. The concepts are revisited from scratch in Grade 11. In 2022 and 2023, we used the ISLE activity from the PUM resources (Rutgers University, 2022) with the Grade 9 groups and in 2023, we used the same approach with the Grade 11 group as well (Appendix 3: ISLE approach and ISLE-inspired activities; p. 350).

Each student was given a tennis ball and another ball (ping-pong ball, hockey ball, cricket ball or marble). Through a series of guiding questions, students were asked to describe what they felt when holding each ball, and the concept of a force as an interaction between two objects was introduced. Students were then guided through a series of steps that enabled them to draw a free-body diagram of the forces acting on the tennis ball. Having done this, the Grade 11 students were asked to think about whether air interacts with an object and, based on their answer, to predict what would happen to a sealed plastic bottle that was suspended from a spring inside a bell jar when a vacuum pump removed the air from the jar. Having predicted an outcome, they watched a video of the experiment to see what happened.

#### Activity V: Observational experiment: Newton's third law

Newton's third law was introduced to the Grade 9 and Grade 11 students through two activities (Appendix 3: ISLE approach and ISLE-inspired activities; p. 353). The first activity, which was my own design, was a demonstration involving two student volunteers on office chairs. When they pushed against one another, the class observed that both students moved backwards after the push. Next, only one of the students pushed against the other and the class observed that they still both moved away from one another. Lastly, one person stood up and the student still on an office chair pushed away from the standing student. In this case, if the standing student braced themselves sufficiently, the class observed that only the student on the chair moved backwards. We used the same activities to introduce the concept to both grades.

The second activity was an ISLE experiment, performed in pairs (Etkina, Brookes and Planinšič, 2019). Each pair of students had two spring balances, which they hooked together. They were told that initially one of them (student A) should pull with a force of 3 N and observe the reading on the other spring balance (held by student B). Student B should then pull with a force of 5 N and they record the reading on student A's spring balance. They wrote down a 'rule' for the readings on two spring balances that were attached and pulled apart. Lastly, the students were told to predict whether it was possible, based on their rule, to pull the attached spring balances so that one of the spring balances read 3 N and the other read 5 N. Once they had made their prediction, they tested their prediction by performing the experiment.

In the ‘time for telling’, the teacher was able to discuss how, when objects exert forces on one another, those forces are oppositely directed and always of equal magnitude.

Activity VI: Testing experiment: water in a glass

This activity is a good example of the application of the ISLE process, as students are encouraged to observe a phenomenon, come up with explanations for the observation, design experiments to test these explanations and make predictions based on each explanation. It is often used to illustrate the ISLE process and is a common introductory activity to the ISLE approach (Etkina, Brookes and Planinšič, 2019). We used it with Grade 8 and 9 classes over the three-year period of introducing the ISLE approach.

This activity (Appendix 3: ISLE approach and ISLE-inspired activities; p. 355) requires no prior content knowledge and can be done in a stand-alone lesson. I chose to include this activity because it illustrates the ISLE process so well, but also because it encourages students to take risks in coming up with ‘crazy ideas’ and to think of how they could test these explanations. Thinking about how you can test something is a valuable approach.

The purpose of the activity is to have students make observations and come up with explanations for their observations which they then design experiments to test. The activity is structured to guide students through this process and so there are three parts to the activity:

- a ‘mock’ task using a video showing many cameras in a house,
- a guided task, which I developed to help students understand how to structure their observations, explanations, testing experiments and results in the table provided, and
- the focus task of observing a glass of cold water.

The activity begins with a description (for junior grades) or a reminder (for senior grades) of what a hypothesis is and what a prediction is. The class is then shown a video of a tour of a house where there are many cameras and they are asked to come up with ‘crazy ideas’ or explanations as to why there are so many cameras in the house (without asking the person who lives in the house) (Etkina, Brookes and Planinšič, 2022). The class works in groups to come up with these explanations and then discuss their ideas as a class to scaffold or model the ISLE process. The teacher asks how each idea could be tested and what outcomes of the experiments would convince them of an answer.

The ISLE activity of observing a glass of cold water requires students to complete a table, Figure 5.1, called a Testing Multiple Explanations (TME) chart (Etkina and Planinšič, 2015), where they write their explanations for what they have observed down the left hand side of the table and describe the testing experiments that they will perform across the top row of the table. For each testing experiment, they predict the outcome, should the explanation be correct. The first few times I did this activity, students struggled to complete the table as they did not understand where to write their explanations, testing experiments and predictions. I set up a guided example to illustrate how to complete the table, which is shown in Figure 5.2.

## Question that you want to answer

| Testing experiment / Explanation for original observation | **Testing experiment 1:** | **Testing experiment 2:** | **Testing experiment 3:** |
|---|---|---|---|
| **Explanation 1:** | | | |
| **Explanation 2:** | | | |
| **Explanation 3:** | | | |
| | **Outcome of testing experiment 1:** | **Outcome of testing experiment 2:** | **Outcome of testing experiment 3:** |
| **Accepted explanation:** | | | |

**Figure 5.1:** A generic Testing Multiple Explanations (TME) chart (Etkina and Planinšič, 2015).

From May 2022, I presented the following scenario as an example of how we could answer a question, and to explain the TME chart. On our school campus there is a field (Hodgson Field) where one corner of the field is often flooded and usually wet. We want to know the source of the water. Students come up with ideas for where the water comes from and decide that it could be there as a result of a municipal water leak, ground water welling up or run-off from the cement walkways and yards above the field. I talked through the entries in Figure 5.2, discussing how predictions for the testing experiments were made for each explanation. For example, if we test for chlorine and the water is municipal water, chlorine will be present, but if the water is either ground water or run-off, we would not expect chlorine to be present in the water sample. This shows how testing for chlorine, calcium and nitrates could offer clues as to the source of the water. Once the tests are performed, the outcome of the tests would eliminate the incorrect explanations.

## Where is the water on Hodgson Field coming from?

| Testing experiment / Explanation for original observation | **Testing experiment 1:**<br><br>Test for chlorine | **Testing experiment 2:**<br><br>Test for calcium | **Testing experiment 3:**<br><br>Test for nitrates |
|---|---|---|---|
| **Explanation 1:**<br><br>Municipal water (burst pipe) | Chlorine present | No calcium | No nitrates |
| **Explanation 2:**<br><br>Ground water (seeping up) | No chlorine | Calcium present | No nitrates |
| **Explanation 3:**<br><br>Run off (surface water) | No chlorine | Some calcium | Nitrates present |
| | **Outcome of testing experiment 1:** | **Outcome of testing experiment 2:** | **Outcome of testing experiment 3:** |
| **Accepted explanation:** | | | |

**Figure 5.2:** An example from our context to illustrate how to complete a TME chart.

Once the completion of a TME chart had been modelled, the main task of the lesson could begin. A glass was filled with cold water and allowed to stand for a few minutes (or the class was shown a video of a glass filled with cold water if it was a particularly dry day). The class observed that water droplets formed on the outside of the glass. They were asked to work in groups to come up with explanations of where the water came from, which they were expected to fill into the TME chart. These explanations should be testable, and the students were asked to design ways to test their explanations, which were also put into the table. For each test, the students were required to predict the outcome, or their observations, if each of their explanation was true. Figure 5.3 shows an example of some of the explanations and tests proposed.

## Where does the water on the outside of a glass come from?

| Testing experiment / Explanation for original observation | **Testing experiment 1:**<br><br>Put cling wrap on glass | **Testing experiment 2:**<br><br>Put coloured water in glass | **Testing experiment 3:**<br><br>Oil in glass |
|---|---|---|---|
| **Explanation 1:**<br><br>Water comes out of top of glass | No water on outside | Water on outside will be coloured | Oil on outside |
| **Explanation 2:**<br><br>Water goes through | Water on outside | Water on outside will be coloured | Oil on outside |
| **Explanation 3:**<br><br>Water from air | Water on outside | Water on outside | Water on outside |
| | **Outcome of testing experiment 1:**<br><br>Water on outside | **Outcome of testing experiment 2:**<br><br>Water on outside | **Outcome of testing experiment 3:**<br><br>Water on outside |
| **Accepted explanation:**<br><br>As there was water on the outside of the glass in all three experiments, it must have come from the air (the other 2 explanations were disproved). | | | |

**Figure 5.3:** A TME to show possible explanations, testing experiments and predictions for the water on the outside of the glass.

Teachers who implement the ISLE approach usually have students design their experiments and then conduct them (Etkina, Brookes and Planinšič, 2019), but as we usually tried to fit this entire sequence of tasks into 45 minutes, there was only time for the students to come up with their explanations, design experiments and make predictions. This stage of the activity exposed students to ways of thinking that they did not encounter in other experiments or activities.

If there was time, although there rarely was, we played a video that shows how the mass of the glass changes over time (Etkina, Brookes and Planinšič, 2022).

### Activity VII: Testing experiment: How fast do you walk?

The goal of this activity (Appendix 3: ISLE approach and ISLE-inspired activities; p. 360) was to design an experiment that would test whether a student walks at constant speed or not. This required students (in groups) to understand how to measure or determine whether something is moving at constant velocity. I used this activity in 2021 with a Grade 9 boys' class, but they were very uncertain and despite giving them rice bags, they were very unsure what to do. I ended up having to explain that if they dropped the rice bags at regular time intervals, they could measure the distances between the bags to see whether the distances were uniform or changing. Only a few came up with methods involving rulers and stop watches, which were complicated and unreliable. We repeated the activity the following year when this group was in Grade 10, but this time all the physics students tried this activity directly after the introduction to motion (Activities I and II above) and some were able to devise an experiment independently.

This activity provided a context for the use of dot diagrams, which enable students to visualise accelerated and constant velocity with bean (or rice) bags. It involves a very simple, every-day context and prompts students to design an experiment to answer a question about something they see all the time.

### Activity VIII: Testing experiment: current in a circuit

I used this activity (Appendix 3: ISLE approach and ISLE-inspired activities; p. 362) with Grade 9, Grade 10 and Grade 12 classes, when they learnt about electrical circuits. Students were required to test a hypothesis that was given to them. They were told that their friend says that as current flows through a circuit, it is used up by the components of the circuit and they were asked to design an experiment to test this idea. They then made a prediction for the experiment that they had designed, should their friend's statement be true. They were asked to identify the assumptions that they had made. We rarely talk about assumptions and so I discussed these with the class, rather than having them identify them independently. This activity addressed a commonly encountered misconception in circuits. It also had students devise an experiment to test an idea, which empowered them with the thinking patterns to test any idea that is presented to them.

### Activity IX: Modelling behaviour: our physics workbooks

As previously mentioned, colleagues and I have written our own physics workbooks, which all our students use. Influenced by the ISLE approach, I made changes to the workbooks to model behaviours that we value: actively engaging with a concept through investigation, grappling with concepts and drawing diagrams to assist the translation of a problem from one representation to another.

In the original Grade 9 notes, the investigations, exercises and notes were all in the sequence of the teaching. In 2022, I made significant changes to the booklet, including many additional exploratory activities and activities from the ISLE community. These were all included at the back of the book, with a block amid the theory at the front of the book for students to write in a summary of what they had learnt in each investigation. The aim was that the key concepts could be recorded during the ‘time for telling’ so that the learning from the observational experiment was captured and students could be reminded of how they learnt the concepts. Having the activities at the back of the book meant that the flow of text explaining concepts was more succinct, but students could still refer to the tasks at the back of the book to remember how they had learnt a concept.

The Grade 10–12 workbooks included classwork exercises for each concept to give students the opportunity to practise applying the concepts, and additional worksheets were handed out at the end of each section. Past tests were also available digitally and we handed out at least one past test in hard copy for each section. Fully worked solutions were available online for most of the worksheets, and past tests on each section, as well as past examinations, were available to students digitally. In 2023, I made significant changes to the Grade 10-12 books, by including exploratory activities (usually based on the ISLE-approach activities) at the back of each book. Instead of giving out worksheets, I included the worksheets at the back of the book as well. Instead of making fully worked solutions available, the answers (without worked solutions) were included in the book. This was to encourage students to engage and grapple with the problem when they did not get it right and to ask for help, rather than consulting the memorandum to learn how to do a problem and then feeling that they are able to solve it because they had copied the solution.

Another change made to the books in 2023, was to include space with a prompt to draw a diagram for every example where it was appropriate. In our teaching, we all emphasize the importance of drawing a diagram when solving a problem and many of the exercises in the workbook include an instruction to draw a diagram as a separate question, but our hope in including a space to draw the diagram next to every question is that this will become a habit and part of the process of solving each problem. Some examples of the changes made to our workbooks are given in the Appendix on p. 363.

### Activity X: Modelling behaviour: post-lesson reflection task

As mentioned previously, reflection is an important aspect of cumulative learning (Maton, 2014). To encourage students' habitual reflection, they were asked to reflect after each lesson. This reflection task was based on a weekly reflection task developed and used by David May and Eugenia Etkina (Etkina, 2000; May and Etkina, 2002). The activity prompted students to reflect on the lesson by completing these statements:

- In today's physics lesson I learnt…
- I think that I learnt this concept by / through:…
- This still remains unclear / I want to ask:…

For the Grade 9 class that I taught in Term 3 of 2021 and for all (my) classes at the start of Term 1 in 2022 (Grade 9-12), I posted a lesson reflection task (see Appendix 3 on p. 364) on Google Classroom, which is the platform on which we share resources. I initially asked students to complete this reflection in the last 2 minutes of the lesson and then, after a particular ISLE activity, I would remind them to complete it at the end of the lesson. However, I often forgot to prompt them during the lesson and reminded them as they were walking out of the class. After a few weeks, I stopped reminding them altogether. Unfortunately, few students remembered to reflect on what they had learnt, and this is discussed further in Section 7.1.10.

Activity XI: Modelling behaviour: examination reflection task

Reflection is important and students should look for physics concepts across questions to aid cumulative learning. I developed this examination reflection tool to guide students in their engagement with their previous examination. This is one of the activities that I refer to as 'ISLE-inspired' as it is based on the principles of the ISLE approach (reflection, student well-being and building cumulative knowledge). Many students page through a previous exam and 'look at it', but we are trying to develop active engagement, so I created a tool to help them adopt a more structured approach. Students were to work through their exam and indicate, for each question which they answered incorrectly, whether their error was conceptual, learning-based or functional. The idea was that they could then, at a glance, see what kinds of errors they made and in which sections, to help them in their revision for the next examination. There was also space for them to write notes on any concepts with which they had struggled.

**PHYSICS EXAM REFLECTION TOOL - G10 NOVEMBER 2023**

| | Conceptual problem | | | | Learning (definitions) | | | Functional error | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Did not understand the question | Did not answer the question | Missaplied the concept | Did not understand the concept | No attempt (no idea) | Did not know it | Inaccurate wording | Wrong units | Left out units | Maths error | Incorrect value (incorrect copying) | CONCEPT (notes) |
| 1.1 | | | | | | | | | | | | |
| 1.2 | | | | | | | | | | | | |
| 1.3 | | | | | | | | | | | | |
| 1.4 | | | | | | | | | | | | |
| 1.5 | | | | | | | | | | | | |
| 2.1.1 | | | | | | | | | | | | |
| 2.1.2 | | | | | | | | | | | | |
| 2.1.3 | | | | | | | | | | | | |
| 2.1.4 | | | | | | | | | | | | |
| 2.2 | | | | | | | | | | | | |
| 2.3 | | | | | | | | | | | | |
| 3.1.1 | | | | | | | | | | | | |

**Figure 5.4:** The examination reflection tool which was developed to help students categorise their errors and see problematic sections at a glance.

This was introduced in 2023 and piloted for the Grade 12s (in physics and chemistry) who worked through their Preliminary Examinations, which are written a few months before their Final Examinations (see Appendix 3 on p. 366). All students (in each grade) used these reflection tools in the last lesson of the last term in 2023, before they wrote their end of year set of examinations, and we have continued to use these in 2024.

### Activity XII: Well-being: Expertise Activity

A positive attitude and a learning-orientated mindset are important for learning in the physics classroom (Adams, 2006; Yeager and Dweck, 2012). One of the activities developed by the ISLE community to mitigate against students' frustration when they struggle with physics or with the learning process is called the Expertise Activity (Brookes and Lin, 2012; Etkina, Brookes and Planinšič, 2019) described in Appendix 3 on p. 368.

Students are given whiteboards and asked to write down a list of activities or pastimes that they feel they are good at. Once each student has made their list, the teacher walks round and comes up with a list of categories based on what is written on the boards. For example, students might, amongst them, include the following on their lists: playing the piano, swimming, basketball, guitar, solving a Rubik's Cube, hockey, baking, singing, solving puzzles, crosswords, playing the violin and tennis. The teacher might then use sports, music, cooking and puzzles as broad categories and ask students to regroup themselves into those categories where their activity fits. Each group is then asked to think about how they became an expert in their chosen activity. They work together as a group to construct a repeatable process which someone can follow to go from being a novice to an expert in the activity that they consider themselves good at. Once the groups have had a chance to do this, they report back to the class.

I used this activity with my Grade 11 classes and Grade 12 classes at the start of 2022, and my colleague, Teacher B did the same with her Grade 11 and Grade 12 classes. We felt that the students in these classes had lost confidence as a result of a poor set of end-of-year examinations the previous year. In 2023, we used the same activity with two of the Grade 11 classes soon after their mid-year examinations which these classes had found particularly difficult. The classes were demotivated and lacked confidence in their physics ability and we hoped to motivate them and encourage a learning-orientated mindset.

The learning cycles described by students for the activities they felt they were good at, usually included practice, watching an expert, trying for themselves, trying again, investing time, asking for help and listening to an instructor or seeking advice. I wrote these up on the board as each group reported back and by the end of the activity, most students realised that they could apply the learning sequence that they had discussed to their physics learning process. The activity concluded by drawing the parallel that this is what they need to do in order to become experts in physics.

This reminds students that they are all experts in some area and know how to learn and how to progress, which provides motivation to persevere (Brookes, Etkina and Planinšič, 2020).

### Activity XIII: Well-being & modelling behaviour: re-tests

One of the tenets of the ISLE approach is an emphasis on student well-being. The approach also embraces the concept of universal design (Scott, McGuire and Foley, 2003) and the idea that all students need the opportunity to reach learning goals at their own pace (Etkina, Brookes and Planinšič, 2019). This means that not everyone will get everything right the first time and ISLE instructors believe it is important that students have the opportunity to improve their understanding of work, based on feedback, and to resubmit their work for subsequent assessment. In ISLE classrooms, this means that work that is submitted, is returned with feedback and students have the opportunity to improve their work based on that feedback before resubmitting.

In our context, because the bulk of our marks are made up of summative assessment tasks such as tests, we tried re-tests for the duration of 2022 for all senior grades and for my Grade 9 classes. Tests were returned without a memorandum or set of solutions and all students had the opportunity to apply to rewrite. Resubmission has been used in various ways by ISLE instructors, but I adapted Matt Blackman's approach (Blackman, 2022) and adapted it for our situation (See Appendix 3: ISLE approach and ISLE-inspired activities for test resubmission policy, resubmission application form and guide to completing the reflection form, beginning on p. 369).

Blackman's (2022) approach requires students to apply to rewrite, which makes the process sufficiently onerous to hopefully discourage students from not preparing for the first assessment with the view to rewriting (other ISLE instructors allow rewrites without an application process). A new test on the topic is set for the rewrite, but not returned to the students, so this test can be used in future so that work is not doubled each time the topic is taught. ISLE instructors use this approach for "quizzes" which they ask at the start or end of a lesson to assess understanding and students have the opportunity to retake or reattempt quizzes to improve their understanding. Many ISLE courses allow multiple submissions of experimental write-ups (Etkina, Karelina and Ruibal-Villasenor, 2008; Buggé, 2020) and some allow multiple attempts on examination questions (Etkina, Brookes and Planinšič, 2019)

To apply for a rewrite, students were required to complete a rewrite application form. They had to correctly solve each problem that they had answered incorrectly and to identify the mistakes that they had made the first time. They were then required to articulate (on their page) why they had made these mistakes. This required engagement with their understanding and identification of ‘what went wrong’ or what they had previously misunderstood. Students are then asked how they learnt to do this correctly, which gave me insight into how they corrected their understanding.

The application process was done online. Students completed one form for every question that they answered incorrectly and uploaded their completed forms with a scanned copy of their original test. I either replied to say that they met the criteria to rewrite (they had completed the reflective process adequately) or that they should resubmit. Initially, many students were not reflecting on their physics mistakes, but rather on their preparation methods, typically giving answers such as ‘I should have prepared better’ as their reason for incorrectly answering a question. As a result, we prepared a guide to answering the test reflection form, which was available to download and read alongside the application form.

A new test on the same work was set and students had one opportunity to write the re-test. The test was marked and the mark was shared with the student and recorded, but the test was not made available to the students so that it could be used again to reduce teacher work load. The new mark replaced the original mark, in line with the ISLE-approach philosophy that students should not be penalised for their original misunderstandings if their understanding of a concept has subsequently improved (Brookes, Etkina and Planinšič, 2020).

### Activity XIV: Well-being & modelling behaviour: take-home tests

This activity is one that I have not seen ISLE instructors use, but the idea is influenced by the emphasis on student well-being. Many students experience anxiety and high levels of stress during summative assessments, and this negatively impacts on their performance. Take-home tests were introduced in

2022 to give the Grade 10 to Grade 12 students the opportunity to complete one test each term without the time pressure or the associated anxiety of writing under test conditions. They usually had a week to complete the test and could use their notes or work together and could even bring similar questions to Support to ask for help (although not the take-home test itself).

We did warn students that taking shortcuts on this activity such as copying from one another or asking someone else for help, would rob them of the opportunity to build understanding. We asked at least one concept from each take-home test in the examination. Take-home tests were not always on the work that we were currently busy with, but we used them to encourage revision of previous work. This was usually either in the lead-up to an examination or where prior knowledge would be useful for the next section of work. This was so that the activity doubled as a prompt for students to revise previous work or build confidence for examinations, while offering them an assessment under less stressful conditions.

One of the downsides of take-home tests was that often students worked with one another or asked for help from a senior student and this meant that the work that was handed in was not always a reflection of their own understanding. This may have been exacerbated because the activity counted towards their term result. After two terms of trialling take-home tests, we stopped setting them, as these assessments were inflating marks and not achieving their intended objective of encouraging appropriate engagement.

### Activity XV: Well-being & modelling behaviour: pre-tests

In the third term of 2022, the Grade 10 students were struggling with the section on motion in two dimensions and we gave them a past test to complete and then asked them to mark their work as we went through it in class. This seemed to draw their attention to their errors and to allow them to correct misunderstandings before the actual test.

From Term 2 (start of May) of 2023, we introduced ‘pre-tests’ to the Grade 10s and 11s. The task summary is given in Appendix 3: ISLE approach and ISLE-inspired activities; p. 372. Students were given the previous year’s test on the current work to complete about a week before their test on the work. They were encouraged to complete the test and hand it in, although there was no credit given for the work. We ‘marked’ it, but only indicated right or wrong with ticks and crosses and circled errors in places. No corrections were made by the teacher and no overall mark was written on the test paper. In some cases, part-marks were indicated for sub-questions (e.g., 1 out of 4) to show students to what extent they achieved success in answering the question. This was so that students had to engage with each question to see how they had performed.

Students were encouraged to do corrections on their pre-tests and to engage with the questions for which they did not score full marks, to improve their understanding of the concepts. They were asked to briefly articulate what went wrong in the question. For example, some may have forgotten to include direction when the answer was a vector quantity, or may have left out a force in a free-body diagram. The rationale for this exercise was to ensure that every student practised a past test before the ‘real’ (summative) test. It allowed teachers to gauge each student’s understanding of the concept before they wrote the test, offering an opportunity for intervention where there were misunderstandings. Simply asking students to complete a past test without engaging with the areas that they did not fully understand, did not allow them to improve their understanding. For this reason, we introduced the reflective part of the exercise to encourage self-reflection and the improvement of understanding.

The Grade 9s wrote pre-tests in class under test conditions (no books, no collaboration) as they needed the structure to ensure that they did the activity alone and that they allocated enough time to complete the task. This meant that they needed to prepare for the test before writing the pre-test, so it was a false deadline. They were then given the opportunity to do corrections in their own time and were expected to hand these corrections in.

Pre-tests had no impact on students' results. Teachers recorded a tallied mark for our own reference to see whether there has been improvement in the summative test, for the purposes of this study. In the Grade 9 survey at the start of 2023, I asked students whether they had done better in the pre-test or the actual test and to speculate on why. I removed this question from the surveys after one iteration to reduce emphasis on marks.

The pre-tests were intended to be a learning activity. The idea was that we take the best aspects of our previous trials and give students the opportunity to learn from their mistakes to practise questions on a section and get feedback and to complete the activity in a low pressure setting rather than in a high-stakes test.

### *5.3.3 Data collection tools*

As previously described, not all cohorts experienced exactly the same set of activities. Table 5.4 shows the activities that each cohort experienced, as well as the data collection tools used with each cohort.

**Table 5.4:** The ISLE and ISLE-inspired activities that each cohort was exposed to over the period of 2021-2023, as well as the data collection done.

**KEY:** ☐ 2021 ☐ 2022 ☐ 2023

| | Pilot | Trailblazers | Pioneers | Explorers | Last Chance |
|---|---|---|---|---|---|
| Grade 8 | | | | pilot of water on glass activity | |
| Grade 9 | | | pre-CLASS<br>introduction to acceleration; force concept; Newton's third law; circuit design (one class only)<br>survey; post-CLASS | pre-CLASS<br>reflections; re-tests; introduction to acceleration; force concept; Newton's third law; circuit design<br>survey; post-CLASS | pre-CLASS<br>pre-tests; water on glass; force concept; Newton's third law; circuit design<br>survey; post-CLASS; focus group (1) |
| Grade 10 | | | reflections; relative motion; introduction to acceleration; How do you walk? re-tests; circuit design | relative motion; pre-tests; examination reflection tool<br>survey; post-CLASS; focus group (1) | |
| Grade 11 | pre-CLASS | pre-CLASS; re-tests<br>expert activity; reflections<br>interview (1) | expert activity (selected classes); reflections; force concept; Newton's third law; examination reflection tool<br>survey; post-CLASS; focus groups (3) | | |
| Grade 12 | expert activity; reflections; re-tests<br>survey; post-CLASS; interview (1) | pre-tests; examination reflection tool<br>survey; post-CLASS; focus groups (2) | | | |

## A. Colorado Learning Attitudes about Science Survey

In Physics Education Research (PER), reference is often made to expert-like and novice-like attitude to learning and approach to problem solving (described in Section 2.2.4). Novice problem solvers usually rely on equations and see physics as a collection of disconnected facts, which have to be learnt, while experts see the relationships between information and stored knowledge and are able to reason through an unseen problem using concepts (Gerace et al., 2001). Attitudes to problem solving can be classified as more expert or more novice.

The Colorado Learning Attitudes about Science Survey (CLASS) is an instrument developed and validated by the PER group from Boulder Colorado which is “designed to measure student beliefs about physics and about learning physics” (Adams et al., 2006, abstract). It is administered as a pre- and post-test so that a shift in student beliefs over a course can be determined. The CLASS survey consists of 42 statements with a 5-point Likert-scale for the responses (strongly agree, agree, neutral, disagree and strongly disagree) (Adams et al., 2006). The 5-point scale was chosen to reduce the number of responses of ‘neutral’ which is more prevalent with a 3-point scale, but in the analysis, ‘strongly agree’ and ‘agree’ responses are contracted, as are ‘strongly disagree’ and ‘disagree’ responses (Adams et al., 2006). The survey was designed to be easy for students to interpret and the statements were intended to be accessible to all students, requiring no prior physics knowledge, and it takes American students an average of just 10 minutes to complete (Adams et al., 2005).

A favourable score is the percentage of students who agreed with the ‘expert’, while an unfavourable score is the percentage of students who disagreed with the ‘expert’ (Adams et al., 2006). It is common for student attitudes and beliefs to deteriorate through a physics course, unless the teaching specifically addresses student beliefs (Adams et al., 2005). This is consistent with findings from other studies which found that students' expectations of learning physics deteriorate after some period of the course, although this was in a calculus-based course setting (Redish, Saul and Steinberg, 1998).

In order to analyse the CLASS results, we used the spreadsheet template available on the American Association of Physics Teachers resources website (AAPT, 2019). This was set up with formulae to calculate the percentage of favourable and unfavourable responses, as well as showing the shifts in response from 'more novice' to 'more expert' responses or from more expert-like to more novice-like responses. The data generated from the student responses was used to contribute towards an answer to the research question of how the student experience of the ISLE approach demonstrates the development of behaviours that we value in physics knowers. To allow researchers to see emerging patterns in the data, the CLASS survey questions are divided into clusters, as shown in Table 5.5.

**Table 5.5:** Categories for CLASS questions and responses (Adams et al., 2006).

| **Category** | **Overview of questions in this category** | **Example of response statements to this question** |
|---|---|---|
| Personal interest | Whether students feel a personal interest in or a connection to physics. | I think about the physics I experience in everyday life. |
| | | I study physics to learn knowledge that will be useful in my life outside of school. |
| Real world connection | Seeing the connection between physics and real life. | Reasoning skills used to understand physics can be helpful to me in my everyday life. |
| Problem solving general | How students approach problem solving in general. | If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works. |
| | | When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented. |
| Problem solving confidence | How students feel about their problem-solving ability. | I can usually figure out a way to solve physics problems. |
| | | Nearly everyone is capable of understanding physics if they work it out. |
| Problem solving sophistication | Student strategies to problem solving. | After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic. |
| | | I can usually figure out a way to solve physics problems. |
| Sense making / effort | For me (the student) exerting the effort needed towards sense-making is worthwhile. | I am not satisfied until I understand why something works the way it does. |
| | | In physics, it is important for me to make sense out of the formulae before I can use them correctly. |
| Conceptual understanding | Understanding that physics is coherent and is about making sense, drawing connections, and reasoning not memorizing, making sense of maths. | I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations. |
| Applied conceptual understanding | Understanding and applying a conceptual approach and reasoning in problem solving, not memorizing or following problem-solving recipes. | When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values. |
| | | If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations. |

At the start of this study, before ISLE was introduced in our context, students were asked to complete the CLASS survey in a lesson and, in subsequent years, students completed the survey at the start of their physics course (the pre-test). Instead of using a paper-based version of the CLASS survey, I entered the questions into a Google Form for ease of administration and capture of the responses. At the end of a group's Grade 12 year or, at the end of my data collection period, the students completed the same survey (post-test). The Grade 9 groups only do physics for a term and so they completed the CLASS survey at the start (pre-test) and at the end (post-test) of their term of physics. The pre- and post-test dates are shown in Table 5.6, for clarity. The different intervals between the pre- and post-tests may have had an impact on the shifts.

**Table 5.6:** Timeline of pre- and post-tests for CLASS for each cohort.

| Cohort | Grades of participation | Data collection year(s) | CLASS Pre-test | CLASS post-test |
|---|---|---|---|---|
| Pilot | 11 - 12 | 2021 - 2022 | Sept 2021 | Sept 2022 |
| Trailblazers | 11 – 12 | 2022 – 2023 | Jan 2022 | Sept 2023 |
| Pioneers* | 9 – 11 | 2021 – 2023 | Jan 2022 | Nov 2023 |
| Explorers* | 8 – 10 | 2021 – 2023 | Jan 2023 | Oct 2023 |
| Last Chance | 9 | 2023 | Start of physics term | End of physics term |

* *These cohorts completed the CLASS pre- and post-test in their Grade 9 year and again for their time in the senior phase (Grade 10-12).*

B. Surveys

In addition to the CLASS survey (Adams et al., 2006), which was research-validated, students completed a survey that I had devised to explore student experiences of the ISLE approach.

Students were surveyed at the end of the study period, which was near the end of the Grade 12 year for the 2022 and 2023 Grade 12 students, at the end of 2023 for the 2023 Grade 11 and Grade 10 groups and, for the Grade 9 students, at the end of their term of physics.

**Table 5.7:** Timeline of post-learning experience surveys with each cohort.

| Cohort | Grades of participation | Data collection year(s) | Survey on physics learning |
|---|---|---|---|
| Pilot | 11 - 12 | 2021 – 2022 | Sept 2022 |
| Trailblazers | 11 – 12 | 2022 – 2023 | Sept 2023 |
| Pioneers | 9 – 11 | 2021 – 2023 | Nov 2023 |
| Explorers | 8 – 10 | 2021 – 2023 | Oct 2023 |
| Last Chance | 9 | 2023 | End of physics term |

The survey questions can be found in Appendix 4: Data collection and analysis tools on p. 384 (along with the codes used for the data analysis to avoid duplication of the table). The survey asked the students to reflect on their experiences in the physics classroom and on their beliefs and ideas about how they learn physics. The survey included questions on what makes them feel comfortable in class, whether they feel pressure to do well in physics and how they feel about their ability in physics and whether this has changed. They were asked to comment on whether working in groups in physics impacts their learning experience. To explore student ideas of epistemology, students were asked how they learn a new concept and how they are convinced of a new concept. They were also asked whether their understanding of how they learn and their approach to learning had changed over the time that they had done physics. In terms of practice, students were asked whether they had used or seen benefit in the reflection task (Activity X above). The surveys then included questions to gauge student experience on re-tests and the use of the memorandum in 2022, and on pre-tests and investigations in 2023.

### C. Interviews and focus groups

Interviews and focus-group discussions were facilitated to explore the extent to which the ISLE approach that we implemented had developed the behaviours that we value in physics. I had just one formal, recorded discussion with my physics teaching colleagues (Teacher A and Teacher B) in June 2023, although I had many conversations, debates and discussions with colleagues over the course of this study about the ISLE approach, its introduction and the merits and pitfalls of its implementation. Teachers A and B were happy that I recorded the discussion, having consented to allow me to use their responses in my analysis (Appendix **2:** Ethical clearance 2.6; p. 336). I asked about their experience of the conceptual introduction to forces and about their experience of pre-tests.

I conducted just two interviews with individual students. The first was with a Grade 12 student in September 2022 who volunteered to come and talk to me about her experience of learning physics. The other individual interview was with a Grade 11 student in November 2022 who had strong views about re-tests and wanted to voice them. She volunteered for the interview, consented that I record the interview and was satisfied with the transcript.

I facilitated semi-structured focus-group discussions with groups of students from each grade, focussing on their experience of learning physics in general and specifically their experience of the ISLE approach. As the boys and girls were being taught separately in class, the focus groups were single gender. I facilitated two pilot focus groups (one with boys and one with girls) specifically about the Grade 11 ‘introduction to forces’ investigations. Most of the focus groups were between September and November 2023, with Grade 12 boys ($n = 5$), Grade 12 girls ($n = 8$), two different groups of Grade 11 boys ($n = 6$ and $n = 4$), Grade 11 girls ($n = 4$), Grade 10 girls ($n = 6$) and Grade 9 boys ($n = 4$) participating.

These interviews and focus-group discussions were semi-structured as I followed a sequence of questions (see Appendix 4: Data collection and analysis tools 4.1; p. 373), but I allowed the students to steer the conversation and discuss their experiences of learning physics amongst themselves. I tried to keep the questioning conversational, with the aim of getting students to talk comfortably about their experiences of physics and the classroom, without making them feel that they were under scrutiny or that I was making judgements on their comments. I tried to emphasise my role as the researcher, rather than my conventional role as the teacher, so that I could encourage responses that they might offer an outsider, without fear that they were criticising me.

### *5.3.4 Data analysis processes*

The data in this study were collected through the student reflections, surveys, interviews, focus-group discussions and by looking at student assessment. Student and colleague interviews and focus-group discussions were recorded and then transcribed. The transcription was carefully cross-checked against the recording and sent to participants to be member checked for validity (Creswell and Creswell, 2017). Quotes to illustrate trends in responses and to add depth to the quantitative results, were chosen from these transcripts, from the survey responses and from students' reflections.

Student responses to the survey were coded inductively according to the codes that emerged from the data, rather than codes being imposed on the data based on an external theoretical framework (Creswell and Creswell, 2017). The emergent codes are given in Appendix 4: Data collection and analysis tools 4.5 on p. 384. A sample of responses were coded by my two supervisors to establish intercoder reliability (O'Connor and Joffe, 2020). This was done by comparing the codes assigned to each response by the three coders and tallying how many of the total were coded the same, to determine a percentage agreement. We found an agreement of 90% on the sample of 284 codes. Items where there was a difference of opinion were discussed, to align coding. This check was done to reduce the risk of insider bias, as both supervisors were outsiders to the classrooms where the research was conducted. In addition, the inclusion of an intercoder comparison improved the rigour of the research by increasing the trustworthiness of the data (O'Connor and Joffe, 2020).

I spent time with my data, coding it according to the themes that emerged and analysing it to see the patterns that emerged from student responses. The emergence of patterns in the data allowed me to generalise findings, and the exploratory nature of the inductive approach allowed unexpected themes and findings to emerge that I would not have seen, had I used a deductive approach (Bertram and Christiansen, 2020). The responses gave insight into the students' experience of the activities before I came to look at those activities. It also confirmed the behaviours that we value. Some of the questions gave binary options for the answers, but many were open ended, offering rich feedback.

Having spent time with the student responses, I looked at each ISLE and ISLE-inspired activity and considered what knowledge the activity legitimated. Some activities valued significant prior knowledge in students, while developing this knowledge further, while others did not require any prior knowledge to develop knowledge through the activity. I drew up a simple translation device (Maton and Chen, 2015) (Table 6.1) to indicate the level of prior knowledge that was valued in each activity.

Once I had decided on our valued behaviours, I spent time looking at each of the ISLE and ISLE-inspired activities and contemplating which of these behaviours the activity would require or legitimate. I constructed a bridge between the data and theory or *translation device* between the activity and these behaviours. I wanted to find out to what extent each of the activities develop these behaviours, which are important for physics knowers. Consequently, I decided to use the number of these behaviours which were legitimated by the activity as the indicator of what is valued. The translation device that I used to look at the activities (Table 6.2) enabled me to look at not only to what extent the activity valued behaviours, but also which behaviours were valued. As I coded the activities, the process of going back and forth between the activities (data) and the theory meant that I refined some of my initial coding with subsequent revisions. The development of a translation device is intertwined with the analysis of the data and so the translation devices can be found in Chapter 6.

Once the responses were coded, the codes were tallied to represent trends in the responses. These were reported, with quotes from the surveys, focus-group discussions and interviews to support the arguments that were made.

As mentioned above (Section A), the data collected from students as they completed the CLASS survey were entered into a spreadsheet, which generated graphs showing the shifts in attitude towards learning over the course of the study for each group. These shifts were shown with arrows as a visual representation to show trends for each group.

The re-test applications were scanned (if submitted in hard copy) or saved (if submitted electronically on Google Classroom). These were examined for corrections and for evidence of active engagement, grappling, reflection and making connections, which suggests cumulative learning. For each re-test application that was submitted, a note was made whether corrections had been done, and whether the student had provided reflective comments. The hard-copy re-tests themselves were scanned and the marks for these were recorded for comparison to the original test mark.

The hard copy pre-tests that were handed in after students had the opportunity to do corrections and reflect on their learning, were scanned so that student engagement could be documented. The pre-test mark (tallied and recorded by the teacher, but not written on the test paper) was compared graphically to the actual test mark.

The following chapter describes how the ISLE activities described here were analysed to describe valued behaviours in physics knowers. The data from the research tools described will be discussed in Chapter 7.

# CHAPTER 6: FINDINGS: ISLE ACTIVITIES AND THEIR LEGITIMATION OF VALUED BEHAVIOURS

*“The researcher must be ‘prepared to live with the muddle which is the unordered data, and enjoy the pleasure of its potential, in order to be able to generate the theoretical apparatus which is specific to it’ (Bernstein, personal communication).”*

(Moss, 2001, p.18)

This chapter answers the research question:

- To what extent do ISLE activities legitimate the behaviours that we value in physics knowers?

In this chapter, I consider the ISLE and ISLE-inspired activities that we used and explore whether they emphasize the behaviours that we value in a physics knower. I examine the ISLE and ISLE-inspired activities through the theoretical lens of Legitimation Code Theory (LCT) to make explicit what is valued in and through the activities. In the first section of the chapter, I define what I mean by a ‘physics knower’ and which of the behaviours valued by Physics Education Research (PER) and the ISLE approach, I aimed to develop. In the next section, I describe the development of the translation devices to explore what prior knowledge and student behaviours are valued in each of the ISLE and ISLE-inspired activities. I then use the translation device that has been developed to code each ISLE and ISLE-inspired activity, allowing me to plot the activities on a Specialization plane. Lastly, I discuss the implications of these findings.

## 6.1 Valued behaviours in physics education

LCT considers physics to have a knowledge code (Adendorff and Blackie, 2022), but both the knowledge and the process of learning, facilitated by the behaviour and disposition of the knower, are important. The ISLE approach places emphasis on the learning process, as students are expected to 'think like scientists' (Etkina and Planinšič, 2014b). A physics knower has the characteristics of a successful knower in other academic fields, such as being actively engaged in the learning process, learning to transfer concepts from one context to another and grappling with concepts to build understanding. However, learning to transfer concepts is a significant challenge to novice physics students and is critical to problem solving (Bransford, Brown and Cocking, 2000). Making connections between the abstract (mathematics and concepts) and the concrete, physical scenario is perhaps peculiar to physics (Greeno, 1989). Experts navigate between these representations with apparent ease, and learning to integrate the various aspects of a problem is one of the most important steps to solving problems and integrating knowledge.

The review of PER literature in Chapter 2 emphasized the importance of actively engaging with concepts through active learning (Section 2.1.2) the use of representations in physics problem solving (Section 2.2.3), being able to transfer knowledge (Section 2.2.1), persevering in solving problems, and reflection (Section 2.4). These behaviours are among those valued in physics education.

The ISLE approach is process-orientated and emphasises the importance of the characteristics that the chosen activities develop (see Section 3.2.1). In addition to these behaviours that are valued by the physics education community in general and the ISLE community in particular, we encourage our students to practise examples to expose them to a wide range of applications of physics and to build their confidence in problem solving.

However, we expect them to actively engage with these examples and to look for patterns as they solve the problems, rather than just focusing on the procedure, while completing them mechanically. Taking a broader view of problems is intended to build understanding and to help students see the patterns in the underlying physics concepts, so that they can transfer their knowledge to new contexts and achieve cumulative learning.

From the behaviours that are legitimated by PER and the ISLE approach, there are certain behaviours that we value which enable students to successfully access physics knowledge in our physics classroom. These valued behaviours require students to

- actively engage with concepts while learning (*actively engage*);
- transfer knowledge from one context to another (which LCT refers to as cumulative learning) (*transfer concepts*);
- Make connections between the concrete, mathematical and conceptual representations of a concept (or problem), often aided by a visual representation (*connect domains*);
- grapple with concepts (*grapple*).

These four behaviours encompass many of those valued by PER and ISLE as actively engaging in learning incorporates many aspects of learning including reflecting, learning from mistakes and interrogating the information that is presented. Grappling with concepts is uncomfortable, but allows deep and transformative learning.

The quote at the start of this chapter refers to being ‘being prepared to live with the muddle’. The phrase in the quote refers to the process of developing a translation device and I was often reminded of the importance of spending time in the ‘muddle’ of data to see what would be revealed. However, this quote also describes the concept of grappling. Students sometimes need to spend time in the muddle before concepts make sense and they can fit the concepts into an organised knowledge structure. This is an uncomfortable phase of learning. Grappling also allows students to focus on the *process* of the learning, rather than the outcome. In this way, the focus of the task is shifted to encourage learning-orientated goals, rather than performance-orientated goals. As previously described, both ‘cumulative learning’ and ‘making connections’ are vital to students’ access to physics knowledge.

If students approach a task that values these behaviours, but have not yet developed them, they will struggle with a given task. By repeatedly encountering tasks that legitimate these behaviours, students have the opportunity to develop them, particularly if these behaviours are made explicit in the activity. By making these behaviours explicit, we communicate that they are important, which encourages students to value them as well. Linking PER and education theory with classroom practice also encourages teachers to choose intentional activities that target specific, valued outcomes (Brookes, Etkina and Planinšič, 2020).

## 6.2 Development of a translation device

A translation device provides a means for the researcher to establish patterns in qualitative data with less subjectivity and enables others to see those patterns, as it makes the enactment of the theory explicit to others (Maton and Chen, 2015). As described in Chapter 5, I developed a translation device through immersion in the data and an iterative process of moving back and forth between the theory and the data. Table 6.1 indicates the level of prior physics conceptual knowledge legitimated in an activity. This translation device enabled the coding of the relative strength of epistemic relations of the ISLE and ISLE-inspired activities that were considered in this study.

**Table 6.1:** Translation device for Epistemic Relations (ER) in ISLE and ISLE-inspired activities

| **Concept manifested as emphasis on** | **Code** | **Indicators** | **Examples from activities** |
|---|---|---|---|
| content knowledge required to be successful in ISLE and ISLE-inspired activities | ER++ | Significant prior physics conceptual knowledge determines access | Pre-tests require sufficient content knowledge to complete the activity. |
| | ER+ | Some prior physics conceptual knowledge determines access | Current in circuit observational experiment requires enough content knowledge to build a circuit. |
| | ER– | prior physics conceptual knowledge does not determine access | Relative motion requires no prior knowledge as students observe. |

I also developed a translation device (Table 6.2) to reveal the relative strengths of the social relations legitimated by each ISLE and ISLE-inspired activity. This translation device allowed me to identify which behaviours were valued in each activity and the extent to which the valued behaviours are legitimated.

**Table 6.2:** Translation device for Social Relations (SR) in ISLE and ISLE-inspired activities

| Concept manifested as emphasis on | Code | Indicators | Examples from activities |
|---|---|---|---|
| Behaviours required to be successful in ISLE and ISLE-inspired activities | SR++++ | All 4 valued behaviours needed | The pre-test requires students to connect knowledge through diagrams, transfer concepts to new contexts, and then, when doing corrections, engage actively with errors and grapple with their understanding (no solutions). |
| | SR+++ | 3 valued behaviours needed | The examination reflection task requires students to actively engage, to identify the underlying concepts in a question (same skill as transfer) and to grapple with what they did not understand. |
| | SR++ | 2 valued behaviours needed | The activities that encourage representations require students to engage actively in learning and to draw diagrams (to connect domains). |
| | SR+ | Only 1 valued behaviour needed | Some of the observational experiments require only active engagement. |

These two translation devices provided an analytic tool to look at the way that knowledge and knowers are valued in ISLE and ISLE-inspired activities.

## 6.3 Valued behaviours in ISLE activities

Once the translation devices for this study were drafted, I applied them to the activities and coded each activity according to the knower's prior knowledge that was valued by that activity and the behaviours that were valued in that activity. This analysis is shown in Table 6.3.

**Table 6.3:** Data analysis showing how each activity was coded.

| ISLE or ISLE-inspired activity | Knowledge required to legitimate knower in activity | Valued behaviours required to legitimate knower in activity | Code |
|---|---|---|---|
| I. Representations: introduction to motion (bean bags) | None | Actively engage<br>Connect domains | ER–<br>SR++ |
| II. Representations: motion diagrams | None | Actively engage<br>Connect domains | ER–<br>SR++ |
| III. Observational experiment: relative motion | None | Actively engage | ER–<br>SR+ |
| IV. Observational experiment: introduction to forces | None | Actively engage<br>Connect domains | ER–<br>SR++ |
| V. Observational experiment: Newton's third law | None | Actively engage | ER–<br>SR+ |
| VI. Testing experiment: water in a glass | None | Actively engage<br>Grapple | ER–<br>SR++ |
| VII. Testing experiment: How fast do you walk? | None | Actively engage<br>Connect domains<br>Transfer concepts | ER–<br>SR+++ |
| VIII. Testing experiment: current in a circuit | Some | Actively engage<br>Grapple | ER+<br>SR++ |
| IX. Modelling behaviour: our physics workbooks | Some | Actively engage<br>Connect domains<br>Transfer concepts<br>Grapple | ER+<br>SR++++ |
| X. Modelling behaviour: post lesson reflection | Some | Actively engage | ER+<br>SR+ |
| XI. Modelling behaviour: examination reflection task | Significant | Actively engage<br>Transfer concepts<br>Grapple | ER++<br>SR+++ |

| | | | |
|---|---|---|---|
| XII. Well-being: Expertise Activity | None | Actively engage<br>Transfer concepts | ER–<br>SR++ |
| XIII. Well-being & modelling behaviour: re-tests | Significant | Actively engage<br>Connect domains<br>Transfer concepts<br>Grapple | ER++<br>SR++++ |
| XIV. Well-being & modelling behaviour: take-home tests | Significant | Actively engage<br>Connect domains<br>Transfer concepts<br>Grapple | ER++<br>SR++++ |
| XV. Well-being & modelling behaviour: pre-tests | Significant | Actively engage<br>Connect domains<br>Transfer concepts<br>Grapple | ER++<br>SR++++ |

Coding the activities enabled me to plot them onto the Specialization plane (Figure 6.1), revealing that all the ISLE and ISLE-inspired activities value the behaviours that knowers bring to the activity, although there is some variation in which behaviours are valued. Prior knowledge is not necessary for access in all activities, although in some, knowers with a significant amount of conceptual knowledge are legitimated.

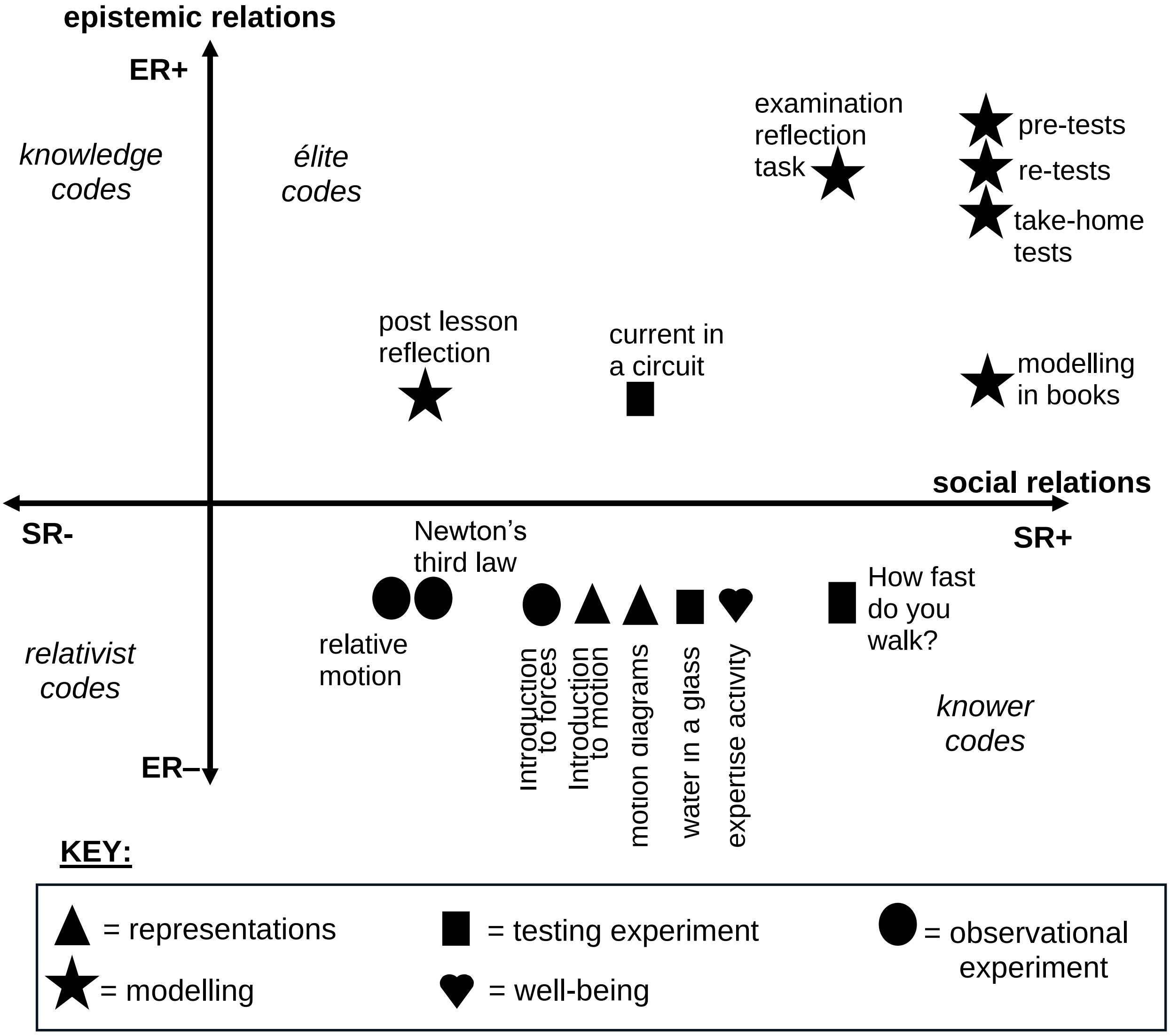



**Figure 6.1:** An adapted Specialization plane to show the relative strengths of social relations and epistemic relations of the ISLE and ISLE-inspired activities in this study.

The *observational experiments* require no prior knowledge (ER–), as the activities are intended to downplay prior knowledge so that all students begin the activity on an equal footing, no matter their backgrounds or prior exposure to physics (Etkina, 2015). These activities either require just observation (Newton's third law and relative motion activities) or observation and constructing a representation (introduction to forces). The *testing experiments* require students to observe, design a testing experiment and make predictions (water in a glass, how fast do you walk and current in a circuit). The current in a circuit activity requires students to know how to connect a circuit and to know the basic functions of circuit components in order to design the experiment, so some physics prior conceptual knowledge is required (ER+). The other testing experiments require no prior knowledge (ER–), although the ‘How fast do you walk?’ activity requires students to connect their understanding to previous knowledge, to design a testing experiment, as well as to use representations and to engage. With the exception of the current in a circuit activity, the observational experiments and testing experiments enact a knower code (ER–, SR+), requiring no prior knowledge, but validating stronger social relations.

The activities that encourage the use of *representations* require students to make connections between domains, although this is developed through the activities, with relatively specific instructions that help students to create the representations. These activities, too, require no prior knowledge (ER–) as the emphasis of the activity is on constructing the representation, rather than on the content, although the representations can be used to visualise the concepts. The expertise activity requires no prior knowledge (ER–), but legitimates engaging with the task (and peers). Students do need to be able to transfer the knowledge that students construct about improving their skill in one area to a learning process for physics. These activities, too, embody a knower code.

All the activities that *model* valued behaviours, legitimate all or almost all the behaviours that we value (SR++++), while also valuing prior knowledge (ER+ and ER++). This means that they enact an élite code. The post lesson reflection task legitimates the fewest valued behaviours, expecting students to actively engage in the task and reflect on their learning experience only, while identifying what they have learnt. The examination reflection task requires students to categorise the questions according to the physics concepts that they test, which requires students to see the connections between concepts and to grapple with any incorrect answers that they gave, to determine what went wrong. This values a high level of engagement and significant prior knowledge. The workbooks model valued behaviour as the full solutions that were available to students have been replaced with only answers for the exercises, which encourages students to grapple with a concept, to consult the worked examples in the book or seek help to improve their understanding. The prompts to draw diagrams in the book encourage students to use representations, in the hope that this will become an automatic starting point for any problem, even when unprompted.

The re-tests, take-home tests and pre-tests were all intended to improve well-being as well as modelling active engagement through practice and reflection, grappling, making connections and building cumulative knowledge. They value all of these behaviours and legitimate significant prior knowledge. The re-test application and the guidelines given for engaging with the pre-tests gave specific instructions to guide students and so not only legitimated these behaviours, but developed them in the students who engaged with the activity.

### 6.4 Discussion: valued behaviours legitimated by ISLE activities

Although some of the activities required no prior knowledge for success in the task, all the ISLE and ISLE-inspired activities valued knower behaviours to some degree. This makes sense as the ISLE approach aims to be transformative, hoping to enable students to ‘think like scientists’ (Etkina, Brookes and Planinšič, 2019). The ISLE approach values the process of learning, and the ISLE activities are designed to change the students’ way of thinking, not just help them learn physics. These activities all implicitly value knower behaviours and process over outcomes.

The activities that are coded as legitimating stronger social relations and stronger epistemic relations (stronger élite code), all model all four valued behaviours and this modelling may have allowed students to engage productively with the activities and benefit from them. High-school students need modelling, guidance and structure (Collins, Brown and Newman, 1987), especially when exposed to a new way of learning. Although one of the aims of the ISLE approach is to develop students who are equipped for lifelong, independent learning, teachers are also responsible for preparing students for summative assessments and for further study. In our context, activities need to be structured and need to account for our time constraints as the teacher balances giving the student greater agency and accountability for their learning, while ensuring that they are well-prepared for their assessments. Structured guidance (see Section 2.2.2) can help students to develop autonomy as they develop the behaviours that enable them to work independently in time (Ellery, 2022).

Every one of the ISLE activities requires students to actively engage in the task, whether through the observation of a phenomenon, making a prediction or reflecting on their learning. As every one of the activities requires engagement, the ISLE approach as a whole is legitimating this behaviour and conveying the message that engagement is important. In fact, it is critical, if we believe we are training or developing knowers through these activities, as a passive observer cannot be trained because training requires participation. Osborne (2007) argues that training our students in science prepares them to do the work of scientists and produce new scientific knowledge, while educating our students in science prepares them to be “critical consumer[s] of scientific knowledge” (Osborne, 2007, p. 1).

In my experience, we see students who believe that they can sit back and the teacher will teach them physics. These students do not realise or believe that active engagement is key to learning. Often, if they do not understand, they go to a tutor who will teach the work again (as they sit passively) or even show them how to solve a problem with which they are struggling. They are unaware that they need to engage to change their understanding and grapple with concepts and problems to interrogate their current understanding and change it, if necessary. They expect physics to come to them more easily than it does. This represents a code clash (Maton, 2014) for some students in our physics classes, as the ISLE approach requires active engagement and some students view physics as a knowledge-based subject where they can 'learn how' to solve problems. They may have been unprepared for the necessary engagement and grappling that the activities demanded. Perhaps by emphasizing the value of active engagement and demonstrating its value through repeated exposure, the ISLE approach can resolve this clash by helping students see the importance of active engagement. Chapter 7 will provide the student view on ISLE activities which will allow further exploration of these clashes and potential means to resolve them.

Physics is not a subject that can be learnt, nor is it a subject where the problems will all look the same. When students resort to rote-learning in physics, trying to *learn* how to solve problems, they are usually looking at the surface features of the problems and not forging connections between the abstract, conceptual and concrete domains of the problem. Remaining tied to the concrete or surface features of a problem or being limited to symbolic representations (those students who do physics with a data sheet in one hand to try to find the formula that they can apply), prevents students from constructing knowledge that they can transfer to new contexts.

We also often hear the complaint that 'the test looked so different to the previous tests'. Again, this represents a code clash for these students, who perhaps expected to be able to apply the knowledge that they have learnt, or the concepts they have practised, in the same contexts as they have encountered before, while we are expecting them to transfer their knowledge to new contexts. Students look at surface features of physics problems, rather than at the patterns and underlying physics (Section 2.2.5). Learning to see the physics concepts and then transfer the application of that physics to different contexts takes active engagement, resilience and tenacity to grapple with the concepts through the uncomfortable process of learning when it does not all make sense immediately.

Learning to see the patterns across physics problems requires ‘stepping back’ from the problem to see the underlying physics, rather than the surface features of the problem and linking the abstract concept to the concrete context. Making these links between the concrete representation and the abstract representation (as well as the mathematical representation) can be made more accessible by drawing a diagram (see Sections 2.2.3, 2.3.1 and 2.3.1). Thus, the behaviours that we value and want to develop in the physics classroom are active engagement, the courage to grapple with problems, the habit of looking for patterns or physics principles across problems and the habit of drawing diagrams.

These valued behaviours are innate to some students, but need to be trained or even inculcated (see Section 4.3)  for many students. One means of training is through repeated exposure with modelling, coaching, scaffolding and reflection, as described through the cognitive apprenticeship model (Collins, Brown and Newman, 1987) and demonstrated through the ISLE approach (Etkina and Van Heuvelen, 2007). The translation devices that were developed and provided in this chapter (Table 6.1 and Table 6.2) allowed me to examine the extent to which each ISLE and ISLE-inspired activities legitimated the valued behaviours that give access to physics learning.

# CHAPTER 7: FINDINGS: HOW STUDENTS EXPERIENCE THE ISLE APPROACH

*"The hallmark of expertise is no longer how much you know. It's how well you synthesize. Information scarcity rewarded knowledge acquisition. Information abundance requires pattern recognition. It's not enough to collect facts. The future belongs to those who connect dots."*
(Grant, 2024)

This chapter answers the research question:

- How does the student experience of the ISLE approach demonstrate the development of behaviours that we value in physics knowers?

The chapter is divided into two parts. The first section (7.1) describes the student experience of the ISLE approach through the presentation of the data analysis of student responses to the Colorado Learning Attitudes about Science Surveys (CLASS), student reflections, student responses in interviews and focus groups, and in formative and summative assessment tasks.

The second section of the chapter (7.2) explains how these student responses demonstrate the extent to which the students have developed the behaviours that we value.

## 7.1 Student experience of the ISLE approach

Students were surveyed and asked to comment on specific questions about how they perceived physics, and then on their experiences in the physics classroom. The questions on their experience in the classroom encompassed general questions and then specific questions about specific ISLE-inspired interventions. The first part of this chapter describes the responses by students to each of these questions, in order to understand how they think about physics, before describing the student responses to six specific ISLE and ISLE-inspired interventions.

Students completed the Colorado Learning Attitudes about Science Surveys (CLASS) as a pre-test when the study began and then as a post-test at the end of the study period. They also completed a survey on their physics learning at the end of their physics course (see Table 5.7). The questions, along with the codes assigned to the responses through an inductive process (Creswell and Creswell, 2017), can be found in Appendix 4: Data collection and analysis tools 4.5 on p. 384. Responses may have fitted more than one of the codes, in which case they were coded to all the relevant codes.

The general questions in the survey on physics learning were:

- Do you feel pressure to do well in physics?
- Where does this pressure come from?
- How do you feel about your ability to do physics?
- Has your answer to the question above changed?
- What makes you feel comfortable in your physics class?
- Does working in groups in physics class affect your learning experience?

Further questions asked:

- How do you learn a new concept?
- Has your understanding of how you learn changed in any way over the time that you have done physics?
- Has your approach to learning changed in any way over the time that you have done physics?
- How are you convinced that a new concept is true?
- How do you use the memo (memorandum / solutions)?

Students were then asked to comment specifically on their experience of six of the ISLE and ISLE-inspired interventions:

- exploratory introductions and investigations (2022 / 2023),
- post-lesson reflection tasks (2022)
- re-tests (2022) and
- pre-tests (2023) and
- investigations (2022 / 2023)
- examination reflection tool (2023)

Although student well-being was not the primary focus of this study, it affects the students' physics learning experience and is an important underlying principle of ISLE (Brookes, Etkina and Planinšič, 2020). Responses to questions on the pressure to do well, students' perception of their ability, and their comfort in class, give insight into their physics learning experience and probe their sense of well-being. This impacts their capacity to grapple with difficult concepts.

Having completed the survey, students were invited to participate in semi-structured focus-group discussions. Quotes from these discussions, as well as from the surveys, are included to illustrate or substantiate trends seen in the quantitative data generated from the coding of survey responses.

### *7.1.1 Student responses to the Colorado Learning Attitudes about Science Survey (CLASS)*

The Colorado Learning Attitudes about Science Survey (CLASS) (Adams et al., 2006) is a research-validated survey which is designed to give an indication of student beliefs about physics, how they learn physics and, critically, how these beliefs shift over time. The survey is conducted as a pre- and post-test survey and the average student responses may shift to more favourable or more unfavourable. *Favourable* responses are more in line with those of experts, while *unfavourable* responses are more typical of a novice (see Section 2.2.4). Studies often consider the shift in beliefs: towards more expert-like beliefs (favourable shift) or towards more novice-like beliefs (unfavourable shift).

Research has shown that most teaching approaches result in unfavourable shifts in student beliefs about physics and learning physics (Adams et al., 2006). Perhaps this shift happens because students come into physics with confidence, but their confidence deteriorates as the course progresses, and they realise that it might not have been as easy as they thought it would be. Redish, Saul and Steinberg (1998) suggest that this deterioration may be because students did not realise the effort that the course would take or do not expect to have to grapple with the concepts as much as is required. Working hard, particularly when the results are not immediately evident, can be disheartening, as expressed by this student: *"I feel that if anything I have become discouraged as I put in so much effort and time and sometimes my marks don't reflect that.*" (G10F, 2022 survey). As physics is a difficult subject it requires grappling and deep engagement, often for some time, before it starts to make sense.

Students completed the CLASS pre-test at the beginning of the study and the CLASS post-test at the end of the study. Specific timeframes and details of the administration of the survey can be found in Table 5.6 in Section 5.3.3. The results are only reported for matched participants for whom I had both a pre- and post-test for CLASS. The pre- to post-test shifts in attitude to learning are shown on each graph using arrows, where the green arrows show a shift towards more expert-like beliefs, the orange arrows show a shift towards more novice-like beliefs and the purple arrows show almost no shift in beliefs. The results are reported for the entire group, then for female and male students separately, then by grade and finally by teacher.

I. Analysis of CLASS response shifts for the entire sample:

The CLASS results for all students are reported first, in Figure 7.1, which shows the overall shift in beliefs while physics students were exposed to the ISLE approach. This gives a useful overview, but when the results are broken into component groups, as shown in Figure 7.2, Figure 7.3 and Figure 7.4 interesting differences are evident.

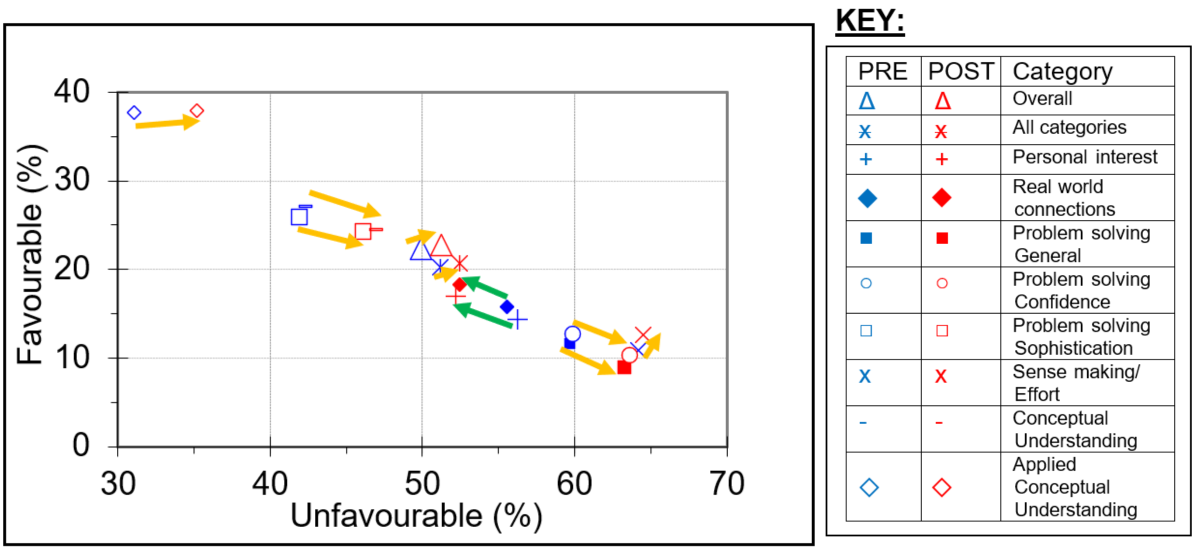



**Figure 7.1:** Responses to CLASS survey by all students ($n$ = 145; F = 68; M = 77), showing shifts to more expert-like beliefs (green arrows) and shifts to more novice-like beliefs (orange arrows) and the key to symbols shown.

The CLASS results for all students in Figure 7.1, show a predominant shift towards more novice-like beliefs, with the exception of the categories of personal interest and real world connections. The overall change in beliefs was a small shift towards more novice-like beliefs, which is common in introductory physics courses (Adams et al., 2006).

**Female students:** **Male students:**

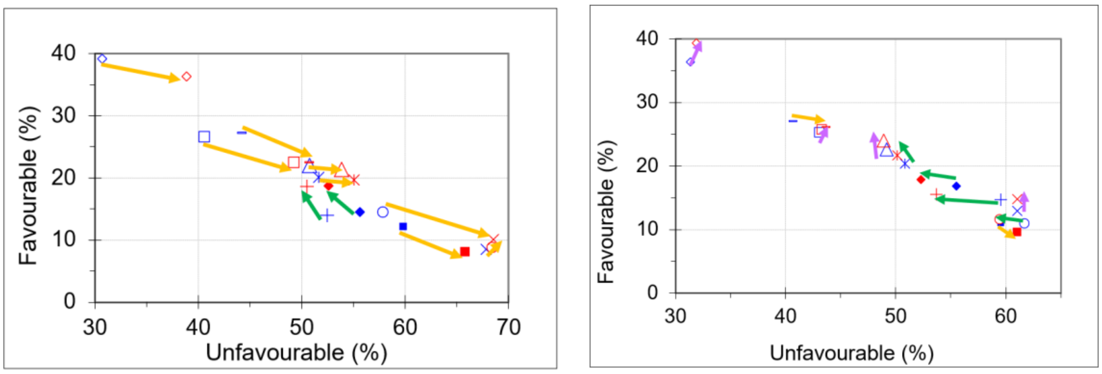



**Figure 7.2:** Responses to CLASS survey by gender: female students (*n* = 68) on the left and male students (*n* = 77) on the right, showing shifts to more expert-like beliefs (green arrows), shifts to more novice-like beliefs (orange arrows) and almost no shift in belief (purple arrows).

From Figure 7.2, it can be seen that, with the exception of two categories (again, the ‘personal interest’ and ‘real-world connection’ categories), the shift for all female students was towards novice-like beliefs. The two favourable shifts were very small compared to the other shifts.

The responses by the male students showed very little shift overall, and also showed small shifts in ‘problem solving’, ‘problem solving sophistication’, ‘sense making / effort’ and ‘applied conceptual understanding’. There was a small shift towards expert-like beliefs in ‘problem solving confidence’ and ‘real-world connection’ and a notable favourable shift in ‘personal interest’.

Comparing the CLASS results for the female and male students, the beliefs of the female students showed a general shift towards more novice-like beliefs. This is in line with findings in other studies where women have been shown to hold less expert-like beliefs on statements in many of the categories (Adams et al., 2006). The shifts in belief among male students were smaller and many categories showed almost no shift in belief.

II. Analysis of CLASS response shifts by grade:

It is interesting to compare the shifts in response by students in the four grades that were studied, shown in Figure 7.3. The group in Grade 12 had the least exposure to ISLE activities, while those in Grade 10 only completed a few ISLE and ISLE-inspired activities. The Grade 11 group were exposed to the most ISLE activities, but were also the group that I spoke to most often about what I was doing and the reason behind the activities. Their responses showed the greatest shift towards expert-like beliefs.

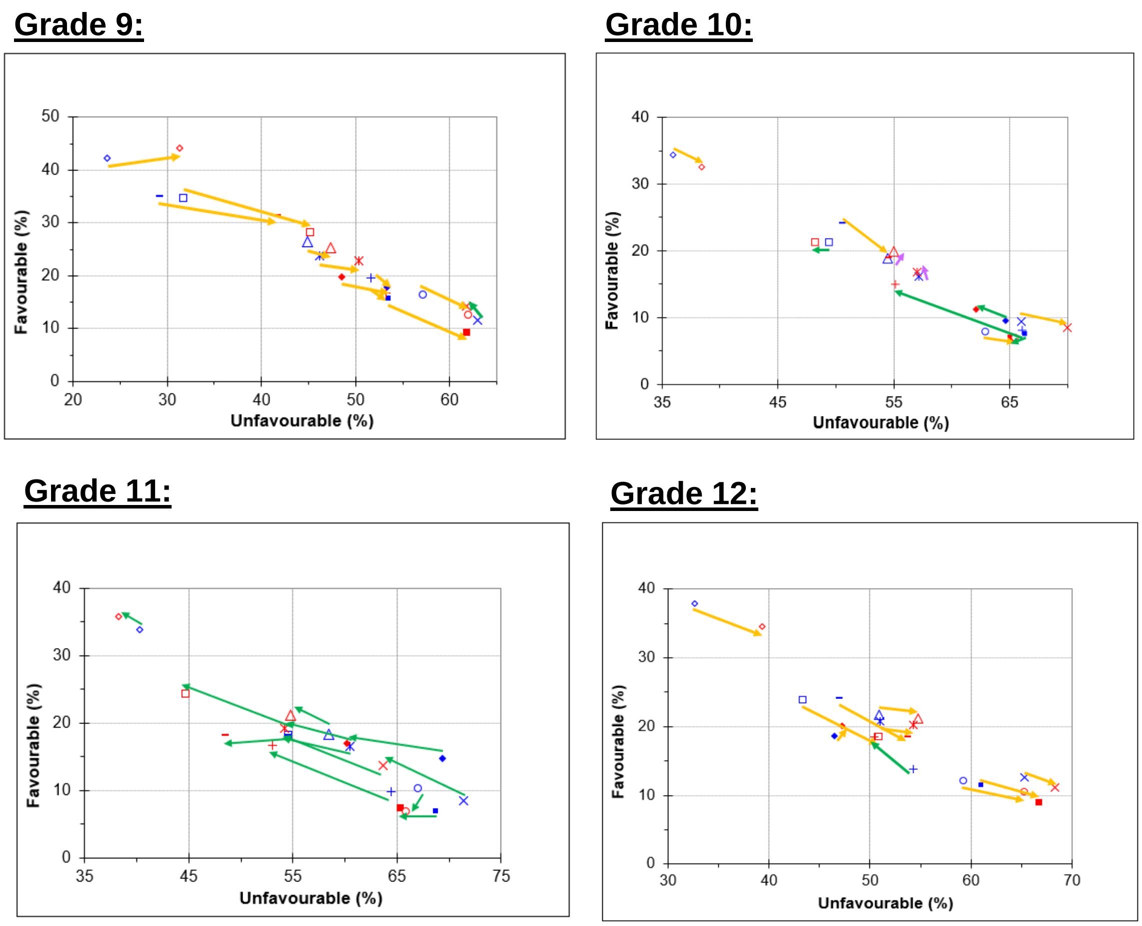



**Figure 7.3:** Responses to CLASS survey by grade: all Grade 9 students (n = 52; F = 23; M = 29), top left; all Grade 10 students (n = 29; F = 15; M = 14), top right; all Grade 11 students (n = 22; F = 12; M = 10), bottom left; all Grade 12 students (n = 36; F = 18; M = 18), bottom right, showing shifts to more expert-like beliefs (green arrows), shifts to more novice-like beliefs (orange arrows) and almost no shift in belief (purple arrows).

The Grade 9 group showed an overall shift towards novice-like beliefs, as evident in Figure 7.3 and most categories showed a shift towards more novice-like beliefs, with the exception of ‘sense making / effort’, which showed a small shift towards more expert-like beliefs. Interestingly, student age has been shown to play a significant role in beliefs, although the age range in the study by Adams et al. (2006) was 18-25 years. The difference in shifts that I saw between the different grades may be due to the age of the participants, although the students in this study are younger.

Many of the Grade 9s had already chosen not to continue with physics beyond Grade 9, which may have affected their motivation and their beliefs about learning. For the Grade 9 group, the pre- and post-test CLASS surveys were also only a few months apart, whereas the other grades had longer to study physics between the pre- and post-tests. Further interviewing would be necessary to find out the reasons for this substantial shift, as this did not emerge from the survey responses or the focus-group discussions.

The Grade 10 group showed predominant shifts towards more novice-like beliefs, with the exception of a substantial shift towards more expert-like beliefs in ‘personal interest’, a smaller shift ‘real world connections’ and very small shifts in ‘general problem solving’ and ‘problem solving sophistication’. Grade 10 is the year when students have chosen physics as a subject and are thus, perhaps, more invested than the Grade 9s.

The Grade 11s completed a number of ISLE activities and experiments and some of them had been exposed to ISLE for three years by the time they completed their post-test CLASS survey. This group showed shifts towards expert-like beliefs for all categories.

The CLASS results for the Grade 12 group showed shifts towards more novice-like beliefs for all categories except ‘personal interest’. The Grade 12s were exposed to fewer ISLE activities and experiments, but are also focused on the examinations. Again, the reason for this shift was not apparent from the survey results or the focus-group discussions.

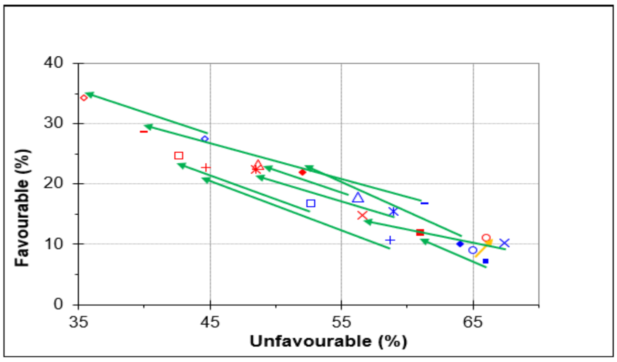
III. Analysis of CLASS response shifts by teacher:

It is interesting to compare the shifts in response for students in classes taught by the three different physics teachers (A, B and C). Each teacher had their own teaching style and approach, but the difference in approach that was noted, and is relevant in this discussion, is the way in which they approached the investigations. Although we (the three physics teachers) discussed the investigations prior to running them with classes, and we discussed the philosophy of allowing students to discover the concepts through independent investigation, the teachers approached the investigations with different levels of intervention.

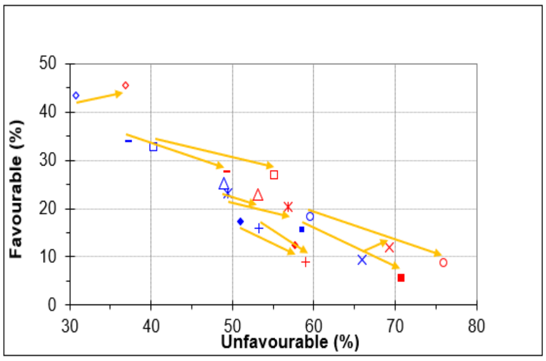
Teacher A reported in the interview that they talked the class through the investigations, and they did them together as a class, writing down the answers as they went. ("*I was very structured in the thing, we did it together and so I didn't just let them go and do it.*" (Teacher A, interview)) Teacher B allowed the class to try the activities on their own, but reported that they found it difficult not to intervene and gave a fair amount of assistance ("*I found it hard not to… lead them to what I know the right answer was. That was hard. I wanted to tell them.*" (Teacher B, interview)). I (Teacher C) gave very little assistance, leaving students to try and do the activities independently, although engaging with students as they worked. I only discussed the findings with the class at the end of the activity.

While these approaches are specific to the ISLE investigations, they are probably in line with the general teaching approaches of the three teachers: Teacher A usually told students how to solve a problem, going through each problem in full with the class. Teacher B usually went through examples in class, and gave examples for students to work on independently for homework. I usually had students solve problems independently with little teacher guidance to the class as a whole, but walked around helping individuals. I only went through problems on the board once students had tried them, if the majority were struggling.

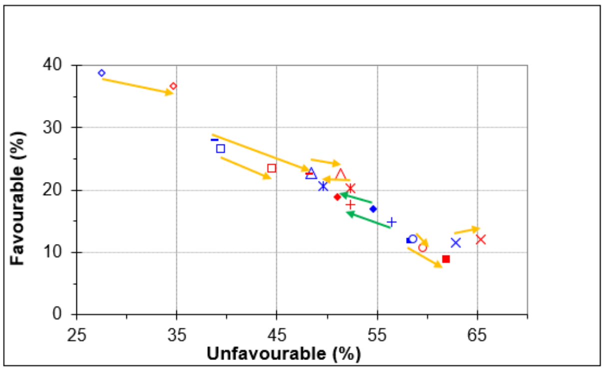
**Teacher A:**




**Teacher B:**




**Teacher C:**




**Key:**

| PRE | POST | Category |
|---|---|---|
| Δ | Δ | Overall |
| x | x | All categories |
| + | + | Personal interest |
| ◆ | ◆ | Real world connections |
| ■ | ■ | Problem solving General |
| ○ | ○ | Problem solving Confidence |
| □ | □ | Problem solving Sophistication |
| x | x | Sense making/ Effort |
| - | - | Conceptual Understanding |
| ◇ | ◇ | Applied Conceptual Understanding |

**Figure 7.4:** Responses to CLASS survey by teacher: all students taught by Teacher A (n = 25; F = 12; M = 13), top left, all students taught by Teacher B (n = 26; F = 19; M = 9), top right, and all students taught by Teacher C (n = 94; F = 37; M = 57), bottom left, showing shifts to more expert-like beliefs (green arrows), shifts to more novice-like beliefs (orange arrows).

The CLASS results, given in Figure 7.4 show that students' beliefs shifted to be more expert-like in Teacher A's class, where they were given greater guidance and scaffolding. 'Conceptual understanding' showed the greatest shift, with 'personal interest' and 'problem solving confidence' also showing large shifts. The students' beliefs in Teacher B's class all shifted to more novice-like beliefs, with 'problem solving confidence' and 'problem solving sophistication' showing the largest shifts. For the students in my (Teacher C's) class, the CLASS results showed an overall shift to more novice-like beliefs, with the largest shift being 'conceptual understanding'. There were shifts towards expert-like beliefs for 'real world connections' and 'personal interest' for students in my class. Interestingly, I implemented more ISLE activities than my colleagues (Teachers A and B) and spoke to my classes about the purpose of the activities. It may be that because the number of respondents from my classes was greater than those from my colleagues' classes, that perhaps only those students in Teacher A and Teacher B's classes with a more favourable view completed the survey. Interestingly, Teacher B commented on the investigations that there seemed to be a "*correlation between engagement with the task and general interest in the world / physics*" (Teacher B, written feedback on investigation experience).

Looking at the CLASS data allowed me to see trends in the changes in student belief over a period of time. The use of a research-validated survey offered trustworthiness in the study.

### *7.1.2 <u>Perception on pressure to do well in physics</u>*

Adopting a mindset that focuses on learning, rather than performance can improve student motivation (Yeager and Dweck, 2012; Brookes, Etkina and Planinšič, 2020). To understand the motivation and well-being of students in the classroom better, I asked whether they feel pressure to do well in physics. Pressure can negatively affect students' learning, particularly when this is pressure related to performance (Zull, 2002). The ISLE approach strives to emphasize learning goals over performance goals, and this may be in conflict with students' mindsets, if they are feeling pressure to perform. For this reason, it was important to ascertain whether students felt the pressure to perform in physics.

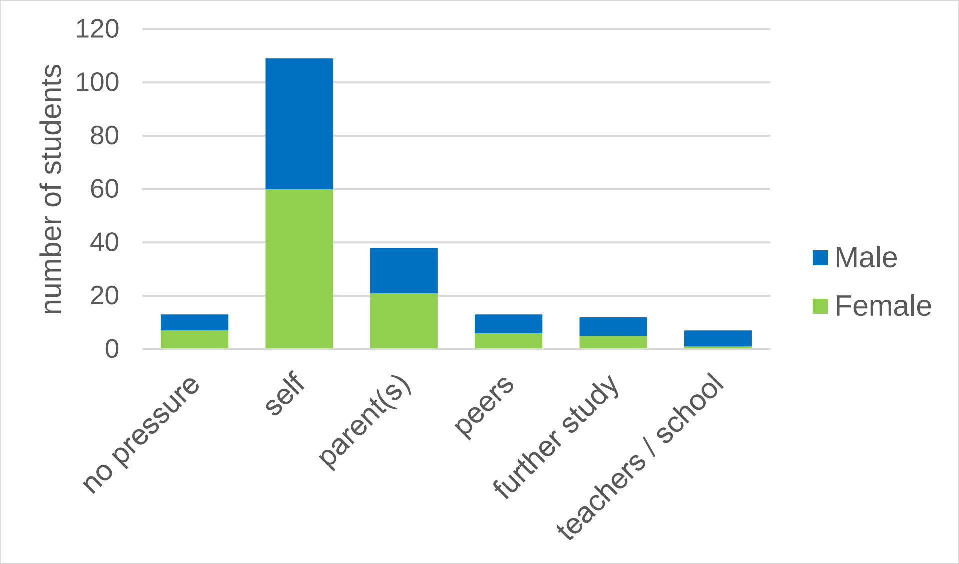



**Figure 7.5:** Students' perception of the source of pressure to do well in physics (*n* = 146; F = 74; M = 72).

Figure 7.**5** shows that the majority of students feel pressure to do well from some source, which will influence their approach to learning. For the majority of students (*n* = 109; F = 60; M = 49) this pressure is from themselves, which should motivate them to do their best. Some students feel pressure from their parent(s) (*n* = 38; F = 20; M = 17) or peers (*n* = 13; F = 6; M = 7) and some feel the pressure to be accepted into further study (*n* = 12; F = 5; M = 7), which is a significant factor for students in South Africa. Employment opportunities are increased by having a university degree (OECD, 2019b) and so in the South African context, it is important to qualify for university entrance, which is highly competitive, particularly for some courses and universities. One of the Grade 12 girls articulated this in their focus group, saying "*I really struggled last year with physics. And, like, especially at the end of the year, like, I think the pressure of Grade 11 exams got to me*" (G12F, 2023 focus group). Most students use their Grade 11 end of year examination results for preliminary acceptance into university. The pressure to perform in assessments remains for students, despite the emphasis in the ISLE approach on the learning process and on the importance of a learning-orientated mindset over a performance-orientated mindset. Despite our emphasis on the importance of the learning process, students feel the

pressure to do well, which often negates efforts to shift the emphasis away from marks.

### *7.1.3 Perception of ability in physics*

When asked about how they feel about their ability to do well in physics, 52% of the students gave a positive response, while 11% were negative about their ability (*n* = 317; F = 163; M = 154). 16% were neutral, with comments like "*mediocre*" (G10M, 2023 survey), *"I feel confident sometimes.*" (G10M, 2023 survey) and "*I have the potential to be good at it I just need to learn how to unlock that potential*" (G11F, 2023 survey). 17% made statements with provisos, such as, "*I feel I do ok but my understanding of concepts could be better*" (G10F, 2023 survey) or "*I feel like I am able to do physics once I have studied and practiced* (sic) *fully for it*" (G12F, 2022 survey). One student commented, "*I am confident, however physics gives you a false sense of hope where after you have written a test you might have thought that you did really well but actually do really badly.*" (G11M, 2023 survey)

50% of the students said that their confidence had not changed over the time that they had done physics, while 21% said that their confidence had improved. 6% said that their confidence had deteriorated (interestingly, F = 15 and M = 3). One student remarked, "*My ability improves the more i* (sic) *practice* (sic)" (G11F, 2022 survey). Student confidence stayed constant or improved for the majority of students, although many more female students experienced a decline in confidence than male students. This cannot be attributed entirely to the ISLE approach, but is interesting to note. This outcome matches the general shift towards more novice-like beliefs that was observed for female students in the CLASS results described above. More data would be needed to delve into the reasons for improvement or decline in confidence and what factors have influenced this. Students who do not feel confident in their ability are less likely to actively engage in class or in activities and may not feel brave enough to grapple with concepts. The ISLE approach's emphasis on well-being strives to ensure that students feel capable and safe in the learning environment, to enhance learning (Buggé and Etkina, 2020).

### 7.1.4 Comfortable in class

When asked about factors that make them feel comfortable in their physics class, students most commonly cited the teacher and the teaching (*n* = 80, F = 53; M = 27), peers in the class (*n* = 68, F = 39; M = 29), understanding the work (*n* = 59, F = 17; M = 42) and the freedom to ask questions without judgment or being made to feel that they are 'silly' questions (*n* = 58, F = 37; M = 21). Interestingly, the proportion of students who attributed their comfort to the teacher was higher for female students (F = 53; M = 27).

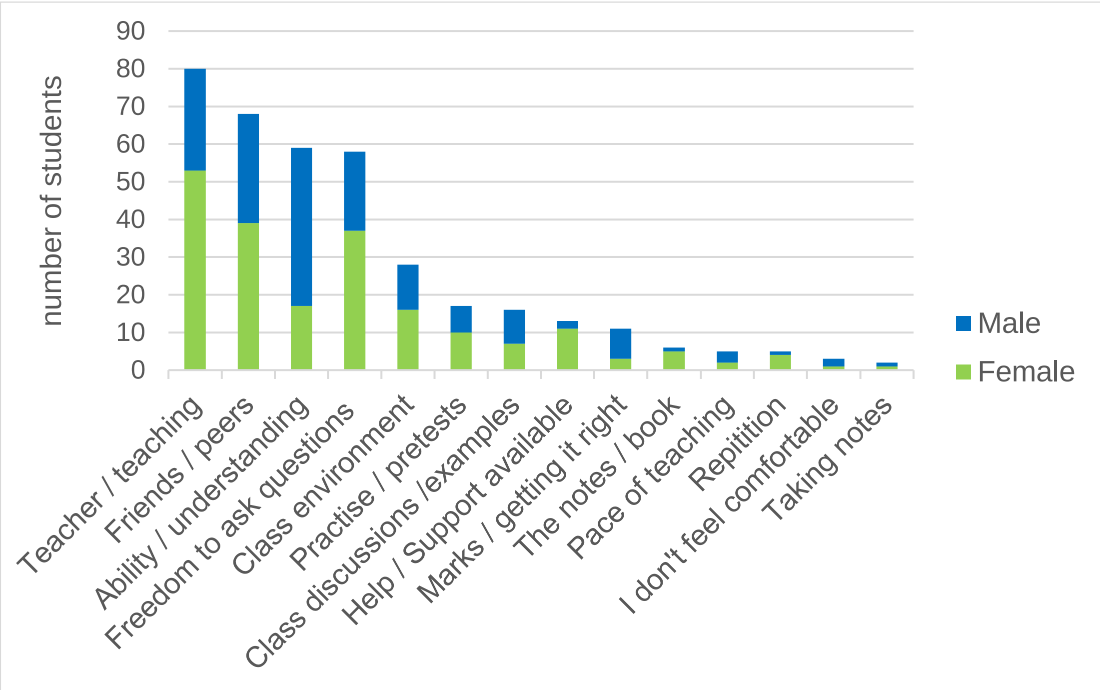



**Figure 7.6:** Student responses to what makes them feel comfortable in the physics classroom (*n* = 317; F = 163; M = 154).

The atmosphere in class or the class environment had an impact on the way that students felt about their ability:

> *"It's not all serious and just work, work, work. We do work but in a comfortable and encouraging way. She [the teacher] makes us all feel like we can do it even if we feel down."* (G11F, 2022 survey)

It is important that the physics classroom is a 'safe' space, where students feel that they can make mistakes and learn, as previously discussed in Section 3.11. This quote highlighted the value of the teacher's role in curating a space where learning goals are valued:

> *"The engagement that [my teacher] allows in the class to explain something when there is confusion or even to actually show it to us in practical work so that we see it in real life. Also the fact that she makes it a space where you can actually make mistakes because she tells us that it's better to get it wrong now than in the final physics paper in matric."* (G10F, 2022 survey)

As mentioned in the Methodology Chapter (Section 5.2.1), we have taught boys and girls separately in Physical Sciences since Covid-19 when the usual classroom learning was disrupted. While I did not ask the students about this, it came up in the Grade 10 girls' focus group and the response was that some of the girls found the boys disruptive in some of their classes and so were in favour of the girls-only physics class, saying,

> *"In physics you can't slack off for one lesson or it's over" (G10F, 2023 focus group), to which her peer replied, "It's very particular to this subject, I think … none of us have any knowledge of what we're learning, really, because it's all new concepts. So then to be able to ask questions, freely without feeling like 'judged' … really makes a difference, I think because we feel free to tell you our problems and with marks and stuff we don't feel as embarrassed."* (G10F, 2023 focus group)

Two female Grade 12s and one female Grade 11 student also mentioned in the survey that the girls-only class made them feel comfortable. However, in the Grade 11 focus group, one of the girls, who was in the girls' class that merged with the boys' class for the last three months of 2023, commented,

> *“I found there was a big difference in having boys in the class than just having girls. It was so much, like, better ‘cause they ask questions that I’m too scared to ask. They don’t care. They’re just like ‘Ja, Ma’am, I don’t understand this.’ Like, it helped me learn.”* (G11F, 2023 focus group)

There were marked differences between genders for two of the responses: understanding the work and feeling capable were mentioned more often by the boys and having the freedom to ask questions and feeling no ‘judgement’ for ‘silly’ questions was valued by the girls. In a fully coeducational setting, separate gender classes would not be considered, but because our schools are separate in most aspects, other than the academic sphere, it is not unexpected that boys and girls do not feel completely comfortable with one another. While this may seem to have no bearing on the research question that I am seeking to answer, it seems to affect how comfortable some students feel in class and student well-being is valued in the ISLE approach. This could affect how actively they engage and whether they have the tenacity to grapple, when they are already feeling uncomfortable in the classroom. Due to the balance of numbers and with no strong justification to retain classes of separate genders, classes were mixed again from 2024, but this is a dynamic that we will need to watch.

Students need to feel comfortable in class because they are being asked to stretch themselves as they engage with new, cognitively challenging work and it is important that they are comfortable enough in other ways to do this. Students feel encouraged by a supportive environment and it is important that the teacher is seen as approachable so that students can ask for help as they grapple with concepts (Nguyen et al., 2021).

It is important to cultivate a supportive environment where questions are valued and encouraged so that students feel ‘safe’ to offer an answer, even if it might be incorrect. Leading discussions based on the answers that are offered and asking guiding questions which challenge students to evaluate their answers in light of what they know, models the approach of improving understanding by questioning.

### 7.1.5 <u>The impact of group work on learning</u>

The ISLE approach values collaboration and group work (Etkina and Planinšič, 2014b). As ISLE activities were introduced, students worked in groups for many of the activities. The survey asked students to comment on whether they felt that group work affected their physics learning experience. The majority of students (125 out of 161 students who answered; F = 62; M = 63) believe that group work had a positive impact on their learning experience, justifying their view with statements such as,

> *"It helps me by hearing how other people go about answering a question and helps me think about a different way of approaching a problem."* (G11F, 2023 survey)

Also, "*as we do it as a group, and then we're able to like explain it to each other. That helps me*." (G10F, 2023 focus group)

The Grade 9 boys expressed in the focus group that they enjoyed the group work as they were comfortable with their peers and,

> *"putting brains and minds together can … improve your knowledge as well and your understanding of the subject … because maybe someone understands something better than you and then if* (sic) *they explain to you."* (G9M, 2023 focus group)

One of the Grade 9 boys highlighted the impact of enjoyment on a positive learning experience and felt that group work helped with this:

> *"I think that it's important that with most subjects you don't do work as a group – it's mostly individual. But I think with physics, this term after doing it in groups, it sort of makes physics more fun…. So, if you're having fun in physics and you're getting the work done, it makes you like more excited and more interested in the subject and you want to learn more and … it's a subject that you're excited to come to."* (G9M, 2023 focus group)

Only 14 students (out of the 161 respondents) felt that group work negatively impacted their learning experience, saying that they prefer to work independently, they are distracted by their peers or that their peers do not work at their pace: "*I prefer to work alone, other people distract me or work too quickly and I feel pressured to keep up and don't [put] enough effort into it*" (G10F, 2022 survey). Five of the students said that group work had no effect and 17 were neutral or hedged their view, mentioning that there were advantages and disadvantages to group work or that it depends on the situation, such as the opinion offered by this student:

> *"I think in a way I (sic) can drag me down as it could easily sidetrack me from what is going on but other times can be helpful to discuss with many other people to get a better understanding of a concept that I don't know"* (G11M, 2023 survey).

Or this student:

> *"Yes in a positive but also negative manner as sometimes it could just be one person doing the work and the others copying or you could have people who didn't fully understand their work at first now help each other to understand"* (G10F, 2022 survey).

The ISLE activities required more collaboration than our usual class tasks, although students did work together in pairs or small groups when working through problems and the majority of students found that group work assisted them in their learning of physics.

### *7.1.6* *Learning a new concept*

Learning a new concept through the ISLE approach usually means discovering the concept through experiment and being convinced of it because you have seen it. Due to time constraints in our context, we were not able to introduce every concept through an experiment, but used activities from the ISLE approach to introduce acceleration, relative motion, forces and Newton's third law, and we encouraged active engagement and urged students to grapple with concepts.

When students were asked in the survey how they learn a new concept, they identified their most common approaches as practising questions, applying their knowledge and completing exercises. These, along with working to understand, repetition and teaching others, all show active engagement with concepts.

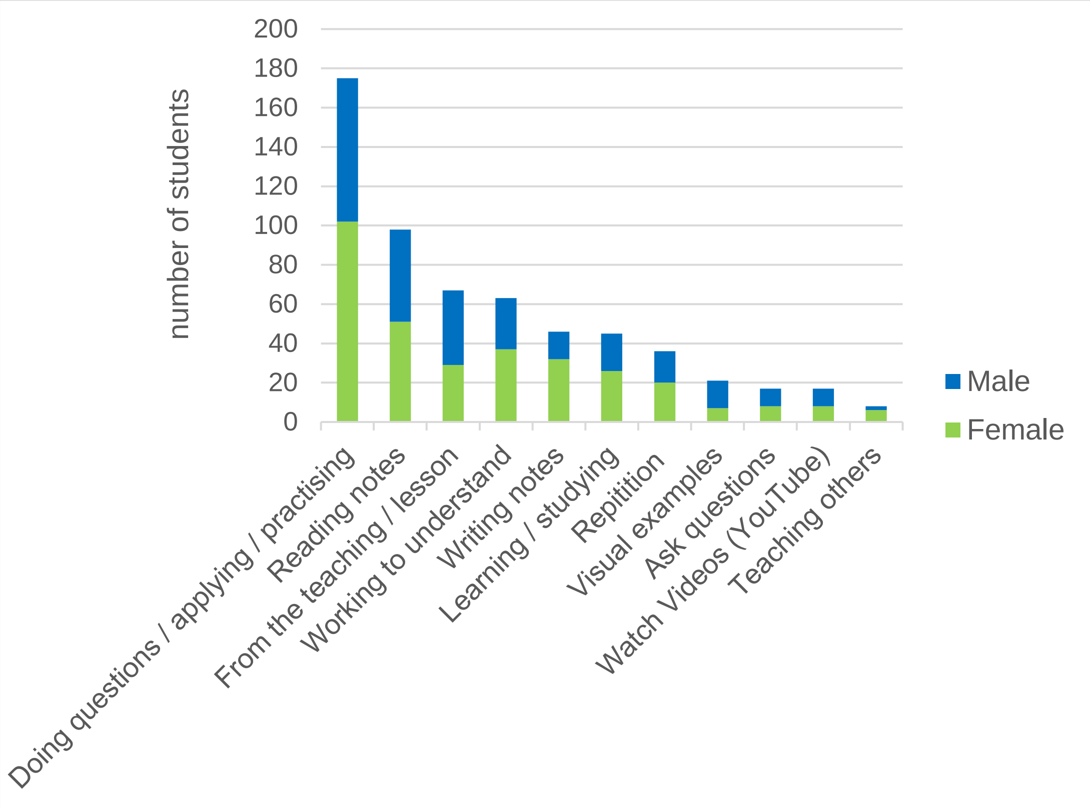



**Figure 7.7:** Approaches that students use to learn a new concept (*n* = 317; F = 163; M = 154), described through survey responses.

A large majority (*n* = 172; F = 102; M = 73) said that they learnt a new concept by doing exercises or practising examples, while others identified passive ways of learning a new concept, such as reading notes (*n* = 98; F = 51; M = 47) and watching videos (*n* = 17; F = 9; M = 8). There were students who attributed their learning to the teaching or the lesson (*n* = 67; F = 29; M = 38), which could be active or passive, depending on the lesson. More traditional study methods such as writing notes (*n* = 46; F = 32; M = 14), learning and studying (*n* = 45; F = 26; M = 19), repetition (*n* = 36; F = 20; M =

16) and asking questions (*n* = 17; F = 8; M = 9) were also mentioned. Fewer than expected mentioned visual examples (*n* = 21; F = 7; M = 14) and only a handful mentioned teaching others as a means to learn (*n* = 8; F = 6; M = 2). Some students (*n* = 63; F = 37; M = 26) wrote about working to understand concepts.

The responses showed a very strong emphasis on learning to solve a given problem, rather than developing a deep understanding of the concepts. This response does not make it clear whether students are looking for the physics in the problems that they solve, or whether they are considering only the surface features (Section 2.2.5) when they practise problems. The approach of practising questions is likely driven by the system as our assessment is largely summative. However, repetition does strengthen retrieval pathways and assist in automating problem-solving sequences (Schell and Butler, 2018) so that a greater proportion of the working memory capacity can go to processing new concepts (Sweller, 1988; Johnstone, 2009).

Time is a significant challenge in our context and so there are limited opportunities for formative assessment. I have attempted to address this through the 'pre-test' (Activity X of Section 5.3.2). However, the emphasis on preparing for an assessment does come through strongly in student responses, which emphasize 'being able to solve physics problems' as synonymous with learning to do physics. This student's response illustrates this:

> *"I feel like I have to do exercises. And then once I've done those exercises, and I understand it, then I feel like I've got a good understanding of the concept. So, I do exercises and [if] I don't know what's going on, then I know I need to do more work, maybe? I think my approach to exercises is probably where I learn concepts."* (G11M, 2023 focus group)

There were responses that indicated that this was not a passive process: "*So instead of just having a concept told to us, you actually have to go and apply* *what you've learnt. If you haven't learnt it, then you can ask about it."* (G11M, 2023 focus group)

Another response in a Grade 12 focus group emphasises the mechanical procedure over understanding:

> *"Even… if you don't fully understand something, … at least learn the method about how to do it until you understand it because that's not going to change… like the way you do like a calculation or solve a problem is not gonna change. Even if you don't understand it, you can still be able to do it, but eventually will come right."* (G12M, 2023 focus group)

I have heard teachers, including Teacher A, suggest that understanding might come through the process of actively engaging with problems, as this student (who was in Teacher A's physics class) experienced:

> *"something I've learnt from physics is that like, even with the toughest things, because when I grasp a new concept in class, I'm like, I'm never ever going to be able to understand this. Once you practise it a bit and get some like, yeah, one on one help and it clicks, then it feels really good."* (G12F, 2023 focus group)

Repetition and completing lots of examples can lead to understanding when the student is eventually able to 'see' the concepts ('it clicks'). However, this approach still requires active engagement ('once you practise it a bit'), so it is not enough simply to do problems mechanically. The volume of problems that is required before the concept 'clicks' is perhaps the *grappling*, in this case. It is the learner's engagement, while solving a problem that is critical to learning (Greeno and Johnson, 1985).

In Grade 11, in particular, students complain about not knowing 'which equation to choose' which suggests that they are thinking about which formula to pick off the data sheet, rather than the underlying physics: "*Sometimes it can get a bit overwhelming with all the different equations. Doing past papers can really help to see how it fits together*" (G11F, 2023 focus group). This is a typical ‘novice’ problem-solving approach (see 2.2.4) where the novice problem-solver looks for a mathematical solution to a problem in isolation, without considering the coherent features of the problem and deciding which physics principles are applicable, as an expert would do.

Merely working through past papers will not help students with this problem of ‘all the different equations’ and knowing which to choose. Students need to be looking for the underlying physics principles, rather than surface features to build understanding which they can apply in any situation (*transfer*). Being able to see the underlying physics concepts or generalise concepts to see the physics behind the context is a skill and is one of the behaviours that we value in the physics classroom and want to develop. This needs to be modelled and developed through guided activities. Students will only be able to transfer their understanding to new contexts if they develop this behaviour of looking for the physics principles in a problem, rather than the surface features.

Another Grade 11 student suggested, “I *think, for me, it's when you link the formula of that concept, and you link it to the definition, it helps putting those symbols that means something into words. That helps me.*” (G11M, 2023 focus group) and, “*I think another reason that always helps is after you’ve explained it, you go through a few examples. And then you can also link it and see how it works.*” (G11M, 2023 focus group). This student recognises the importance of linking the verbal (words), the symbols and the concepts in order to make meaning of a problem or a scenario, as described by Greeno’s model of problem solving and reasoning (Section 2.3.1).

Other students acknowledged the abstract nature of physics and how demonstrations and visual aids can help: “*Physics is kind of hard to grasp. It’s so like abstract almost. Until you see it*” (G10F, focus group) and,

> *“a lot of things can even be practically applied, even though they look extremely abstract. Like when [Teacher B] gives us like, actual, like physical examples and stuff that makes it make more sense. So like, I*

*try and apply that to like, my other learning and stuff."* (G12M, 2023 focus group)

This student, too, is making reference to the value of linking the abstract domain to the concrete domain when the physical example (concrete domain) helps to clarify the abstract concepts (Greeno, 1989; Johnstone, 2009).

The ISLE approach does not encourage teacher *demonstrations*, as they can be seen as 'magic shows' and send the message that teachers reserve the right to do physics, whereas it is important that all students are legitimated as physicists (Etkina, Brookes and Planinšič, 2019; Brookes, Etkina and Planinšič, 2020). Instead, students should conduct the experiments or, if the teacher demonstrates, students need to be actively involved, explaining observations rather than the teacher explaining what the students 'should' see.

Investigations and interactive demonstrations do capture the attention of students and make for memorable lessons, which may well help students to learn and remember a concept: "*There was the one where they did all the demonstrations. That was quite enjoyable. It's nice to see what you are learning. Sometimes things don't make perfect sense until you see them.*" (G12F, 2022 interview)

While there was not always time for full investigations into concepts, it seems that even demonstrations by teachers did help students build understanding: "*Even when you're like demonstrating in the front, it helps a lot. Just to like, see it. Like we said. Like just to like, visualize it.*" (G11F, 2023 focus group) Or, "*whenever we'd learn something new, you'd actually, like, show us, which, which made me understand it more … from the start rather than at the end*" (G11M, 2023 focus group). The students who referred to visual examples recognised that seeing something happen can help them to link the new concept to their internal knowledge structure (Etkina and Planinšič, 2014b).

Linking new knowledge to an existing knowledge structure assists in the transfer of concepts to new contexts (Bransford, Brown and Cocking, 2000), which is one of the behaviours that was valued in this study and is also an ideal of the ISLE approach. Not many students discussed linking physics to their everyday life, so that these concepts become embedded in their thinking, but these quotes show that some students do carry their learning outside the classroom:

> *"I think the contents that that you like parrot learn, you'll forget straightaway. But, like the concepts that you describe with objects, and then how they apply to our life, like for me, after the lesson of you teaching a lesson later on energy, I find that I'm thinking about it more. So, if, like I'm playing basketball. Then I'll see oh that physics actually does apply when I'm playing sport."* (G11M, 2023 focus group)

And

> *"Also like linking it to everyday life. You know, like in sport. You think like, of a physics equation, when you're trying to do something? I know that sounds weird. But if you play like rugby, you know, I'm heavier than this guy, I have more momentum going into that collision. Like cricket, like if you follow through, like follow your shot, your impulse time is longer."* (G12M, 2023 focus group)

These quotes indicate that these two students are not only linking the concepts that they have learnt sufficiently to the real world to transfer them into sporting contexts, but they have also been transformed by the physics learning experience sufficiently to view their world differently: through a physics lens. It would be naïve to believe that all students share this level of engagement, but it is certainly heart-warming when students take their physics with them outside the classroom context.

An unexpected and positive outcome was a student commenting in a focus group on how they had learnt about different ways in which they work effectively in class:

> *“What I used to do with [Teacher A] was I would copy it down off the board the same time as [they were writing]. But I wouldn't listen as much, I'd be more concentrating in writing it down and see where the numbers come from. And then by the time when I came back to learn it in prep later, then I had sort of forgotten how it worked… you tell us not to write the example down when you do it. That's actually something that like, it's a small thing that's made like a huge difference, because then you know, you actually listening 100% of the time.”* (G11M, 2023 focus group)

Another insight into effective learning in the classroom was a student who remarked that,

> *“it's about really taking… on board when the teacher is speaking. … the initial just seeing it, hearing it play out as a concept, it gives you that framework to understand it further, and even with more complicated questions.”* (G12M, focus group)

This quote highlights two important lessons for the learning environment: the teacher should curate activities that provide the framework for understanding, and students should realise the value of being fully attentive and actively engaged in the lesson so that they can build this framework. Teachers can make suggestions, but students often need to experience the advantages of this approach before they value it and adopt it.

A particularly negative comment about what was (not) learnt was, “*To be honest I don’t know there was so my (sic) information getting in that I don’t hear it half the time im (sic) being spoke at not taught”* (G9F, 2023 survey), which was feedback on my teaching style. It may have been that this student was not actively engaging and so felt she was ‘being spoke at’, or it could be that I was talking too much and not allowing the class to learn through engagement.

To gauge whether the change in approach and the emphasis on valued behaviours in class had changed student thinking, I asked two questions about students' perception of how they learn:

- Has your understanding of how you learn, changed in any way over the time that you have done physics?
- Has your approach to learning changed in any way over the time that you have done physics?

As these were binary questions, there was no substantiating evidence given, but among the senior students, more reported a change in both their understanding of how they learn (Table 7.1) and their approach to learning (Table 7.2).

**Table 7.1:** Student response on whether their understanding of how they learn has changed (*n* = 283; F = 154; M = 138).

| | **All students (*n* = 283) (%)** | | **Senior students only (excluding Grade 9) (*n* = 221) (%)** | |
|---|---|---|---|---|
| | Yes | No | Yes | No |
| Female | 60 | 40 | 67 | 33 |
| Male | 46 | 54 | 57 | 43 |
| Total | 52 | 48 | 61 | 39 |

**Table 7.2:** Student response on whether their approach to learning has changed (*n* = 253; F = 127; M = 126).

| | **All students (*n* = 253) (%)** | | **Senior students only (excluding Grade 9) (*n* = 198) (%)** | |
|---|---|---|---|---|
| | Yes | No | Yes | No |
| Female | 63 | 37 | 71 | 29 |
| Male | 52 | 48 | 56 | 44 |
| Total | 57 | 43 | 64 | 36 |

Interestingly, there is not a large majority of students who changed their understanding of how they learn or their approach to learning when you look at the entire cohort (Grade 9 to Grade 12), but when the Grade 9 group is excluded, a greater proportion of students have changed both their understanding of how they learn and their approach to learning. This may be because the Grade 9s only do physics for one term, because they are younger (and perhaps less mature in their academic attitude) or because some of those surveyed knew that they would not continue with physics beyond Grade 9.

#### *7.1.7 Epistemology: being convinced of a concept*

When students were asked how they are convinced of a new concept, a large proportion of students said that they needed to be convinced by visual or practical demonstrations, evidence or further proof (*n* = 134; F = 59; M = 75). One student said, "*Not convinced at all until I understand it and the origins of it*" (G10M, 2022 survey), while another wrote "*I rationalise it and sometimes research it until it makes clear sense to me in my head*" (G12M, 2022 survey). There was, however, still a belief that the internet holds the truth, "*When multiple sources confirm it's truth and when it thoroughly makes sense and also...Google.*" (G11M, 2022 survey)

A large number of students were still convinced because 'the teacher said so' or because it was in the textbook (*n* = 90 F = 49; M = 31). Some answers mentioned qualified teachers or the syllabus or the school, such as "*Because they are teaching it and they wouldn't be teaching a concept if it wasn't true as this is a very expensive school.*" (G10M, 2023 survey)

Still others (*n* = 11; F = 6; M = 5) were not convinced by the concepts, but just believe it or learn it, giving reasons such as, "*I'm not really convinced, I just go with it*" (G10F, 2023 survey) and, "*I'm not sure, I just hope it is*" (G12F, 2023 survey). Some implied that the truth was irrelevant, given that this content was being assessed, saying, "*I just believe the teacher because it's true for what I'm going to be tested on*" (G11F, 2022 survey), and, "*if it is true or not i* (sic) *still have to learn it so i* (sic) *don't need to be convinced that it it* (sic) *true*" (G12F, 2022 survey).

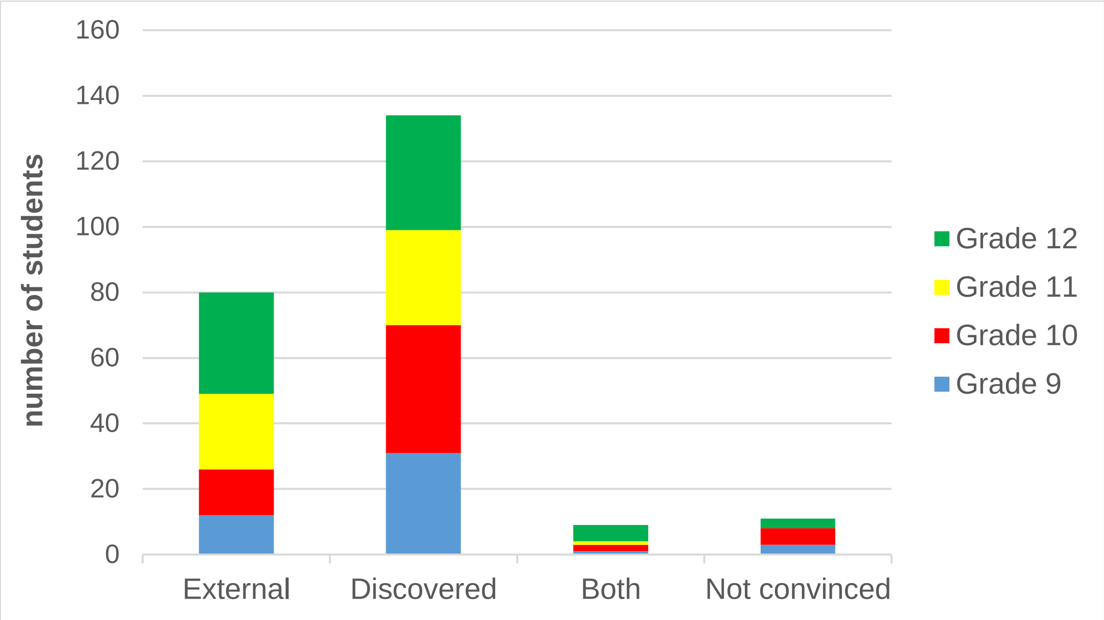



**Figure 7.8**: The number of students (*n* = 317; F = 163; M = 154) in each grade over the period 2021 – 2023 who were convinced of a new concept in physics by being told or reading it or by needing to see it or be given further evidence.

Figure 7.8 shows how students are convinced of a new concept in physics, divided by grade, irrespective of the year of this study (i.e. anyone who was in Grade 12 in any of the years, but no students were counted twice, even if they responded to the survey more than once – only their first response was counted). More students are convinced of a concept when they discover it or see it than those who believe what they are told or taught. It is interesting to note that fewer Grade 9 and 10 students are convinced by being told something, although there is a less noticeable difference among the Grade 11 and 12 students. More of the Grade 10s are not convinced of a concept and this may be because they are entering a new phase (Grade 10-12) of school and have just begun to study Physical Sciences.

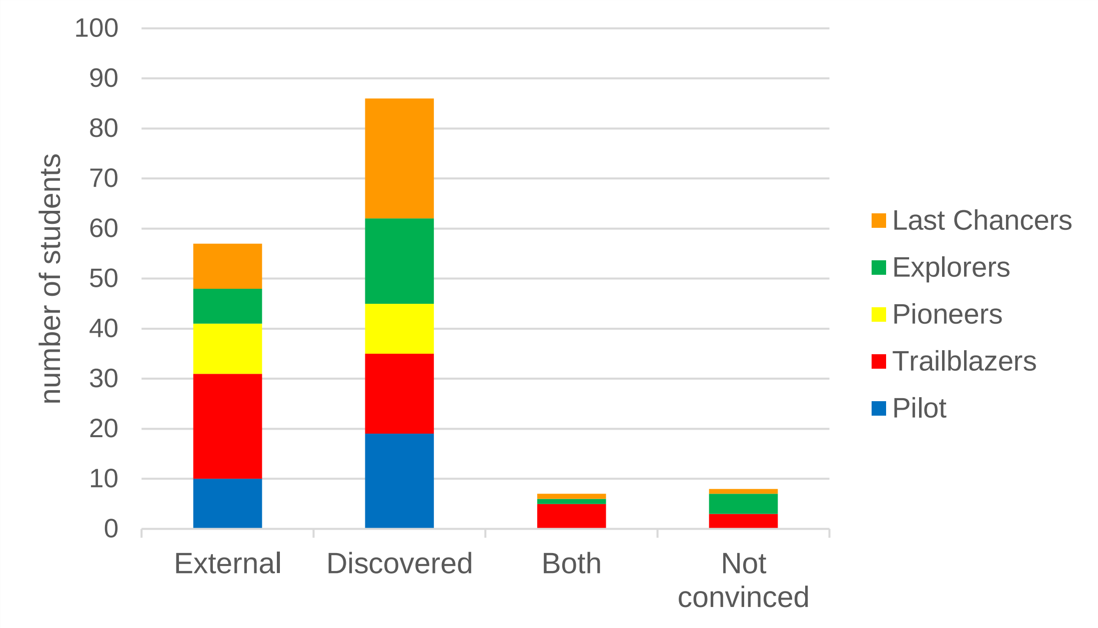



**Figure 7.9:** The number of students (*n* = 208; F = 107; M = 101) in each cohort who were convinced of a new concept in physics by being told or reading it or by needing to see it or be given further evidence.

Figure 7.9 shows how students are convinced of a new concept in physics, divided by cohort, to show the responses by each group. This is interesting as the Pilot group, who were in Grade 12 when this study began and would have already been in Grade 10 in 2020, when students were out of the classroom for a number of weeks due to Covid-19, were convinced by discovering a concept themselves. The students who answered in Grade 9 (Last Chancers) and Grade 10 (Explorers) were also convinced by discovery, while the Trailblazers, who answered the survey at the end of their Grade 12 year and who had little exposure to the ISLE-approach method, were convinced by being told or taught a concept.

Comparing Figure 7.8 and Figure 7.9 suggests that the grade in which the student is had an impact on their epistemology, rather than it being particular to a particular cohort of students. As the Grade 9 and 10 students were convinced by discovery, rather than teaching, perhaps students should be exposed to the ISLE approach in junior grades to reinforce this mindset, before the pressures of the high-stakes examinations loom.

### *7.1.8 Use of the memorandum*

The use of the memorandum came up extensively in discussions and responses and I suspect that it is partly the way that students use the memorandum that is detracting from their learning by completing past papers. From the section on student epistemology above, it is evident that many students rely on the teacher as the source of knowledge, and this is tied to the way they use the solutions provided for problems. In the 2022 survey on learning, I asked the Grade 10, 11 and 12 students (*n* = 130; F = 74; M = 56) four questions to better understand their use of the memorandum ('memo') when practising questions:

- Do you mark your work? If so, how do you go about the process?
- Do you look at the memo / solutions when you get stuck on a question or when you don't know how to do a question?
- When you get a question wrong, do you
    - Mark your answer wrong and move on
    - Copy the right method off the memo
    - Study the memo and trace the steps to see where you went wrong
    - Go back to the question and try it again with a different approach
- If you are given answers only to a revision or homework exercise (not full solutions), what will you do if your answer does not match the answer given?

These questions were posed to gauge the level to which students actively engage by reflecting on the work that they have done, clarify concepts (make connections) and grapple with problems. More than half the students (*n* = 88; F = 51; M = 37) referred to the memorandum when they were stuck with a question. This student's response describes the behaviour that we see:

> *“What I did, and I realize it was wrong. But every time I got, I got stuck, I’d straightaway just reach the memo and then see there’s this and this. But that didn't like, didn't let me struggle enough with the question and then realize where I went wrong. Because I didn't try the question, I just sort of like, I don't know how to do it and then I looked at the memo.”* (G11M, 2023 focus group)

As this student acknowledges, this denies him the opportunity to grapple with the question and try multiple ways of approaching it. Students do find it tempting to look at the memorandum with full solutions when they are stuck: “*If I don’t know a question, I’m going to look at the memo*.” (G12F, 2023 focus group) and “*when I work by myself at home, it's there's a much higher chance of me just looking at the memo instead of getting help. So, I like to come and just sit at Physics Support and work. So, when I do have a question, I don’t look it up, but ask for help.*” (G12F, 2023 focus group)

I was concerned that some students reported not using the memorandum to mark their work (*n* = 16; F = 5; M = 11). Two of these students said that they checked their answers against peers’ work, but I am not sure that students who are applying their knowledge, but not checking that they are applying it correctly, are learning. Self-assessment, correction of errors and reflection are important for learning (McDonald and Boud, 2003; Sadler and Good, 2006).

A large number of students (*n* = 55; F = 33; M = 22) said that they use the memorandum to do corrections, having completed the exercise or the past paper and the majority of students reported (see Figure 7.10 below) that they are following a sensible way to engage with the memorandum and correct their mistakes, saying that they study the memorandum and trace the steps to see where they went wrong or that they went back to try the question again. A small proportion of students (*n* = 7; F = 6; M =1) reported that they just mark the question and move on, although the six girls who gave this response were in Grade 10 and so this approach certainly did not last into the senior years (the response by the boy in Grade 11 did not match his other responses).

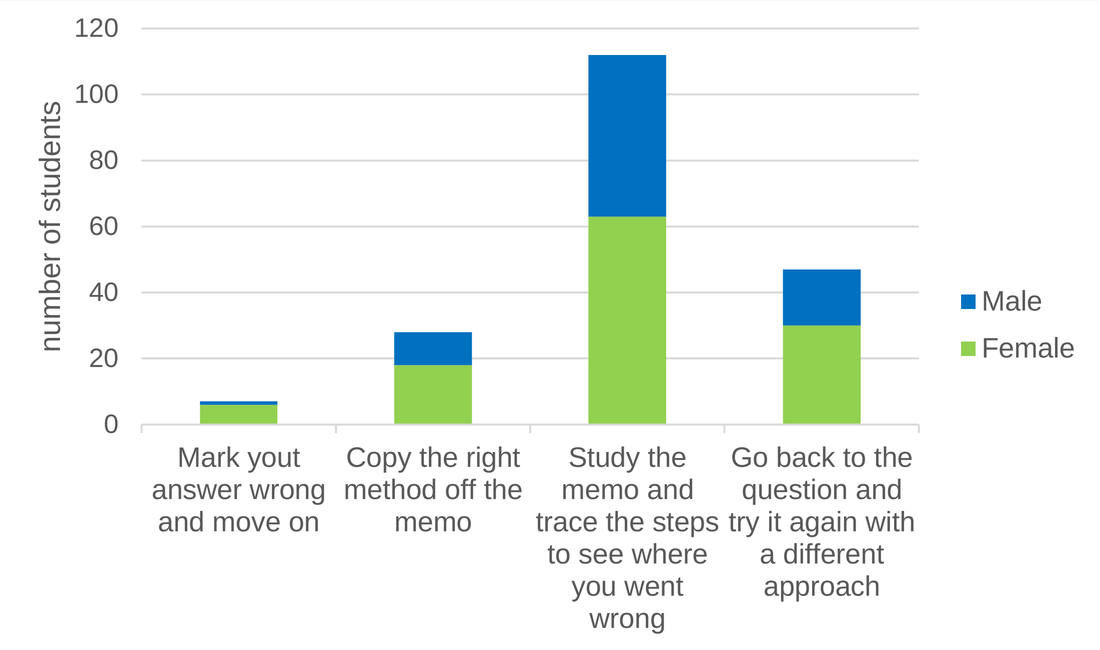



**Figure 7.10:** Student approach when they get a question wrong (*n* = 130; F = 74; M = 56).

Engaging with the memorandum and tracing their steps should help them to fix mistakes and learn: "*I feel like sometimes I can learn from the memo. And like see where I went wrong and then understand. But then sometimes if I don't understand at all…oh, yeah! (laughs)*" (G12F, 2023 focus group). Her peer agreed, saying, "*sometimes I don't understand where they got the numbers. Why they did that equation?*" (G12F, 2023 focus group)

In the Grade 12 focus group, students spoke about how they sometimes struggle to make sense of the memorandum, saying, "*they … don't really give an explanation in the memo, which is also hard if you needing help with how they got something, if you have no idea*" (G12F, 2023 focus group), which is when grappling is required. The same issue was mentioned in the Grade 11 focus group, where the students said that the memorandum, "*might just give you a straight answer and it might not show you like the steps or the thought* *process to getting that answer*" (G11M, 2023 focus group). Both of these responses suggest that the student was looking for these "missing steps", rather than making the connections themselves. The memorandum does not come with explanations, but the student needs to interrogate the physics and grapple with the concepts to make sense of the steps.

A student in the Grade 12 focus group spoke about not being able to follow how the problem was solved on the memorandum: *"I feel like sometimes when there's like a really like a question that you didn't get, and you see like, Okay, I don't know* ***how*** *they got it on the memo, then it's kind of like, okay, like, I* ***really*** *don't understand.*" (G12F, 2023 focus group)

This is when seeking help might be required ("*that's why you have to go to Physics Support*." (G12F, 2023 focus group)) and some students realise that this is important in building understanding, rather than abandoning problems that they could not solve by themselves or where they could not make sense of the solution on the memorandum: "*then I'll go ask, but why did they do the steps in the memo, instead of leaving it, and I used to leave it… And then that obviously didn't work. Now I have to use the memo to help me.*" (G12F, 2023 focus group)

Students who focus on getting a problem right (performance goal) and those who try to deepen their understanding of a concept (learning goal) may seek help in different ways when they struggle with a problem. Copying from a friend or asking a friend for the answer to a problem or 'how to solve' the problem is very different to sitting with a peer or a teacher who explains the process or the conceptual connections.

The memorandum does seem to limit the students' grappling and some expressed that they need to find ways to be more disciplined about not looking at the memo. One way to remove this temptation would be to provide answers only to all exercises, past tests and practice examinations (no solutions). When the students were asked their approach if they were only given answers without solutions, they responded that they would either seek help from a teacher, a friend or go to Physics Support or they would try to redo the problem or try another method until they reached the correct solution and a few opted to abandon the problem, as shown in Figure 7.11.

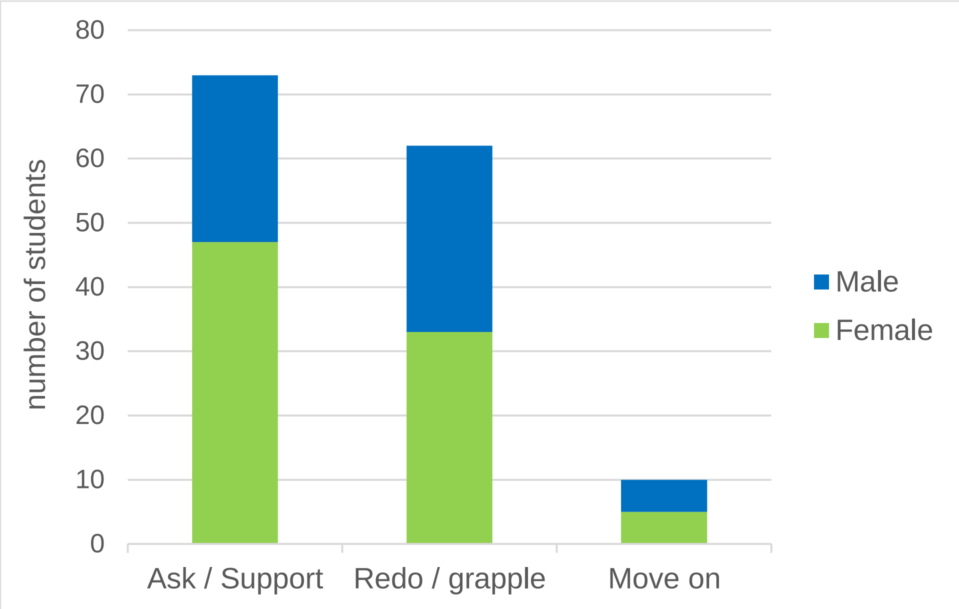



**Figure 7.11:** Reponses from Grade 10 to 12 students (*n* = 130; F = 74; M = 56) when asked what they would do when their answer did not match the answer given, if they were given only an answer, without full solution.

As shown in Figure 7.11, a few students would just move on if they did not get the answer and there was no full solution: "*Put a star and try to find time to come to a teacher but often I don't have time or I forget so I end up just marking it wrong and moving on*." (G11F, 2022 survey). Many students did say that they would grapple with the problem, but there were many negative comments which suggest that students would not embrace this approach to try to work out how to get to the correct answer on their own. Some of the responses had a tone of helplessness, like the student response that said she would, "*Ask A* (sic) *friend or just move on as there is no explanation to why my answer is wrong therefore there is only so much I can do to correct it.*" (G10F, 2022 survey), although this girl also said that, "*seeing physics in class doesn't further my understanding but rather complicate it*" (G10F, 2022 survey) and so takes a dim view of our efforts to encourage active engagement and grappling!

Some of the responses gave the impression that the students felt aggrieved when they did not have the full solutions, suggesting that this is an inconvenience: "*I would try different ways to get it, this however can be very time consuming*" (G11F, 2022 survey) and "*I would do the only thing I can do, which is to go to a teacher or a student that understands this concept and ask them to help me find the correct answer.*" (G11M, 2022 survey)

Many commented that not having the full solutions would negatively impact their learning: "*I will want to know why I didn't get the answer right or where I went wrong because just being given the answer doesn't help me learn and grow for the next time*" (G11F, 2022 survey); and "*I would try the question again, but it would not be beneficial to me as it would be more difficult for me to personally recognise what errors I have been making so that I can reflect on them and learn not to do them.*" (G11F, 2022 survey). A student who said that he copies the method off the memorandum, wrote that he would "*go and ask the teacher, I think we must get the full solutions else we are not learning anything*" (G11M, 2022 survey). This suggests that this student is not yet convinced that he can develop his own coherent understanding of concepts through grappling, but is reliant on knowledge from authority.

This student made it clear that full solutions are expected and,

> "*Being given only the answer to an exercise and not the proper explanation is very demotivating and quite frankly annoying. If a question doesn't need a long solution, then it is fine, but for a 3 or 4 mark question which need an explanation or long solution, it is not fine. But, normally I would ask a friend or go back and see what I might've done incorrectly.*" (G10F, 2022 survey)

The comments shared above, conveyed the message that (some) students expect to be told how to get to the answer and they do not consider having to get there themselves. Perhaps we have made it too easy for students by providing full solutions for worksheets, past tests (with the exception of the pre-test) and past examinations? Students have come to expect full solutions and are not prepared to grapple with the problem to find their own way to the correct solution. Or perhaps we should be explicit about what is expected of students and offer some guidance and support to help them learn to grapple and reach the solution on their own. The decision not to share the memorandum for the pre-test (even after they have done their corrections, or the night before the test, as requested) is a step towards this.

One of the Grade 12 students shared her experience in the focus group, explaining how she learnt to better approach her physics learning:

> *"For my past papers, like I think I low-key 'gaslit' myself into thinking that I knew the answer when I look at the memo…". She was then interrupted by a friend suggesting, "literally hide the memo!" before she continued, "…I think my big mistake was that I would focus too much on past papers and less on grasping the actual content. Yeah. So, then I wouldn't understand how to work out the tension question because I didn't understand the basics of how tension works, for example, and like, especially with like, the photoelectric effect section we're doing now, like, I had to go back to like, the like basics of what is work function and … threshold frequency. Because I … just rushed into past papers like with math, but I didn't know if you skipped over the content - if I didn't know the content - It didn't match. … I didn't have my basics, so I couldn't understand like the paragraph before the picture. And you have to understand the paragraph with the directions and the picture. So like, ja, going to like the content, building off of that, and then practising past papers, like they do work together. They're not two separate things - I used to think of them as separate."* (G12F, 2023 focus group)

This student has articulated her reliance on the solutions to short-cut the learning process by avoiding the 'grappling' experience. She has recognised that she was working in the symbolic and abstract domains ('like with math'), but not using the model domain (‘the picture’) and so was unable to make connections between the words and the physics. She realised over time that she needed to integrate practising problems with active engagement with the concepts and making connections between the domains of a problem.

Another of the Grade 12s described in the focus group how the memo, in some instances, improved her confidence, giving her affirmation when she was correctly solving problems and answering questions:

> *“The memo does also have its like place because for me is when it's not tempting me, but when I get it, right, it boosts my confidence, because I know that I'm right, then I feel more capable to do the rest. So like, the memo definitely has its place.” (G12F, 2023 focus group)*

Providing a memorandum (or full solutions) is not altogether a bad thing, but students need to use it in a way that it supports learning without just being a source of comfort that precludes active engagement and grappling. Providing only the answers may offer the confidence boost to students who are getting the answers right, without offering the shortcuts to those who are not. Those students who do not get the answer right, can grapple to improve their understanding. They can access help with grappling, through the support offered, and are not abandoned to struggle alone, but must engage with the problem. Alternatively, the effective use of solutions needs to be modelled for students, so that they can learn how these solutions can benefit them, without offering them a way to escape the grappling that supports their learning and their development of valued behaviours.

#### *7.1.9 Student experience of ISLE experiments*

Students were asked whether they remembered the investigations we had done the previous term and 65 (out of 171) did (F = 39; M = 26), with 21 of these recounting the physics that they had learnt through the investigations F = 8; M = 13). A large proportion of students (*n* = 51; F = 28; M = 21) said that a practical activity helped them to learn or change their understanding of a concept: "*Also doing like, pracs and stuff helps a lot to like, understand the concept.*" (G11F, 2023 focus group)

There was a feeling, particularly in Grade 11 where many of the exploratory introductions were done, that it was helpful to see and do the investigations as the concepts were made easier, "*By physically seeing how it works instead of having to picture it*" (G11M, 2023 survey) and the investigations helped to make the theory real and connected to the real context: *"You kind of go 'there's something that I saw' when you see it in the book - you remember doing it*" (G11F, 2023 focus group). This brings meaning to the theory: "*So you like basically figuring it out and then you meet it, and you say, 'This means something now'*" (G11F, 2023 focus group).

One of the boys in the Grade 12 focus group acknowledged the positive impact of investigations and practical work and how not all students have the opportunity to do them:

> *"we did a lot of practicals in Grade 10, 11. It really does help with conceptual understanding and I'm glad that we're like in a position that we can do that because other schools obviously don't have the time or don't have like the privilege of being able to."* (G12M, 2023 focus group)

In the last term of 2023, we did almost no investigations with the Pioneers (Grade 11 in 2023) because we were under time pressure. To gauge how students value investigations and how important they are perceived to be in the learning process, I asked this cohort in their survey on physics learning, how they felt the lack of investigations that term impacted their learning experience and 25 students offered responses to this question (F = 10; M = 15). Their responses are summarised in the table below.

**Table 7.3:** Survey responses on whether not doing investigations impacted their learning experience in physics (*n* = 25; 10 female; 15 male).

| Category | Total answers | Total female | Total male | Typical response in category |
|---|---|---|---|---|
| Negative impact | 7 | 4 | 3 | "*i* (sic) *know that not having investigations has really impacted how much i (sic) have really absorbed and made it a bit more difficult for me to visualize what is happening and what steps i* (sic) *want to take to the questions*" (G11M, 2023 survey) |
| More time for exercises / concepts | 6 | 1 | 5 | "*I think this has had a positive impact. More time focusing on the book and asking questions around things we will be tested on.*" (G11M, 2023 survey) |
| No impact | 4 | 0 | 4 | "*I don't think it has changed the way I learn physics*" (G11M, 2023 survey) |
| Demonstrations were sufficient | 3 | 3 | 0 | "*i* (sic) *think that my learning this term as still be very good. [Teacher C] does practical examples in class which help with the visual aspect of learning which i* (sic) *think is important*" (G11F, 2023 survey) |
| Had to focus more to understand | 3 | 2 | 1 | "*not having investigations lead to lessons being less interesting and therefore, students losing focus*" (G11M, 2023 survey)<br>"*Found it quite difficult to visualise concepts and have had to concentrate harder in class to understand topics*" (G11F, 2023 survey) |
| Unrelated comment made | 2 | 0 | 2 | "*The last section felt a bit rushed and I was unsure of what equations to use in the various situations*" (G11M, 2023 survey) |

One of the students commented that investigations detracted from his learning, "*because it makes me focus on something else*" (G11M, 2023 focus group). He was referring to the investigations to gather data, rather than the introductory investigations to build conceptual understanding. This student went on to say,

> *"'cause every time I come to a physics lesson, especially this term, I know what I'm going to do, I know the concept of a single focus, I*

> *know that I'm going to keep improving my knowledge of a certain topic. And then one day to think about tennis balls bouncing doesn't really help me at all, even though it is to build up certain skills. I just don't think it helps."* (G11M, 2023 focus group)

His peers agreed with this sentiment, and this speaks to the opinion given by six students in the survey who felt that the investigations impinged on time to learn concepts. The student quoted above went on to suggest doing these investigations (to teach skills, rather than concepts) in the lesson after a test for least impact. His suggestion is a valid one, but this sentiment again suggests that students are focused on the outcome (performance), rather than the process (learning).

The teachers also felt that the investigations were not all about learning, with Teacher B saying (in 2023 interview) that the students were "*easily distracted, someone always wanting to play up for someone else. It brings out the class clown – someone's throwing the ball around…*" and Teacher A, responding (in the 2023 interview) said, "*You can't be naïve about this: you put 24 tennis balls and 24 ping pong balls into a class of Grade 9 boys and I mean, you know…but that doesn't mean they weren't engaging with it… maybe it's the age?*" It could be that if students learnt through experiments every lesson, they would be less distracted and would see the learning opportunity, rather than an opportunity to play.

In the Grade 12 boys' focus group, there was a discussion about the practicalities of investigations, where one of the students commented on how we simplify questions, saying, "*Not having to worry about air resistance and like, the questions where it says there's no friction, even though that's not possible. Like it's easier to work with that.*" (G12M, 2023 focus group) and how the reality of experiments can confuse students when "*things just … don't work the way that the book says it does. Like it's close, but it's never like, like exactly right*" (G12M, 2023 focus group).

My colleagues acknowledged that it is easier to understand concepts if you see them demonstrated, particularly when dealing with unfamiliar concepts where it is more difficult to imagine the set-up because it is less familiar (they were referring to an AC generator, as opposed to blocks and a pulley). When I asked in the Grade 12 boys' focus group whether it would help to do more demonstrations and investigations, a student responded,

> *"I think if you did more things with, like, the blocks, and the pulleys and stuff, I'm not sure if that would work – this was probably why you don't - but like, they're always over-simplified like … the weight of the string is negligible. And like the resistance of the pulley and other stuff. So, I think if you did it, and then people saw how … inaccurate it would be … I think it might, like, confuse some people to an extent - they don't really understand … why it's become different. And also with the examples where on the horizontal plane, there's no friction, but there is when you do an experiment. It would just be a bit weird."* (G12M, 2023 focus group)

This student was alluding to the assumptions that we make and that we apply when solving physics problems. At school, these are often implicit, and we rarely articulate the assumptions that we make in the models that we use to explain concepts. The ISLE approach is more explicit about the assumptions that are made and even has students identify assumptions (Etkina, Brookes and Planinšič, 2019). Due to time constraints and the complexity of considering assumptions (which would 'confuse some people to an extent'), I did not include a consideration of assumptions in any ISLE activities, other than the current in a circuit activity (Activity VIII). This might be something to include in future when the rest of the 'new' aspects of the ISLE approach have become more familiar.

In a discussion about the investigations with Teachers A and B, Teacher A commented on the conflict between teaching a conceptual understanding of physics (our idealised approach) and preparing students for the assessment, where the emphasis is on learning to solve problems (translating between the picture (by which they meant the graph), numbers and the words). Teacher A went on to say,

> *"I think it's… about how well … the demonstration does introduce a concept, and create understanding about the concept. Our physics is so mathematically based, you know, so that's why, you know, unless you're drawing graphs, and seeing patterns, and taking data, and things. I, the whole theoretical aspect of the physics is based in maths, you know, and so … I always talk about the picture, the number, the words; picture, the number, the words. So that is the triangle that you in, you know, so it's pictures, numbers and words, and you're understanding pictures, numbers and words. And there's no tennis ball in there. And so it's the nature of the of the subject that we are teaching. And maybe that's the problem." (Teacher A, 2023 interview)*

Demonstrations and/or investigations need to be carefully chosen and curated to fit with content, facilitate understanding and add value. Due to our time constraints, there is no time to 'play' to discover, and Teacher A suggested that activities are chosen only for concepts that are difficult or where misconceptions are likely to occur. They further suggested that we "replace the talking with doing" and make the activities as well-integrated into lessons as possible, rather than separate activities (perhaps using a pencil case instead of a tennis ball to minimise disruption of handing out tennis balls and the distraction of having a tennis ball to throw!). Each activity needs to be structured to meet an outcome through a clear process. Teacher A continued to say that the timing of the activity so that it was in context was important and that activities need to be familiar, but not trivial and "*you need to put boundaries around what you are talking about*" (Teacher A, 2023 interview), and make the purpose of the task known. This is important, as the goals of an activity may be clear to us, but not to our students, unless we are explicit about the knowledge that we want them to learn and our expectations of them (Martin, Maton and Doran, 2020). This aligns with the ISLE approach where scientific abilities rubrics guide students in what is expected of them (see

Section 3.4), and with LCT's view of making the paths of success explicit. The goals of the activity and the paths to success were not immediately obvious to the three teachers who implemented ISLE and were inexperienced in following the ISLE approach, and this is where training and apprenticeship for teachers is important (Buggé et al., 2023; Rutberg, Jammula and Ahmed, 2023).

The Grade 11 focus group were questioned specifically on the exploratory investigations that they had done on forces and the normal force. These were taken directly from the ISLE resources (Etkina, Brookes and Planinšič, 2022) with no adaptation initially (we later adjusted the activities) and the students and teachers alike found these difficult, with one of the students responding, "*I think that just because we hadn't done an example like that previously, like set out in this way, and that challenged our brains a bit to like figure it out*" (G11F, 2023 focus group). While another responded to the normal force activity, "*I don't think I learnt a particular concept. I just followed the instructions*" (G11F, 2023 focus group), to which her peer responded, "*Ja. I just followed the process*" (G11F, 2023 focus group). Teacher B commented that there was "*mass confusion over the questions, simply because they struggled to picture it or because they could only think of the 'obvious' answer*" (Teacher B, written feedback on investigation experience).

When conducting the water in a glass activity, I have been explicit about the purpose and value of the process of this activity: to design experiments that test the predictions that the groups have made based on their explanations. The reaction of most students was rather impatient: they knew that the water was due to condensation and just wanted to write that and be done with the process. This is perhaps indicative of the learning approach that they are used to, which is outcomes based, not process focused. They are used to the answer being valued and so place less emphasis on the process of getting to the answer or solving the problem. In 2023, I had a class of Grade 9 students who struggled to understand the Testing Multiple Experiments (TME) chart, despite talking them through the model TME chart about the water on the field. After a lesson of struggling, I gave them the ‘crazy ideas’ and had them devise the testing experiments and make predictions. This gave them the opportunity to design experiments and to think about predictions and falsification, which was a benefit of the task, even though they did not come up with the ideas themselves.

Teacher A used the water in a glass activity for the first time in April 2023, after I had used it previously and told them about my experiences. They began with an explanation of climate change and asked the class for explanations of this and how we could test them. Their rationale was that without a real purpose, their class would be less engaged. They did not have their students work in groups but used the time that this saved, to show the increase in mass of the glass using a sensitive scale.

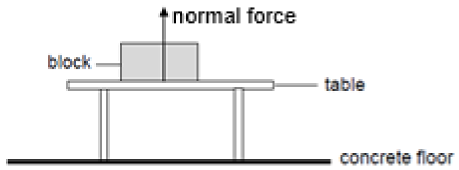
There were many comments about the ‘right answer’, which is a common sentiment when the ISLE process is introduced and is an important consideration in developing valued behaviours that focuses on process, rather than answers (Brookes, Etkina and Planinšič, 2020). Students responded, “*I didn’t really understand what it was asking… I didn’t quite know whether I had it right*” (G11F, 2023 focus group) and found the investigations uncomfortable because of their uncertainty. This general discomfort with not knowing whether they have the right answer was discussed in the previous section about how students use solutions to exercises. The teachers commented in an interview that the students were frustrated as they were unsure what to write and lacked the confidence to write what they observed. Teacher B said, “*They weren’t happy with what they were seeing. They wanted it to be clearer and more obvious.*” (Teacher B, 2023 interview)

Expecting a ‘right’ answer is a symptom of the way they are taught in most classes (and how they are usually taught physics). Some students said that the task and video were confusing, but the teacher’s explanation helped them to make more sense of them. I noted at the time of doing the experiments introducing forces, that students wanted the ‘right’ answer from the teacher to write down and were reluctant to write down their own observations. This self-doubt may also have been reflected in the students’ response to investigations that they found confusing. The questions may have been unclear, or the structure of the activity may not have worked, but the students lacked the agency and confidence to question the activity (authority) and, instead, questioned themselves. A student hoped for another chance to ‘get the investigation right’ suggesting that, “*Once you’ve explained it on the board, it would be nice to do another one as a class so that now that you’ve got your own understanding of what it is, you can actually apply it.*” (G11F, 2022 interview)

There was a resounding sense that the office chair experiment, which I had developed (described in Chapter 5, Section 5.3.2, Activity V), changed understanding and embedded the concept. In the focus group, I asked “When you see a question in your test that says that there’s a heavy mass and a light mass and they collide. Which one exerts a bigger force?” and the group responded “*neither*” and when asked how they know that, the responses were “*we know Newton’s third law*” and “*You’ve experienced it.*” (Both G11F, 2023 focus group)

Despite these students’ conviction that they knew Newton’s third law, there was little evidence that it was understood by all, as there were still a number of students who gave the incorrect answer to the question shown in Figure 7.12 in the examination a few months after the concept had been taught.

1.3 A block rests on a table. The table stands on a concrete floor. The normal force on the block is shown in the diagram below.




Which ONE of the following forces will complete the Newton third law pair with the normal force?

A Force of the Earth on the block
B Force of the block on the table
C Force of the table surface on the block
D Force of the block on the concrete floor

**Figure 7.12:** Question 1.3 on the July 2023 Grade 11 examination, which tested an application of Newton's third law.

The question shown in Figure 7.12 is often asked in various guises, and the most commonly chosen answer is usually the option corresponding to the distractor that identifies the equilibrant force of the normal force (option A in this case), whereas the correct answer here is option B. The distribution of answers shown in Figure 7.13 indicates that many students still answered 'A', but more students answered correctly than incorrectly.

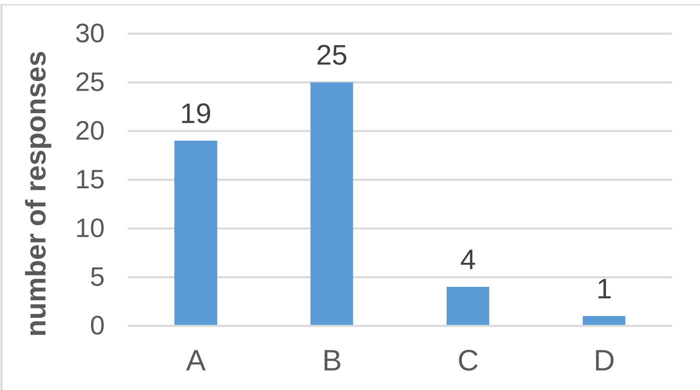



**Figure 7.13:** Distribution of answers to question 1.3 on the July 2023 Grade 11 examination (Figure 7.12 above).

The same Grade 11 group from 2023 was asked a sub-question in their Grade 12 July examination which was a direct application of what they had tested with the spring balance experiment in Grade 11, and the concept that the students in the girls' focus group had been convinced they knew ('we know Newton's third law' above). The question involved the collision of Ball A and Ball B, as shown in Figure 7.14.

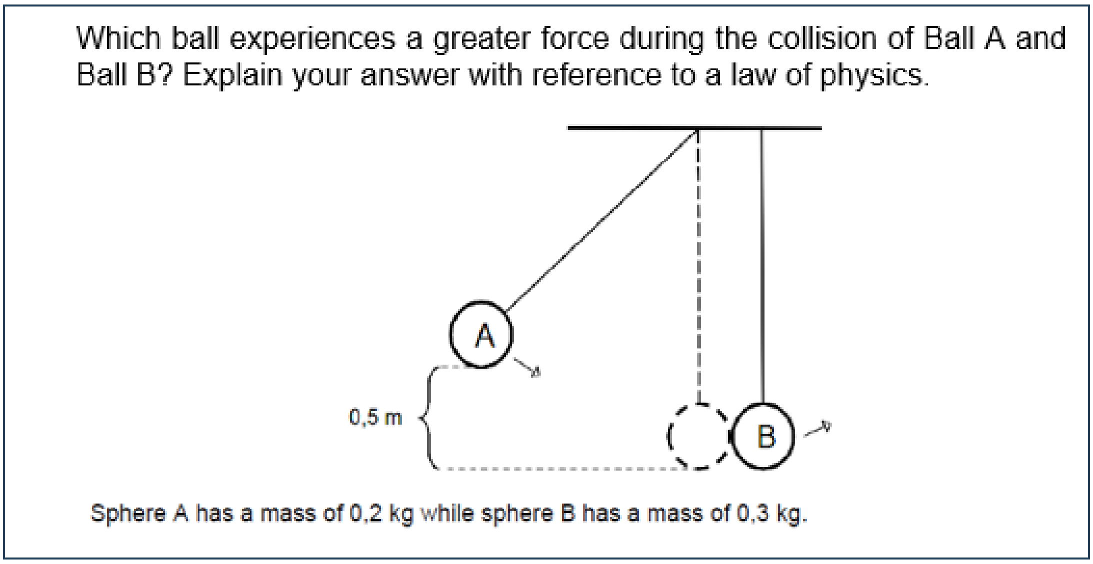



**Figure 7.14:** The diagram and information given in the Grade 12 July 2024 examination for the question involving a collision of Ball A and Ball B.

To see how many students were still able to apply Newton's third law correctly a year after learning it, I examined the students' answers to this sub-question (*n* = *47*; F = 20; M = 27). Most of the students (*n* = 40; F = 18; M = 22) answered this sub-question correctly, although two of the boys gave incorrect explanations (they did not attribute the equal forces to Newton's third law). Students often hold misconceptions about the force between objects of different masses. The very high proportion of students who answered this question correctly cannot be entirely attributed to the office chairs and spring balance demonstrations (2023) without further interrogation, but it was pleasing to see so many students answer this correctly.

The ISLE and ISLE-inspired activities that were implemented in this study, seemed to fall into two broad categories:

- those that were trying to lead students to an understanding of a concept, such as the introduction to forces investigation or the relative motion introduction; and
- those designed to elicit an ‘aha! moment’ or change the students’ understanding, such as trying to pull two spring balances apart with forces of differing magnitudes.

The latter investigation should convince students of a new concept or perhaps a new understanding of a concept and we need to select activities carefully to achieve this. The former investigation, where new terms are introduced and students are given time to explore and discover a concept, seemed too unstructured and ‘slow’ for our context. However, it could be that more frequent exposure to such activities would increase student confidence to give them the courage to try and construct their own understanding and thus transfer the knowledge to new contexts.

#### *7.1.10 Student experience of reflections after lessons*

From the end of 2021, I posted a Lesson Reflection Task on Google Classroom, for students to complete at the end of each lesson (Activity X, described in Section 5.3.2). The activity was intended to prompt them to reflect on what they had learnt and how they had learnt that concept:

- In today's physics lesson I learnt…
- I think that I learnt this concept by / through:…
- This still remains unclear / I want to ask:…

Reflection is valuable for learning (Faletic and Planinšič, 2020) and prompting students to think about how they learnt something, reminded them that knowledge is constructed and that they should constantly be asking themselves, “How do I know this?” and “How do they know that?” to ensure that they are truth seekers. While this activity asked students to reflect on their *knowledge*, its primary goal was to develop them as *knowers* as they were encouraged to think about what they had learnt in the lesson (and how they had learnt it) to develop reflexive knowledge-building skills.

In the lesson reflections, students were able to articulate their learning to various degrees. There were 344 recorded entries (148 female, 196 male). Some included just a word or phrase ("*conservation of momentum*" (G11F, 2022 reflection); "*ticker tape*" (G11M, 2022 reflection) and others included longer descriptions of what they had learnt, sometimes describing the concept that they had learnt ("*If I see something moving it is relative to me, but if I'm moving with the object it is not relative to me*" (G10M, 2022 reflection) or "*I learned about ticker tapes and that the bigger the space between the dots the faster the object is moving.*" (G10F, 2022 reflection)) and other times stating what they had learnt in conceptual terms ("*I learnt how force is linked to momentum*" (G11F, 2022 reflection)).

As shown in Figure 7.15, the majority of students (*n* = 151, 83 female, 68 male) reported that they learnt a new concept by doing exercises or through practice questions. This supports the responses in the survey (see Section 7.1.6) where the majority of students answered that they learnt a new concept this way. A large number of students (*n* = 91, 32 female, 59 male) attributed their learning to the teacher's explanation, the teaching or listening in class, while slightly fewer students (*n* = 82, 40 female, 44 male) felt that investigations, demonstrations and visual representations were what helped them to learn the concept.

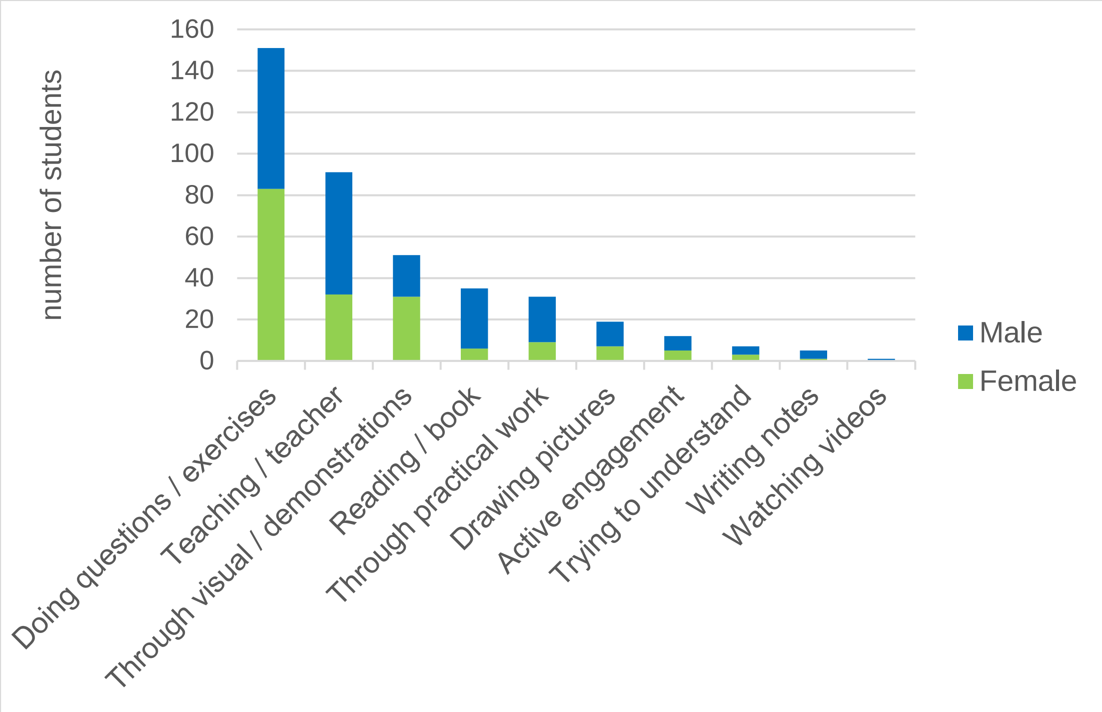



**Figure 7.15:** Student description of how they learnt a concept, provided in post-lesson reflection task (*n* = 344, F = 148, M = 196).

These data suggest that most students expect to be taught concepts by the teacher or through material prepared for learning by the teacher (the book and the examples in the book). This quote supports the view that students rely on being taught:

> *"I learn a new concept through having it explained to me and understanding it, I also think it helps when the concept is revised or taught twice as that usually fixes my understanding in case I missed something vital the first time."* (G12F, 2023 survey)

Again, this echoes the survey result (Figure 7.7) where students attributed their learning of a new concept to the teaching, the lessons and the notes. In the survey, many students also wrote that they learnt through working to understand the concept. Often this is expressed as reliance on the teacher to explain, rather than grappling and taking ownership of their learning, as this student's response suggests: "*Once I have practised many questions on the topic and a teacher has explained the ones I don't understand, I think I am capable of doing well in Physics*" (G11F, 2022 survey). Unfortunately, this shifts the agency from the student to the teacher. It is a fine line to tread for the teacher who makes students feel comfortable in their classroom, as reported in Section 7.1.4, but still challenges students to grapple and solve problems independently. Teachers need to guard against fostering reliance by offering students a ‘comfortable’ way out when the problems are tough, as students need to experience the discomfort of tough grappling in order to build new understanding and learn to tackle problems confidently on their own.

If reflecting on learning is valued, it is important to understand why students did not reflect, so that reflection tasks can be more effectively introduced. In the survey at the end of 2022 ($n$ = 146; 74 female; 72 male), I asked why the students did not complete the reflection task and the typical student responses are represented in Table 7.4. The majority of students said that they forgot about the task, while many students in the classes taught by other teachers said that they did not know about the task, as it was posted at the start of the year, but they were perhaps not reminded about it. Others said that they were in a hurry to get to the next lesson or preferred to finish the work that they were busy with, rather than completing this task.

**Table 7.4:** Reasons given for not always completing the reflection task at the end of a lesson (*n* = 146; F = 74; M = 72).

| Reason category | Total answers | Total female | Total male | Typical response in category |
|---|---|---|---|---|
| Forgot | 57 | 30 | 27 | "*I do the reflections i* (sic) *think most of the time when im (sic) asked to but if im* (sic) *not reminded i* (sic) *forget*" (G11M, 2022 survey) |
| No time | 34 | 25 | 9 | "*I sometimes forgot and was in a rush to leave to the next class or to finish all the work assigned in class so that I had less homework.*" (G11F, 2022 survey)<br>"*I ran out of time at the end of the lesson*" (G11F, 2022 survey) |
| Did not know about task | 24 | 10 | 14 | "*Completely forgot about the Reflection Exercise and wasn't reminded about it and was posted on classroom at the beginning of the year but wasn't mentioned after.*" (G10F, 2022 survey) |
| Other priorities | 10 | 6 | 4 | "*I also often forgot because we would be told at the end of the lesson and then there would be no time to fill it in because we had another class. It just took away from the few minutes I could be using to finish the physics question I was on (academic time)*" (G11F, 2022 survey) |

Some of the answers suggested that the activity may have had a better response, had there been a better routine established. One of the Grade 10 girls said, "*there was no set time at the end of every lesson to complete it so by the time im* (sic*) back at the house or in my other class ive* (sic) *forgotten it*" (G10F, 2022 survey). Another said, "*I found it to be too challenging to remember and it hadn't become a routine for me*" (G10F, 2022 survey). Some students said that they did not complete the reflection task, but still speculated as to what the benefits might be ("*It would have summarized the lesson and remind me of what I have learned*" (G10M, 2022 survey)). I only counted responses in the summaries given below from those who had reflected.

The lesson reflections were done via Google Form at the end of the lesson, but I often forgot to remind students in the lesson, reminding them to complete the activity as they were on their way to the next class. This did not place appropriate value on the reflection task. Despite the large number of students who forgot about the task and the fact that regular reflection was short-lived (only implemented for a few months), students felt that such a task would be of benefit to them, as shown by the numbers given in Table 7.5, which were from the coded responses on the 2022 surveys. Only a small proportion of the students saw no benefit in the task.

**Table 7.5:** Perceived benefits in completing the reflection task at the end of a lesson ($n$ = 146; F = 74; M = 72).

| Perceived benefit | Total | Total female | Total male | Typical response |
|---|---|---|---|---|
| No benefit | 12 | 5 | 7 | "*I didn't see a benefit*" (G10F, 2022 survey) |
| Value of reflection / looking back on lesson | 42 | 21 | 21 | *Helped me to understand what I had actually gained and learnt from the lesson as well as what I need to focus on going forward.*" (G11M, 2022 survey)<br>"*It makes you really think about what you did in each lesson*" (G10F, 2022 survey) |
| Identify gaps for future study | 24 | 16 | 8 | "*It enabled me to see what I was struggling with*" (G12F, 2022 survey)<br>"*It made me asses* (sic) *what I had learnt that lesson and think over if I didn't understand something so that I could remember to go over it after school.*" (G11F, 2022 survey) |
| Retention of learning | 11 | 4 | 7 | "*I felt as though it helped me think about what I had learned and helped it stay in my brain*" (G10M, 2022 survey)<br>"*it seals all the knowledge from that lesson in your head and it helps a lot to remember the things you learnt*". (G10F, 2022 survey) |
| Summary of learning | 6 | 2 | 4 | "*It summariser (sic) what you've done and it's a way to find out what you know/remember*" (G9M, 2022 survey)<br>"*It made a summary of all the knowledge i've* (sic) *learned*" (G10F, 2022 survey) |
| Improved well-being | 4 | 3 | 1 | "*Sometimes it was nice to just jot down what I've learnt so as you walk out of the lesson you're reassured that you know the knowledge you've gained.*" (G11F, 2022 survey)<br>"*I could reflect on myself and my physics ability, and was happy and feel secure or safe that I know what I'm doing. I don't feel lost or worried.*" (G9M, 2022 survey) |
| Structure understanding | 1 | 0 | 1 | "*I managed to organise my understanding of physics*" (G10M, 2022 survey) |

There is evidence in these student responses that some students are developing behaviours that we value, such as reflecting (‘*think about what you did in each lesson*’), grappling (‘*go over it after school*’) and making connections (‘*organise my understanding of physics*’) as well as experiencing positive well-being (‘*reassured that you know the knowledge you’ve gained*’).

Students recognised the value of reflection in self-assessment:

> *“It helped reinforce what I learnt in the lesson and helped me assess how much knowledge I gained and how attentive I had been in the lesson.”* (G11F, 2022 survey)

And

> *“You could reflect on the lesson and the work you were just taught, a confidence booster and a gauge to see what you needed help with”* (G11F, 2022 survey).

One student said, “*It made me see what worked for me and what didn’t, in terms of what we did in class*” (G11F, 2022 survey), suggesting that the activity helped her reflect on her learning approach.

Another student mentioned how it helped him to articulate what he had learnt (*“It forced me in a good way to talk about what I've learnt”* (G11M, 2022 survey)). Another student also referred to being ‘forced’ (“*When I did do it, it forced me to engage with the content we just covered and really think about what I might potentially struggle with*” (G11F, 2022 survey)). Students were not ‘forced’ to complete any of the activities, but this nudge to do something may have been required to bring about a beneficial outcome.

One of the students summarised the perception of the activity very well:

> *“Well it made you reflect which in turn made the lesson more memorable. That helps especially with homework however it seems a bit flawed when you can not engage probably* (sic) *with the exercise. Say for example you are stressed about a test in the next lesson.”* (G12M, 2022 survey)

For some students, this reflection task achieved its goals of encouraging them to reflect on their learning after each lesson, which helped them to consolidate, to link new knowledge with existing knowledge through thinking about what was learnt, and to identify knowledge gaps. It demonstrated to the students the value of reflection, as seen in their comments on the perceived benefit of the activity. Reflecting on learning is part of being actively engaged in learning, which is a characteristic which the ISLE approach strives to develop, and reflecting on learning is also a valued behaviour in a physics knower.

The weakness in the reflection task, however, was the way in which it was integrated into the lesson. The fact that so many students forgot to complete it when not prompted to do so, suggests that the way this activity was structured or implemented did not develop physics knowers who reflect on what they learnt in each lesson. The activity could be redesigned to achieve its objectives without being onerous for students and it needs to become a habit so that it is part of their daily class routine. I expected students to complete the questions at the end of every lesson because I felt that consolidation after every lesson would be most effective in assisting cumulative knowledge building (Maton, 2014) and in identifying problems early. However, if similar reflection tasks were administered weekly (Etkina, 2000) they would be less onerous and repetitive. A student comment on the activity was, "*I felt like I was saying the same thing every time and I didn't have any valuable comments to make."* (G11F, 2022 survey)

Alternatively, a new activity needs to be developed that encourages regular reflection and consolidation. Buggé and Etkina (2016) included space for students to reflect on their experimental write-ups. I plan to include a block for specific reflection in the workbook at the end of each section to encourage reflection on learning. This could include a summary of the concept or a space for a mind map to which students add concepts after each lesson, building up a knowledge structure over time. This is mentioned as a recommendation for future implementation of the ISLE approach in our context in Chapter 8. If students reflect regularly, the process of reflecting on learning may become routine. The pre-test (described in Chapter 5, Section 5.3.2, Activity XV) also attempts to develop this habit.

An unexpected finding was that a few students commented on the information that teachers could gain from these reflections. One said that the reflection task would only be beneficial if teachers read each one, and another said, "*I think it's beneficial because it is giving our teachers an insight on how we learn and what works for us and what doesn't*" (G11F, 2022 survey). If teachers are going to use student reflections to inform their teaching, as these students suggest, teachers would need access to student reflections and so reflecting in their books would not easily facilitate this. In planning how students reflect, teachers need to be clear on the desired outcome(s) of the reflection task and make decisions accordingly.

### *7.1.11 Student experience of re-tests (2022)*

As described in Chapter 5, Section 5.3.2, Activity XIII, re-tests were introduced because the ISLE approach strongly supports the philosophy of multiple opportunities for the assessment of understanding (Brookes, Etkina and Planinšič, 2020). All students (Grade 9 to Grade 12) were given the opportunity in 2022 to apply to write a retake test on each section of work that was assessed.

**Table 7.6:** Number of students in 2022 who responded in the survey that they had applied to rewrite their tests or did not apply to rewrite their tests (*n* = 146; F = 74 and M = 72).

| | **Did not apply to rewrite** | | **Applied to rewrite** | |
|---|---|---|---|---|
| | **Female** | **Male** | **Female** | **Male** |
| **Grade 9** | | 8 | | 8 |
| **Grade 10** | 7 | 6 | 18 | 11 |
| **Grade 11** | 23 | 12 | 11 | 7 |
| **Grade 12** | 5 | 17 | 13 | 2 |
| **TOTAL** | **35** | **43** | **42** | **28** |

Not all students who applied to rewrite actually wrote the re-test, as their application to rewrite had to be accepted. Those whose applications were not accepted had the chance to improve their application and resubmit to be allowed to rewrite, but the reality was that most students submitted their application just in time to meet the deadline and so there was no opportunity to resubmit an unsuccessful application. One of the main reasons that applications were unsuccessful was that students were required to submit their original test so that we could match their corrections and reflections to their incorrect answers. Many students were not able to submit their tests as they had misplaced them. This would limit the learning potential of the activity, as they would not be able to refer back to their original test. Applications where the reflection was not on specific concepts (e.g. 'I should have studied harder') were also unsuccessful, as were those where there was no reflection. Although not all ISLE practitioners require an application for students to rewrite, we followed the approach implemented by Blackman (2022), which required students to submit an application to rewrite, showing reflection (see Activity XIII in Section 5.3.2).

81% of those who applied for a rewrite saw benefit in the process and 9% saw no benefit. The comments on the benefits of the process were diverse, while those who said there was little benefit, usually cited the onerous application process as the reason that they did not benefit from the rewrite. In this section, I will summarise the students' experience of re-tests, discussing first the perceived benefits of the re-test process, before mentioning the shortcomings of re-tests.

In the questions about the rewrite opportunity in the survey on learning, 35 of the students who applied to rewrite (F = 20 and M = 15) identified learning from their mistakes as an outcome of the rewrite application process, while 31 students (F = 19; M = 12) said that it offered them the opportunity to improve their understanding of the topic: "*just going over what you got wrong and weren't sure of, helps to fully understand the concept*" (G9M, 2022 survey).

A few students said that the process ‘forced’ them to engage with the topic and that this helped them to improve their understanding:

> *“it forced me to sit with the questions I got wrong instead of ignoring them and in the past i (sic) used to never try to figure out why I made mistakes in tests, which would lead me to making similar errors in exams”* (G12F, 2022 survey).

This student has actively engaged, which they did not do previously, and their grappling (‘*try to figure out*’) may improve their understanding.

Another acknowledged that writing down the mistakes, helped:

> *“I think the reflection process is helpful because when I put down on paper what I did wrong and why I went wrong it helps me to not make the same mistakes agin (sic)”* (G11M, 2022 survey).

There were students who saw benefit in the process of reflection and engagement that the application to rewrite provided, saying it …

> *“was very helpful!! the reflection process was really good and I really understood where I went wrong and how to improve it whereas if I didn't reapply I wouldn't have gone into that much depth and really gone through my mistakes”* (G11F, 2022 survey).

And

> *“I liked how you send out the thing and you had to apply for the re-test. I found that really useful. And I think that instead of actually doing a re-test next, if I had another chance, I’d rather just do the application just because I found that very, like, useful.”* (G12F, 2022 interview)

One of the responses flagged the need for *active* engagement from the student to benefit from the process of the re-test application, saying, “*the actually* (sic) *reflection on why I might have got things wrong didn't help me, but having to rewrite and correct my mistakes was helpful*” (G11M, 2022 survey).

It also seems that the way students engaged with the re-test application determined the benefit that they derived from it. Some used the process to learn (*"I find that I learn for the rewrite while doing the application form*" (G10F, 2022 survey)), while others who took short cuts in the process, such as copying from friends, saw less benefit: "*It was good, except when we write our correct answers it's mostly us going to ask someone who go (sic) it right how to do it*" (G12F, 2022 survey).

This suggests that the process of applying for the rewrite and preparing for another test on the same work, may only have been beneficial to those who actively engaged with their mistakes and grappled with the concepts that they had not been able to apply correctly in their original test, to improve their understanding of these concepts.

Just two students (both female) said that the application and test reflection process improved their confidence. However, 44 students (F = 25; M = 19) said that knowing that there would be a re-test opportunity had a positive effect on the way that they felt during the test. As assessment is a stressful situation and high stress can reduce optimal performance, reducing this stress was an additional benefit: "*There was less pressure so I'm* (sic) *the end I answered better*" (G11M, 2022 survey) and

> *"I would feel less stressed if I knew I could possibly have a second chance if I knew I hadn't worked hard enough, I generally stress a lot in tests and I'm not able to think properly and clearly." (G12F, 2022 survey)*

There was an acknowledgement that sometimes the test does not go well and the re-test mitigated against this:

> *"The rewrite is just a good opportunity to improve a mark if you had a good understanding of the work but your original testing did not reflect that. It does not make one study any more or any less knowing there's a rewrite chance." (G11F, 2022 survey)*

82 students (F = 40; M = 42) said that the re-test opportunity had no effect on their feelings during the test. One student's comment was, "*Still was stressed,*

*rewrite just gives the opportunity to correct mistakes*" (G12F, 2022 survey). Some said that they did not know that there would be a re-test, while others said that they were not sure whether they would be able to make the re-test opportunity and so did not want to risk not doing their best in the original test. One of the students expressed an unexpectedly negative experience of the process:

> *"When you get a lot of things wrong it is a very long and extremely frustrating* (sic) *see all the things you did not get right especially when you were confident about the test and studied and practiced* (sic) *hard for it."* (G10F, 2022 survey)

Another student's well-being was negatively affected by the re-test application process, saying, "*The process is quite a long one and quite strenuous when one is already feeling down about having to redo the test*." (G10F, 2022 survey)

A more common sentiment against re-tests was that the process of a 'second chance' was unfair. One of the Grade 9 students explained why he had not applied to rewrite: "*Because I was satisfied with my mark but also don't think rewrites are fair if you didn't do well in the test that is your own fault for not seeking help or studying enough*" (G9M, 2022 survey) and a Grade 11 girl expressed rather philosophically:

> *"I don't feel as if I should rely on a rewrite, I feel that i* (sic) *should ensure that I do well in the first paper so that I am satisfied with my mark, we won't get rewrites in life so I always work hard towards the first test and that is what I get"* (G11F, 2022 survey).

This stoic perspective was not uncommon. A Grade 11 student said that knowing that there would be a re-test had a negative effect on how she felt during the original tests, saying, "*I felt frustrated that I had studied hard for the test, yet I had conversations with girls who told me that they didn't study or care because they knew there would be a rewrite*" (G11F, 2022 survey). This student was interviewed, elaborating that it would be a fairer process if rewrites were offered in other subjects:

> *"There was one thing though, which has kind of bothered me is, is that we have physics rewrites, but we don't have rewrites, for any other subjects. And I don't really understand that. Because it's like girls are failing maths and girls are failing chemistry - lots of subjects - but it's only in physics, are you allowed to, like improve your work, which is hard if you're somebody who does well in physics, but not in chemistry, and they are part of the same subject so you kind of it's like, yeah, it's like if that's your you're good at that, and they're good, you know…" (G11F, 2022 interview).*

She also said that in the boarding houses, where the majority of the girls study, there is an attitude that girls can get away with not studying as they can write the re-test. This did not come through in the survey responses to the question of whether they prepared differently for the assessment, knowing that there would be a re-test. The majority of students said that the onerous rewrite application process, learning for another test and the time to rewrite, motivated them to study properly for the first test. This student suggested that weighting both tests, rather than allowing the re-test mark to replace the original mark might help restore the appropriate work ethic and attitude to the assessments.

The same student mentioned in the interview that the tests are very similar and so the re-tests present an unfair advantage to those writing, as they have seen a similar test. This perception seems to be shared by the Grade 10 student who offered this response in the survey, which suggests that the test and re-test are perceived to be similar, while these may differ from past papers on the same section:

> *"because sometimes the tests are completely different from the past papers and it is something I have never seen before. Knowing there is a rewrite makes me a bit more calm because it tells me that I can get a second chance to improve my mark since I now know the format it will come in." (G10F, 2022 survey)*

This student's comment raises two concerns about their mindset about learning and their view of physics problems. They appear to be studying to succeed in the test ('c*hance to improve my mark since I now know the format*'), rather than adopting a learning-orientated mindset and studying for understanding. The purpose of introducing re-tests was to improve student learning and understanding, and not only to offer students a chance in improve their performance. The students' emphasis on performance goals alone was in conflict with our intended goal, resulting in a code clash.

The Grade 10 student also appeared not to see the underlying physics across problems, as the tests appear to them to be '*completely different from the past papers and it is something I have never seen before*'. This suggests that they are looking at the surface features of the problems, rather than at the physics, making it difficult to transfer their knowledge from one context to another.

The process of the re-tests was not popular, and the comment was made by a Grade 10 boy that he does not …

> *"… think we should have to do the rewrite reflection as I think it's more beneficial for kids to just show up and write their name on a list saying they rewrote it doesn't have to be this complicated unless you are really trying to weed out people that are just going to waste your time".*
> (G10M, 2022 survey)

He misunderstood the purpose of the application process, which was certainly not 'to weed out' students, but was rather intended to assist students in addressing previous problems and to look for the physics concepts in the problems that they answered incorrectly. Another student commented on the re-test application process that, "*it was very long, and there were vague guidelines with not much help on the concept of where I went wrong*" (G10F, 2022 survey). Both these comments suggest that not all students were aware of the rationale behind the reflection process and the potential benefit of working through errors (and asking for help where required). One of the students suggested that the re-test application should be simplified:

> *"Not to make a whole page for each individually incorrect question, rather give back the original paper and make the corrections on that paper and make notes on where you went wrong and how you fixed it" (G11M, 2022 survey).*

The perception that the rewrite application was onerous served as motivation to prepare thoroughly for the first test ("*It didn't change how I studied for the first one as I would rather not have waisted* (sic) *more time to write a rewrite, I would've rather done well in the first one*" (G9M, 2022 survey)). The number of students who applied to rewrite generally declined after the first re-test in each grade, as seen in Table 7.7. Perhaps this was because students were put off by the onerous application process. However, many Grade 10s opted to apply to rewrite the test on basic electric circuits (Test 4), which was not the first test that they had written which allowed rewrites.

**Table 7.7:** Number of students who rewrote each test in 2022.*

| | **Grade 10 (n = 48) (F = 20; M = 28)** | | | **Grade 11 (n = 55) (F = 29; M = 26)** | | | **Grade 12 (n = 44) (F = 21; M = 23)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | F | M | All | F | M | All | F | M | All |
| Test 1 | 2 | 6 | 8 # | 9 | 0 | 9 | 13 | 2 | 15 |
| Test 2 | 10 | 13 | 23 | 6 | 6 | 12 | 2 | 1 | 3 |
| Test 3 | 4 | 10 | 14 | 1 | 2 | 3 | 3 | 0 | 3 |
| Test 4 | 11 | 9 | 20 | | | | | | |
| TOTAL | 27 | 38 | 65 | 16 | 8 | 24 | 18 | 3 | 21 |
| By grade | 65 | | | 24 | | | 21 | | |
| ALL | 110 | | | | | | | | |

*In some cases, a student was absent for the first test and wrote the rewrite as an alternative. I did not include these students in the rewrite numbers.
# The first re-test for the Grade 10 group was the trial run of re-tests and so only a few students took the opportunity to reapply as it was not as well publicised as the others.

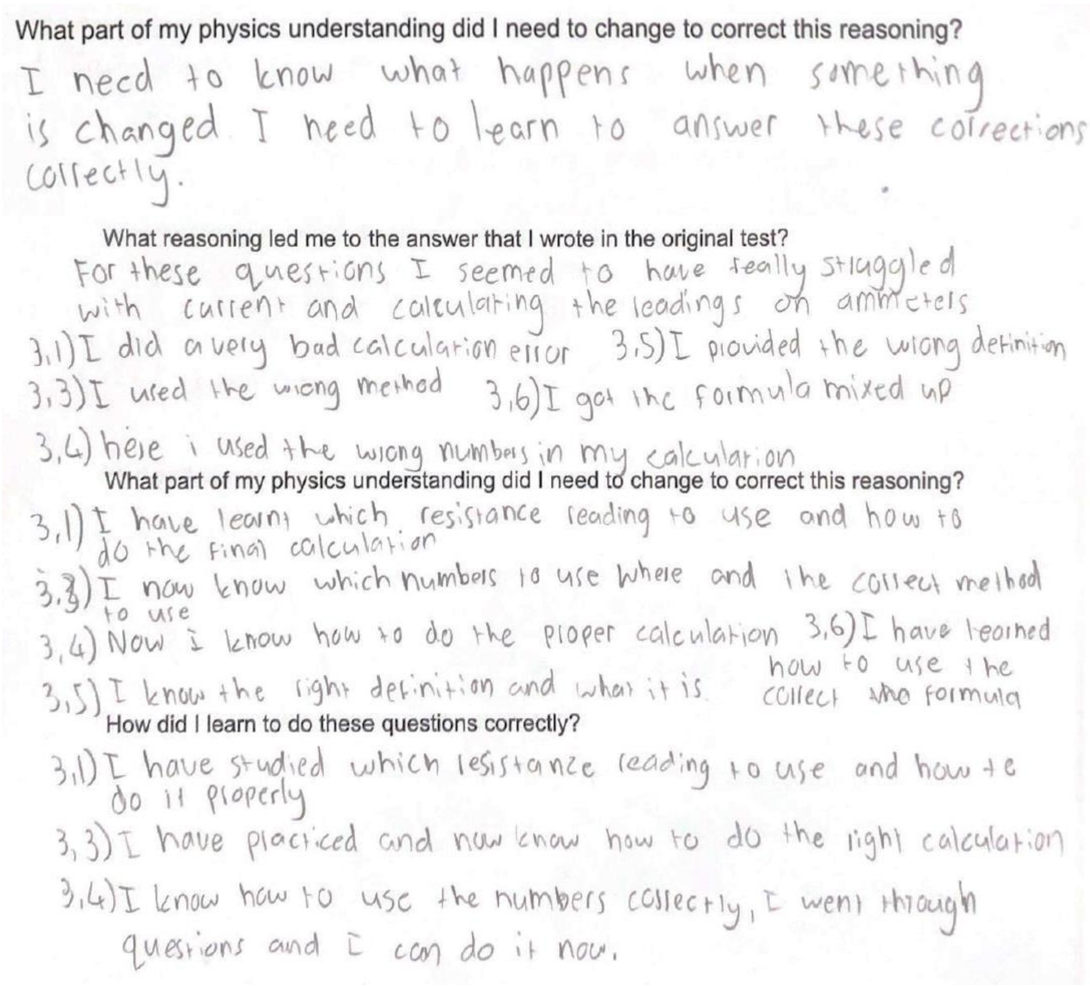
Out of the 110 rewrites, most of the marks improved, except for 23 (of which 3 stayed the same and 4 went down by only 1 mark). In Test 4, the last test for the Grade 10s for the year, 4 girls' marks and 5 boys' marks for the rewrites were lower than for the initial test.

A Grade 10 student was hoping for more teacher engagement in the process of addressing what went wrong. She suggested that, "*maybe the teacher will offer an extra class to all rewrite applicants to see if anything major is wrong conceptually*" (G10F, 2022 survey). Another student (also a Grade 10 girl) also suggested that we *"[h]ave extra lessons just for the people who are rewriting to make sure they understand*" (G10F, 2022 survey), suggesting that she did not believe that she could learn physics independently. This is not an unusual finding as students have been found to rely on the teacher to guide them to correct answers and teach them (Hammer and Elby, 2003). However, both of these Grade 10 students mentioned concepts and so they were looking for improved understanding (learning), rather than just seeking to improve their results (performance).

The re-test process was intended to encourage students to grapple with their understanding of a concept and so concepts were not retaught. Often students look for short cuts in learning, whereas there is much learning that happens in grappling. Another Grade 10 girl acknowledged this benefit: "…*i* (sic) *believe it does improve original understanding as it makes you focus on your mistakes and unpack them yourself and in that comes great learning.*" (G10F, 2022 survey)

One of the aims of the ISLE-inspired activities was to encourage students to grapple with concepts and with the process of learning. When students want to be guided and 'rescued' from the discomfort of having to grapple with a concept, this represents a code clash between our intended outcomes for the activity and their expectations of the activity (see Chapter 4, Section 4.3).

Student A's reflection is shown in Figure 7.16, and she improved her mark from 40% in the initial test to 49% in the re-test. Interestingly, this student commented that she needs '*to learn to answer these … correctly'*. She also wrote that she '*learnt which resistance reading to use and how to do the final calculation*' and that she now '*knows which numbers to use where and the correct method to use*'.


What part of my physics understanding did I need to change to correct this reasoning?

I need to know what happens when something is changed. I need to learn to answer these corrections correctly.

What reasoning led me to the answer that I wrote in the original test?

For these questions I seemed to have really struggled with current and calculating the readings on ammeters

3,1) I did a very bad calculation error 3,5) I provided the wrong definition

3,3) I used the wrong method 3,6) I got the formula mixed up

3,4) here i used the wrong numbers in my calculation

What part of my physics understanding did I need to change to correct this reasoning?

3,1) I have learnt which resistance reading to use and how to do the final calculation

3,3) I now know which numbers to use where and the correct method to use

3,4) Now i know how to do the proper calculation 3,6) I have learned how to use the correct the formula

3,5) I know the right definition and what it is

How did I learn to do these questions correctly?

3,1) I have studied which resistanze reading to use and how to do it properly

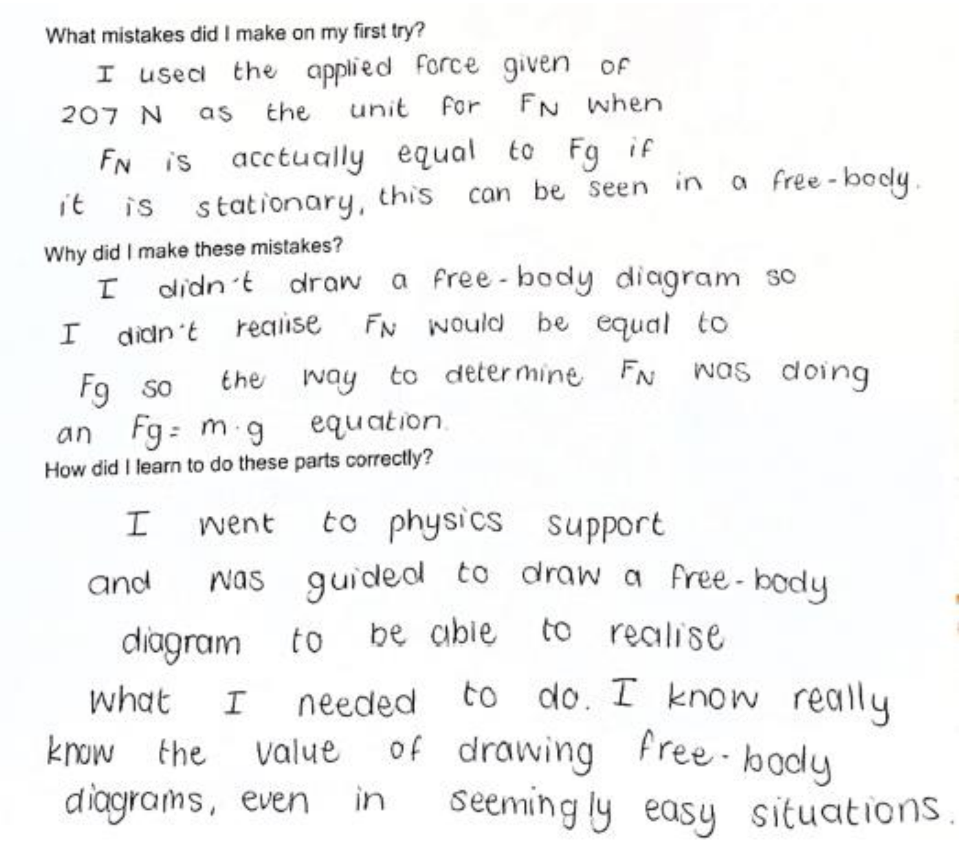
3,3) I have practiced and now know how to do the right calculation

3,4) I know how to use the numbers correctly, I went through questions and I can do it now.

**Figure 7.16:** Reflection for re-test application by a female Grade 10 Student A.

Student A's reflections suggest that she is trying to learn how to answer a question, rather than understanding the physics principles behind the question. The aim of the activity, with reflections over and above doing corrections, was to emphasize the underlying physics so that students could understand the concept in order to apply it in new contexts. While Student A reflected extensively, she did not quite achieve the learning goals that the activity intended.

Student B (Figure 7.17) reflected on the mistakes that she made and also speculated as to why she made the mistake, saying that she should have drawn a free-body diagram and realising the importance of this in the process of the reflection. She improved her mark from 69% in the initial test to 76% in the re-test.



What mistakes did I make on my first try?

I used the applied force given of 207 N as the unit for $F_N$ when $F_N$ is acctually equal to $F_g$ if it is stationary, this can be seen in a free-body.

Why did I make these mistakes?

I didn't draw a free-body diagram so I didn't realise $F_N$ would be equal to $F_g$ so the way to determine $F_N$ was doing an $F_g = m \cdot g$ equation.

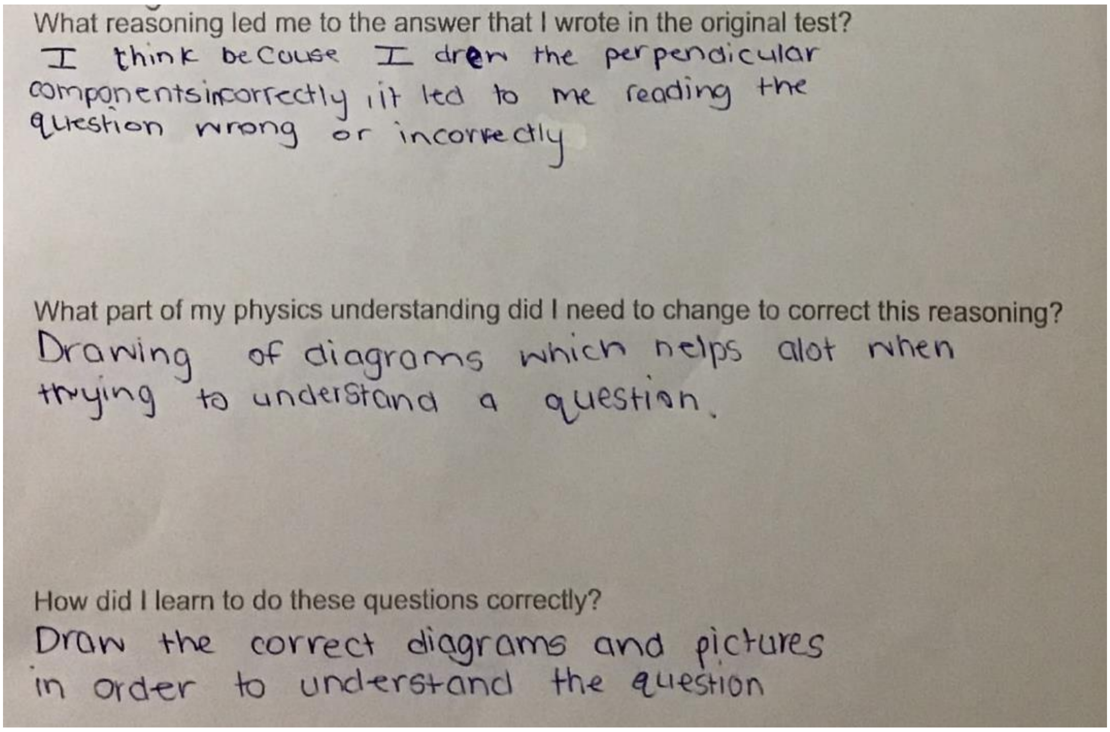
How did I learn to do these parts correctly?

I went to physics support and was guided to draw a free-body diagram to be able to realise what I needed to do. I know really know the value of drawing free-body diagrams, even in seemingly easy situations.

**Figure 7.17:** Reflection for re-test application by a female G11, Student B.

Student B wrote that she was ‘guided to draw a free-body diagram’, which suggests that she was helped at physics support, but still expected to actively engage and think about what she was doing. She emphasized the importance of drawing diagrams in the discussion in the focus group when she was in Grade 12 as well. Using representations is valued by the ISLE approach and is also one of the valued behaviours that we sought to encourage and develop.

Student C, whose reflection is shown in Figure 7.18, also learnt the importance of drawing diagrams through reflection. Her mark improved from 56% in the initial test to 73% in the re-test. This was an application to rewrite in Grade 10 and in Grade 11 this same student drew diagrams to help her solve problems on every test and pre-test, even when not prompted to do so. Not only has she learnt the importance of drawing diagrams, but she has transferred the knowledge to other contexts (tests and pre-tests).

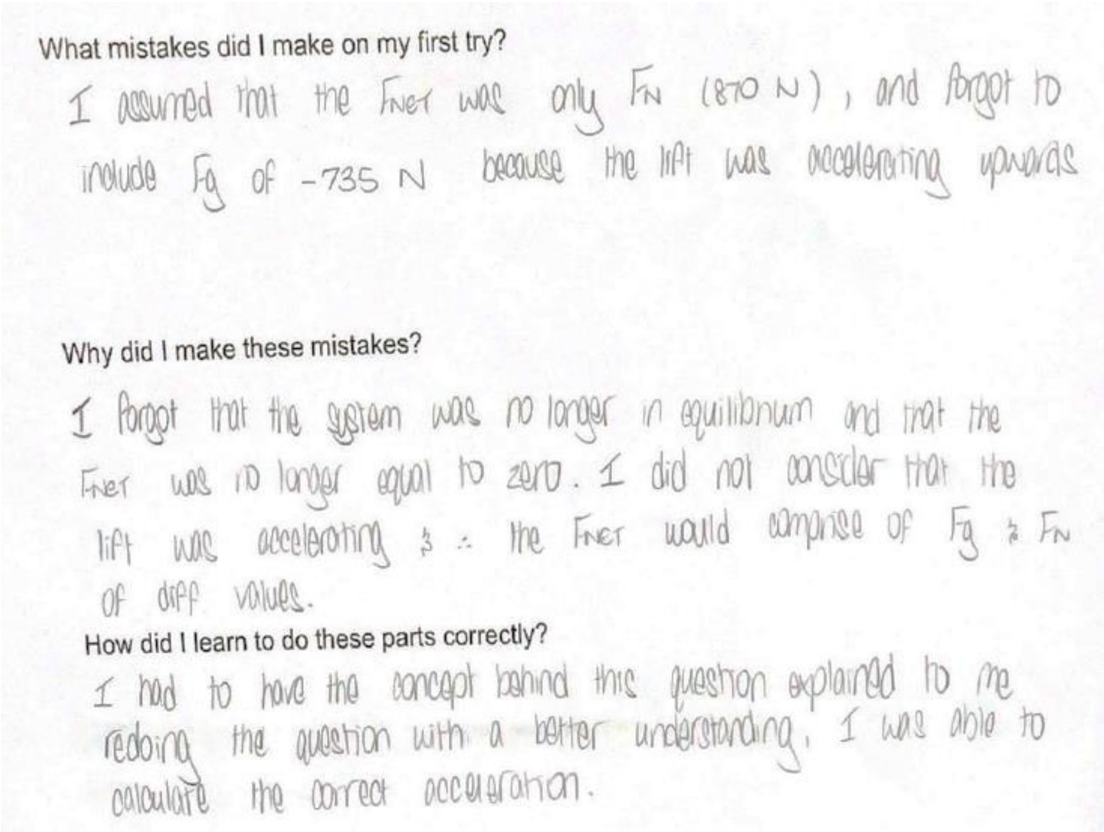

What reasoning led me to the answer that I wrote in the original test?
I think becouse I drew the perpendicular componentsincorrectly ,it led to me reading the question wrong or incorrectly

What part of my physics understanding did I need to change to correct this reasoning?
Drawing of diagrams which helps alot when trying to understand a question.

How did I learn to do these questions correctly?
Draw the correct diagrams and pictures in order to understand the question

**Figure 7.18:** Reflection for re-test application by a female Grade 10, Student C.

Student D, whose reflection is shown in Figure 7.19, was able to generalise her errors. She improved her mark from 78% in the initial test to 96% in the re-test.



What mistakes did I make on my first try?

I assumed that the $F_{NET}$ was only $F_N$ (870 N), and forgot to include $F_g$ of −735 N because the lift was accelerating upwards

Why did I make these mistakes?

I forgot that the system was no longer in equilibrium and that the $F_{NET}$ was no longer equal to zero. I did not consider that the lift was accelerating & ∴ the $F_{NET}$ would comprise of $F_g$ & $F_N$ of diff values.

How did I learn to do these parts correctly?

I had to have the concept behind this question explained to me redoing the question with a better understanding, I was able to calculate the correct acceleration.

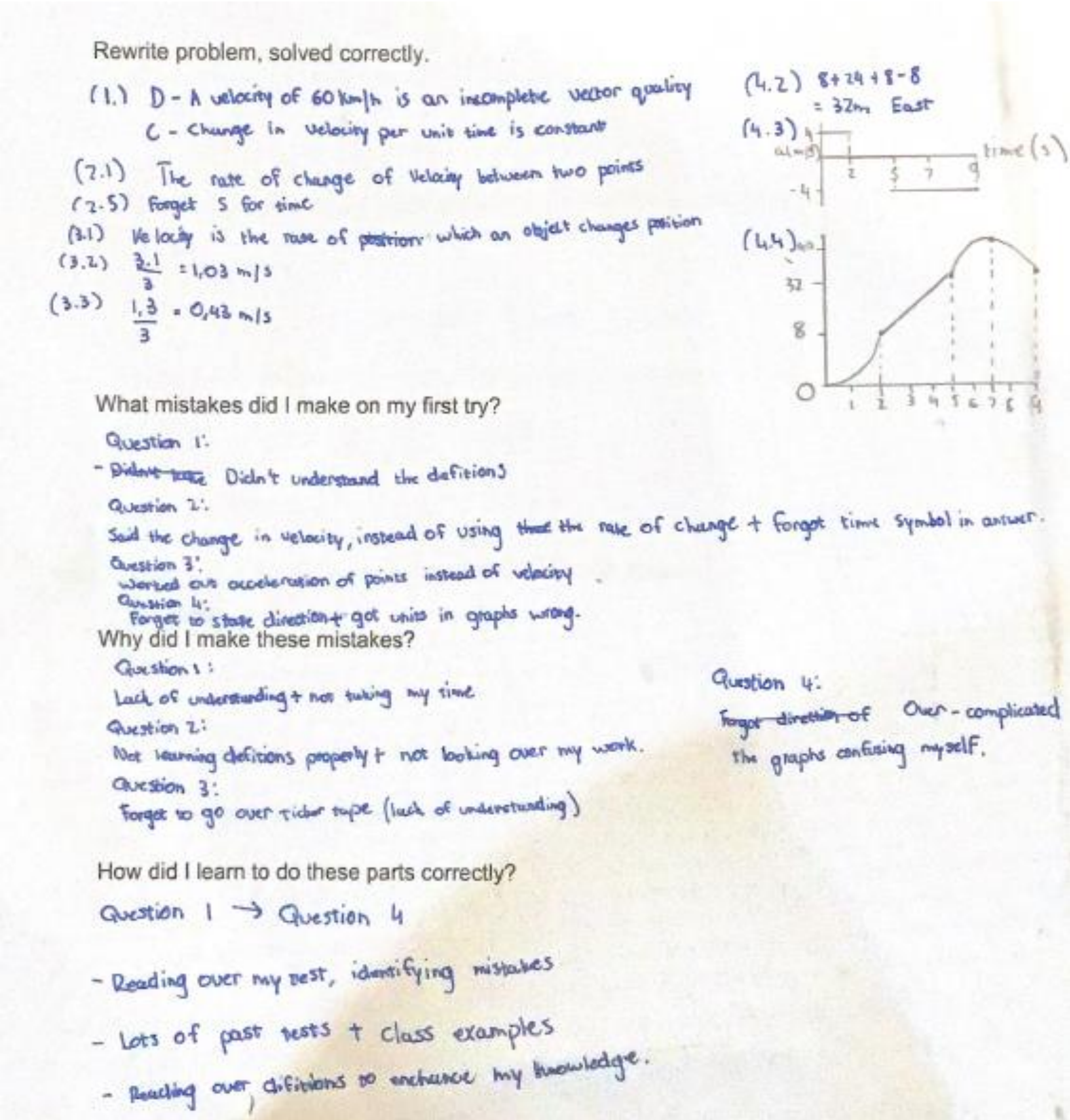
**Figure 7.19:** Reflection for re-test application by a female G11, Student D.

Student D mentions having 'the concept behind this question explained' to her, which is a very passive approach to learning. However, developing understanding is important to her, as illustrated in her comment on re-tests in the 2022 survey was that,

> *"It's* (sic) *was good because it makes one sit down and take into account all the mistakes you made. It also forces you to truly understand where you went wrong and after that process it is difficult to forget about that mistake which helps us not make it ever again".*

This quote emphasises how deep engagement with effort brings about lasting conceptual change.

The usually high-achieving Student E, whose reflection is shown in Figure 7.20, was able to do well in the re-test (91%), having made errors in the initial test (73%) that he could avoid in the re-test, despite fairly superficial reflection on his errors. These were largely procedural errors, rather than conceptual errors, with the exception of ticker-tape calculations, which he needed to revise. This was a ‘second chance’ test, rather than an opportunity to address misconceptions or to improve understanding.


Rewrite problem, solved correctly.

(1.1) D - A velocity of 60 km/h is an incomplete vector quality
C - Change in velocity per unit time is constant

(2.1) The rate of change of velocity between two points
(2.5) Forget S for time
(3.1) Velocity is the rate of ~~position~~ which an object changes position
(3.2) 3,1/3 = 1,03 m/s
(3.3) 1,3/3 = 0,43 m/s

(4.2) 8+24+8-8
= 32m East
(4.3)
(4.4)

What mistakes did I make on my first try?

Question 1:
- ~~Didn't~~ Didn't understand the defitions
Question 2:
Said the change in velocity, instead of using ~~the~~ the rate of change + forgot time symbol in answer.
Question 3:
Worked out acceleration of points instead of velocity
Question 4:
Forgot to state direction + got units in graphs wrong.

Why did I make these mistakes?

Question 1:
Lack of understanding + not taking my time
Question 2:
Not learning defitions properly + not looking over my work.
Question 3:
Forgot to go over ticker tape (lack of understanding)
Question 4:
~~Forgot direction of~~ Over-complicated the graphs confusing myself.

How did I learn to do these parts correctly?

Question 1 → Question 4

- Reading over my test, identifying mistakes
- Lots of past tests + class examples
- Reading over difitions to enchance my knowledge.

**Figure 7.20:** Reflection for re-test application by a male Grade 10 Student E.

The students’ focus on marks rather than on understanding was one of the reasons why we stopped offering re-tests. While this did not come through in the survey responses, a number of students rewrote with a focus on improving their marks, rather than their understanding. While improved performance is an important outcome, the ISLE approach aims to encourage an emphasis on learning goals and improving understanding rather than a focus on marks or performance goals (Yeager and Dweck, 2012; Brookes, Etkina and Planinšič, 2020). There were students who lost just four or five marks out of 45 and rewrote to aim to get full marks.

In the surveys, there were a few responses that indicated students' aim to improve their results: "*you learn from your mistakes and you up your mark from the previous*" (G10F, 2022 survey) and, "*I think that while I might not do well on the first test it definitely helps for me if I can see where I went wrong and how I can improve off that point and better my mark*" (G10M, 2022 survey) .

On the other side of the argument, some students were opposed to the philosophy of rewrites, as has already been described above. One of the Grade 11 students wrote in the survey:

> *"I don't want to have to rely on the 'safety net' of a rewrite because for finals and important exams and test there is no rewrite"* (G11F, 2022 survey).

There were other students who referred to the fact that there was no second chance for the exit examination and this is where our context differs from other contexts in which ISLE has been implemented (Etkina, Brookes and Planinšič, 2019) because we are preparing students for an examination where there is no re-test. This is an important consideration as the exit examination at the end of Grade 12 carries such weight.

At the same time, colleagues teaching other subjects (particularly mathematics and chemistry, where students also often struggle) did not all agree with the process of offering re-tests, particularly when students asked why re-tests were not offered in their subjects. As discussed previously, some students felt that it was unfair that only physics offered a re-test opportunity, particularly if they performed better in physics than in some of their other subjects.

After almost a year of re-tests, we decided to stop offering re-tests. This decision was influenced by a number of factors. Student responses in surveys and interviews indicated that the idea of a rewrite was not inducing good study methods amongst students, with some seeing what was intended as a ‘safety net’ as an excuse: “*It’s a back up* (sic) *plan, if I was tired and didn’t feel like studying I would make myself feel better at the fact that there would be a rewrite*” (G11F, 2022 survey).

In the lead-up to the November 2022 examinations, the Grade 11 group (the Trailblazers) were more anxious than we have known them, and many seemed unable to engage with solutions to identify and correct their errors. We speculated that having had the opportunity for re-tests and now facing an examination with no redo, anxiety might have been greater.

However, we wanted to retain the aspects of re-tests that were beneficial, as well as the positive objectives of take-home tests. Take-home tests (Activity XIV) are described in Section 5.3.2, but were a relatively brief trial and did not feature in the surveys. The aspects of re-tests (and take-home tests) that were beneficial are summarised in Table 7.8.

**Table 7.8:** A summary of the beneficial features of re-tests and take-home tests.

| **Beneficial function of re-test or take-home test** | **Typical response** |
|---|---|
| Provide students with an opportunity to correct misunderstandings and highlight errors so that these can be addressed | "*Good to know and find out where I went wrong and happy to be given the opportunity to fix where I went wrong*" (G12F, 2022 survey) |
| Encourage appropriate approach to test preparation | *"I now know to do past exercises without looking at the memo and to dp* (sic) *more practice than writing notes*" (G12F, 2022 survey) |
| | "*It was really helpful. It forced me to work through my mistakes and understand where I went wrong but it also was a form of studying. When I got a better result in the rewrite, it gave me a confidence boost.*" (G12F, 2022 survey) |
| Encourage active engagement with errors to maximise learning | "*actively reflecting on my original test indeed improved my understanding of physics as it required me to actively dissect each question and each concept until I understood how to get to the answer.*" (G11M, 2022 survey) |
| Learn from mistakes | "*It was very helpful to have to go back and find reasons for my mistakes. It helped me not repeat my mistakes"* (G11F, 2022 survey) |
| Deepen understanding | "*you learn the content twice understanding it on another level"* (G10M, 2022 survey) |
| Encourage grappling and independent approach to improving understanding | "*I think it was very helpful as it encouraged you to look at your mistakes and figure out the correct answers on your own*" (G11F, 2022 survey) |
| Offer students an opportunity to ask questions when they encounter difficulty | "*Yes, it allowed me to ask further questions and understand where I went wrong and why I went wrong.*" (G10M, 2022 survey) |

Interestingly, one of the reasons that we introduced take-home tests was to provide an opportunity to practise typical assessment questions without the anxiety or time pressure of a test situation. However, this did not emerge as a perceived benefit from the data.

Based on the reasons outlined in the section above, I decided to stop offering re-tests and the beneficial aspects of re-tests and take-home tests outlined above were combined into what we called ‘pre-tests’.

#### *7.1.12 Student experience of pre-tests (2023)*

All students were given pre-tests to complete in preparation for their test on a section of work. Although these were not compulsory, nor were students penalised for not submitting their pre-tests, there was a good uptake of the opportunity, and the majority of students submitted their pre-tests. During the period of this study, students were asked to bring their pre-tests with corrections and reflections with them when they came to write the test and hand these in to be scanned for the purpose of this study.

Pre-tests offered students the opportunity to complete a set of questions (a past test) and have their answers marked correct or incorrect. Teachers indicated right and wrong steps and answers, but (ideally) did not make corrections or write a mark on the pre-test as an attempt to shift the emphasis from performance goals to learning goals. Assessing the pre-test offered the teacher the insight to intervene in the case of misconceptions or incorrect approaches.

The important learning process began when the pre-test was returned and students needed to grapple with their incorrect answers to correct them, and reflect on what went wrong to expand their learning beyond that specific context of the given question to improved understanding of the concept. No memorandum was made available for pre-tests, which meant that students needed to take responsibility for finding out how to correct their answers. We expected them to ask questions or seek help, if they were unable to fix their mistakes alone. The pre-tests were completed by the majority of students (even though they were not compulsory) in the lead-up to the test. This meant that that pre-tests benefitted more students than the re-tests, as only those who chose to apply to rewrite did corrections and reflected on their application of concepts for the re-test.

I examined the Grade 10 and Grade 11 pre-tests that were handed in for evaluation (*n* = 132; F = 76; M = 56) to see how many pre-tests showed corrections and how many pre-tests showed evidence of reflection beyond the corrections. As I had access to more Grade 10 than Grade 11 scripts, I have expressed the number of scripts with corrections only, the number of scripts with reflections and the total number of scripts examined for that grade for each gender, as percentages, as shown in Figure 7.21.

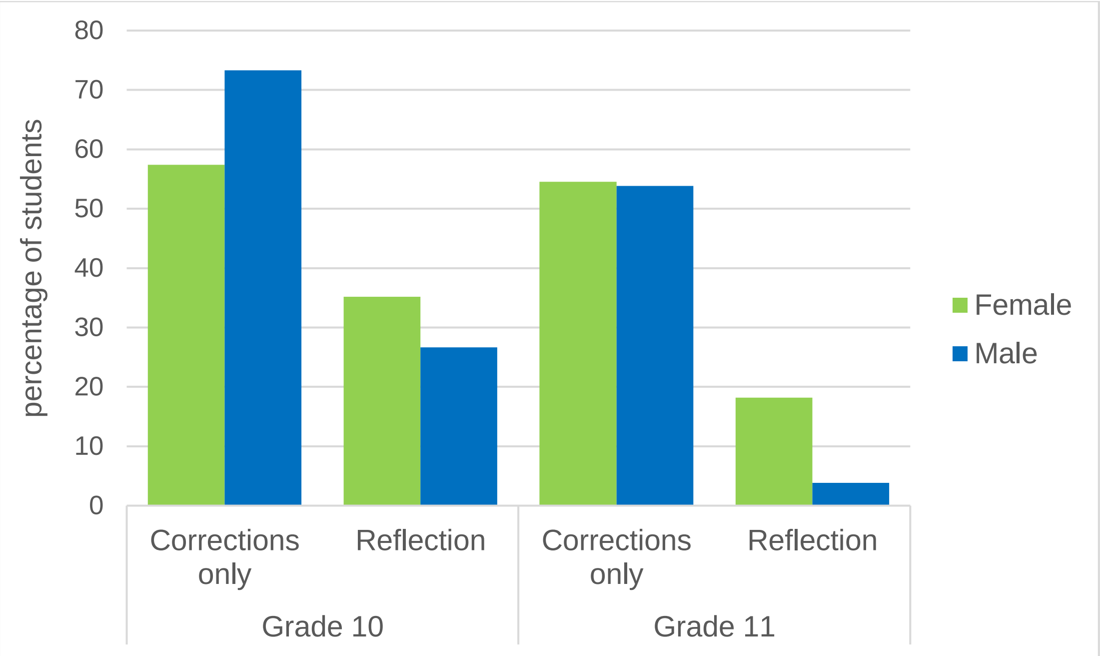



**Figure 7.21:** Proportion of students who showed corrections only or additional reflection on their pre-tests in Grade 10 and Grade 11 (values expressed as a percentage of total number of scripts examined by gender in each grade (*n* = 84 in Grade 10 and *n* = 48 in Grade 11)).

From this graph, it is evident that more female students reflected on their pre-test than the male students. Far more students did only corrections, rather than reflecting on broader physics concepts that they had perhaps misapplied.

Although no mark was written on the pre-test script, teachers recorded the pre-test marks for the purposes of this study. I compared the mark achieved by each student in their pre-test with the mark that they achieved in their actual test (Figure 7.22). In the discussion below, I mention marks and make comparisons based on marks, although, in order to encourage a learning-orientated mindset, I downplayed marks when interacting with the students. Looking at the change in marks from pre-test to actual test is a quantitative means of measuring the extent to which pre-tests affected each student's result. Although mention was made in the Grade 12 2023 focus group of the test on photoelectric effect, it was written just before they left on study leave, and so I was unable to capture their tests to assess engagement.

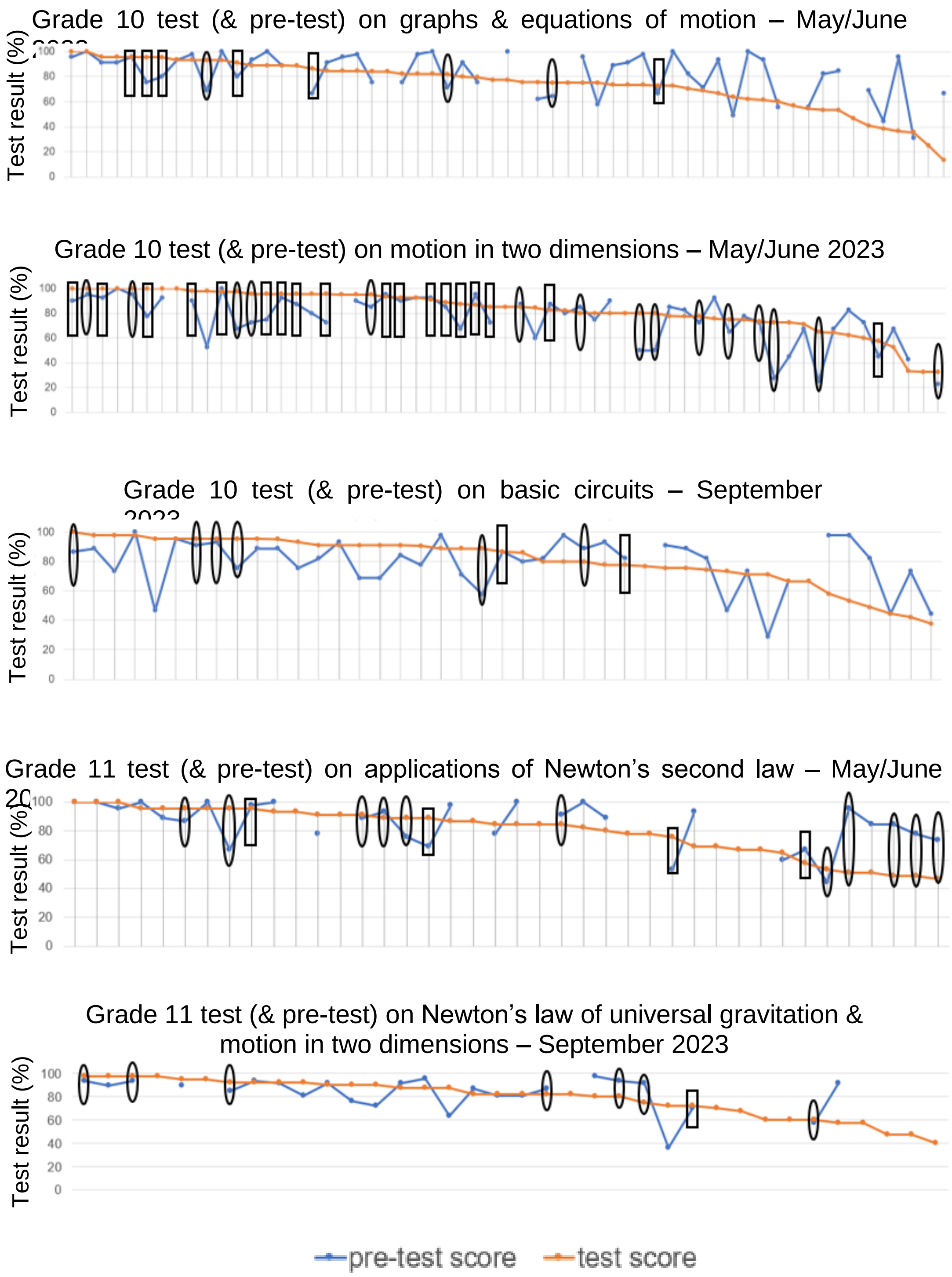



**Figure 7.22:** Graphs showing the comparison between the pre-test score and the score in the actual test for each individual candidate. Ovals show the students who did corrections on their pre-test, while rectangles show those who also reflected on their errors.

The graphs in Figure 7.22 show the scores for the pre-test and actual test for students in Grade 10 (three tests) and in Grade 11 (two tests). The individual students are on the x-axis, but no names are given and, although there is no relationship between each of these students, the data points are joined, to make the graph easier to read.

As the pre-tests were completed as homework, students may have collaborated to complete the pre-test or had help, giving an inflated impression of their understanding of the concept. We compared students' performance in the pre-test and the actual test based on a mark alone and some students may also have made silly mistakes that resulted in a lower mark, rather than an actual misunderstanding. In most cases, students who either only did corrections or who also reflected on their corrections, improved their mark from the pre-test to the test. The quality of the reflections varied, and it was clear that the students would benefit from some modelling of how to reflect in a way that would benefit their learning.

While most of the students who completed the pre-test on this section submitted their pre-tests with corrections, there were some students who submitted identical or very similar pre-tests. There were a number of students who improved their result from the pre-test to the actual test, but there were also many students (particularly those who scored lower marks in the actual test), whose results decreased from the pre-test, suggesting that the way they approached the pre-test did not improve their understanding.

The first motion test written by the Grade 10 group (on graphs and equations of motion) showed a decrease in many of the results from the pre-test to the actual test. As with the Grade 11 test, there were a number of students whose results dropped from the pre-test to the actual test and seemed not to benefit from the pre-test. Despite the decrease in results, students were positive about the benefits of pre-tests in the responses offered in the surveys. This suggests that they have valued the pre-tests for the learning gains they offered, even though they did not always improve performance in the actual test. The higher marks for the pre-test may have been due to the fact that the pre-tests were written without time constraints and with access to notes.

There was a general improvement in student performance between the pre-test and the actual test for the Grade 10 test on motion in two dimensions. The majority of students showed corrections and many also reflected on their learning on the pre-test. Perhaps the students embraced the learning experience more readily because they had a better understanding of the goal of the pretest, having done one before.

The reflection by Student V (Grade 10), shown in Figure 7.23, is an example of a generalisation of knowledge that could be carried to similar problems. This student commented positively on her experience of the pre-tests: "*This pretext* (sic) *benefited my learning and preparation for the test which gave me confidence as I had practiced similar questions and learnt from my mistakes.*" (G10F, 2023 survey) and her extensive reflection may have allowed her to experience these learning gains. She improved from her pre-test to her actual test on graphs and equations of motion (80% to 91%).

Although the position-time graph that had to be drawn in the actual test was simpler, she answered it correctly.

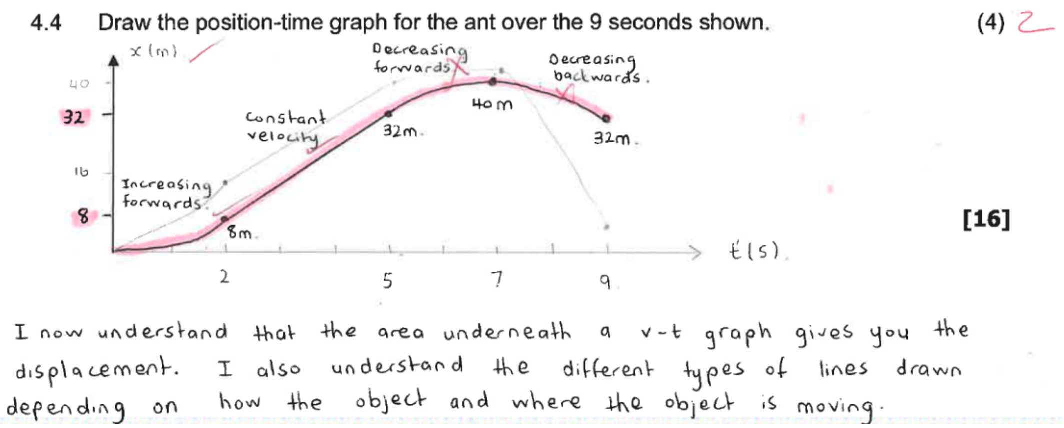



**Figure 7.23:** Correction and reflection shown by Grade 10 Student V on her pre-test.

In Figure 7.24, shown below, Grade 10 Student W reflected on his general errors on motion in two dimensions, but did not correct them. He showed improvement from the pre-test (68%) to the re-test (88%) and so perhaps this flagging of his error was all he needed. He answered a similar question correctly in the actual test.

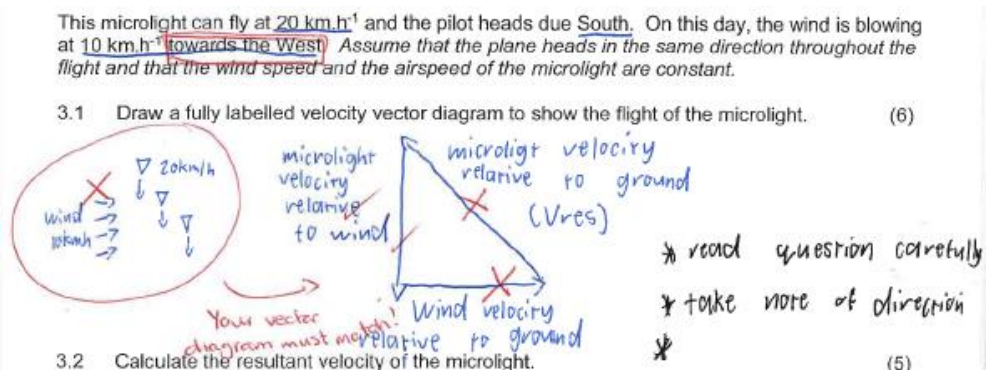



**Figure 7.24:** Reflection shown on a pre-test by Grade 10 Student W who improved from his pre-test to his actual test.

Grade 11 Student X, whose work is shown in Figure 7.25 and Figure 7.26, did corrections and reflections for both her tests and appeared to improve her understanding of the concepts. Despite this, her result went down from the pre-test (67%) to the actual test (58%) on the applications of Newton's second law.

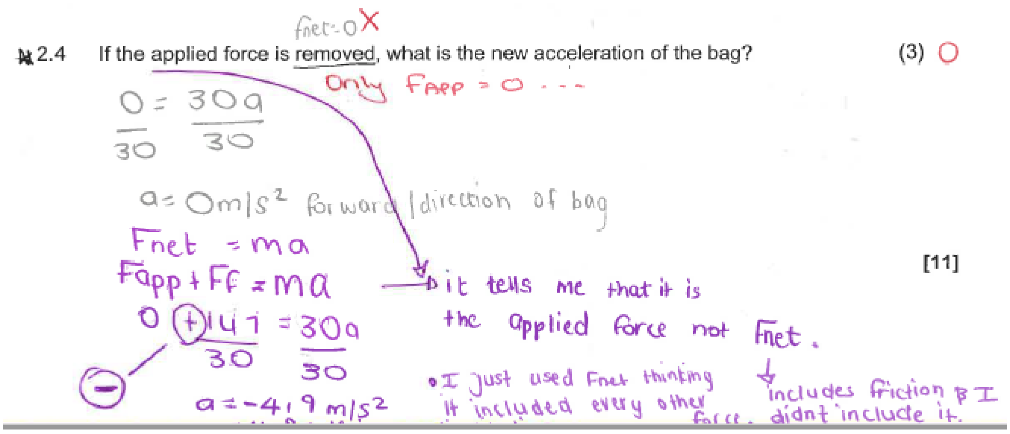
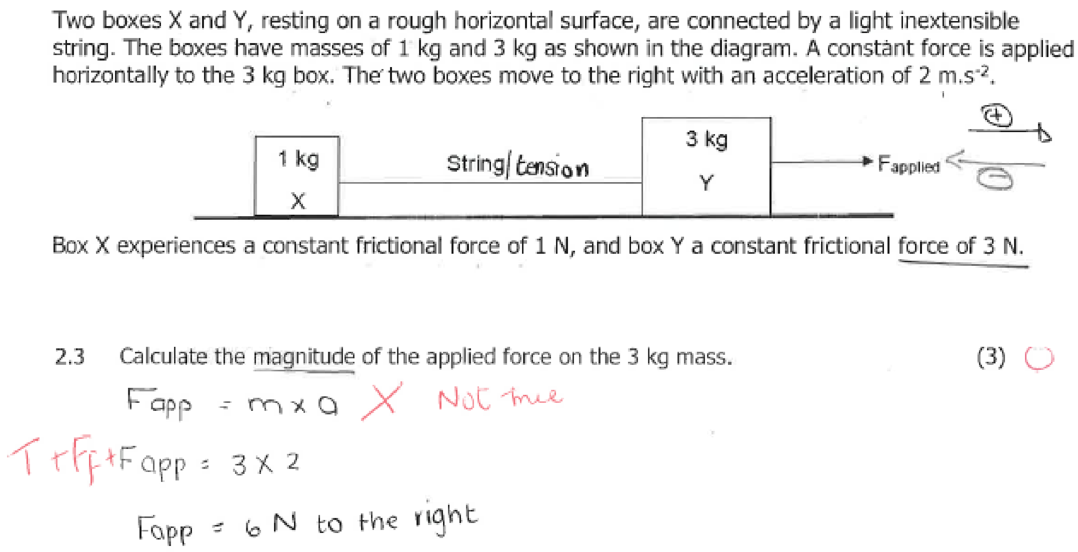



**Figure 7.25:** The correction and reflection in a pre-test shown by Grade 11 Student X.

Unfortunately, she made similar conceptual errors in the actual test on the application of Newton's second law, as shown in Figure 7.26, despite noting them in the pre-test reflection.



Two boxes X and Y, resting on a rough horizontal surface, are connected by a light inextensible string. The boxes have masses of 1 kg and 3 kg as shown in the diagram. A constant force is applied horizontally to the 3 kg box. The two boxes move to the right with an acceleration of 2 m.s$^{-2}$.



Box X experiences a constant frictional force of 1 N, and box Y a constant frictional force of 3 N.

2.3 Calculate the magnitude of the applied force on the 3 kg mass. (3)

Fapp = m x a X Not true

T+Ff+Fapp = 3 X 2

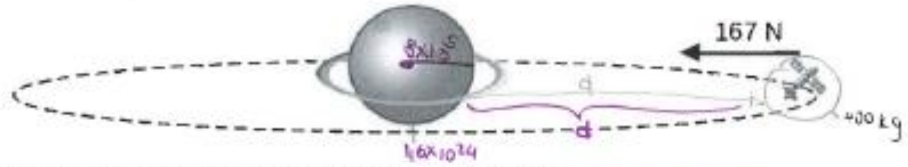
Fapp = 6 N to the right

**Figure 7.26:** A question from the actual test and the answer given by Grade 11 Student X.

Grade 11 Student X's result improved from the pre-test (70%) to the actual test (73%) on forces in two dimensions and Newton's law of universal gravitation. Her corrections and notes on the pre-test are shown in Figure 7.27.

**QUESTION 1 NEWTON'S LAW OF UNIVERSAL GRAVITATION**

A satellite with a mass 400 kg orbits a planet at a distance **d** from the surface of the planet. There is a gravitational force of 167 N acting on the satellite in this position.




The planet has a mass of $1,6 \times 10^{24}$ kg and a radius of $8 \times 10^5$ m.

1.1 Calculate **d**. (5)

1.2 What is the gravitational field strength at the satellite's position? (3)

1.3 At what distance from the surface does the gravitational field strength double? (3)

**11 marks**

.

**QUESTION 4 CLIMBING**

Rebecca (mass 15 kg) climbs up a slide that is at an angle of 20° to the ground. She can climb up due to the friction between her bare feet and the slide only (we will assume that she just uses her hands to balance and we will treat her mass as a point over her feet).

4.1 Draw a free body diagram of the forces acting on Rebecca when she is stationary on the slide, as shown. (3)

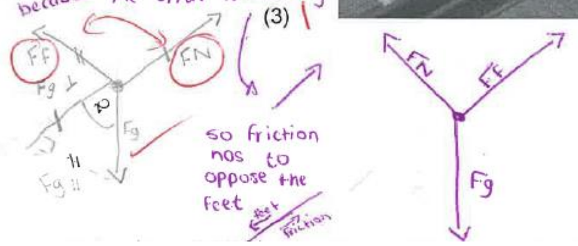


**Figure 7.27:** Extensive correction and reflection on two pre-test questions shown by Grade 11 Student X.

Grade 11 Student X appears to be reflecting in a way that should improve her understanding, but this reflection does not always translate into a substantial improvement. In her actual test on forces in two dimensions and Newton's law of universal gravitation, did not convert the radius (given in km) to metres in the question that was similar to question 1 on the pre-test (Figure 7.27), but she correctly answered a question similar to question 4 on the pre-test, shown in Figure 7.27. She also made other errors, where she had correctly answered a similar question in the pre-test, but made conceptual errors in the actual test. This is the same student who answered in her survey that she has *"the potential to be good at it I just need to learn how to unlock that potential*" (G11F, 2023 survey). It seems that she has yet to unlock that potential, although she is certainly adopting the behaviours that we value: actively engaging, making connections and grappling. These behaviours have yet to help her transfer her concepts to new contexts.

In the pre-tests, most students who reflected, wrote notes next to the questions that they had answered incorrectly, but Grade 11 Student Y, having done her corrections for each question on the test on the applications of Newton's second law, put all her reflections in a summary, written on the back of a Grade 11 pre-test (shown in Figure 7.28).

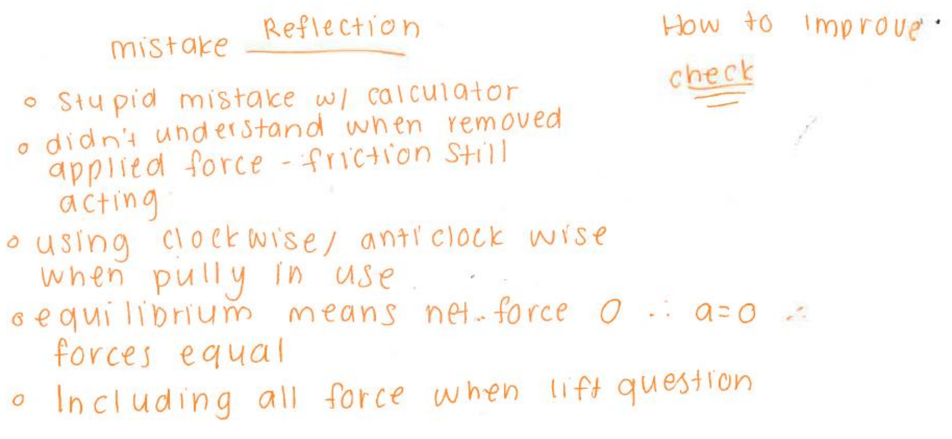



**Figure 7.28:** A summary of pre-test reflections written by Grade 11 Student Y.

Grade 11 Student Y's result improved from her pre-test to her actual test result in both the tests that she wrote. Her notes show abstraction that link the specific question to a general concept.

Grade 11 Student Z's corrections and reflection on her pre-test are shown in Figure 7.29 below. She wrote explanations to herself about concepts that she had misapplied, rather than merely correcting her answers.

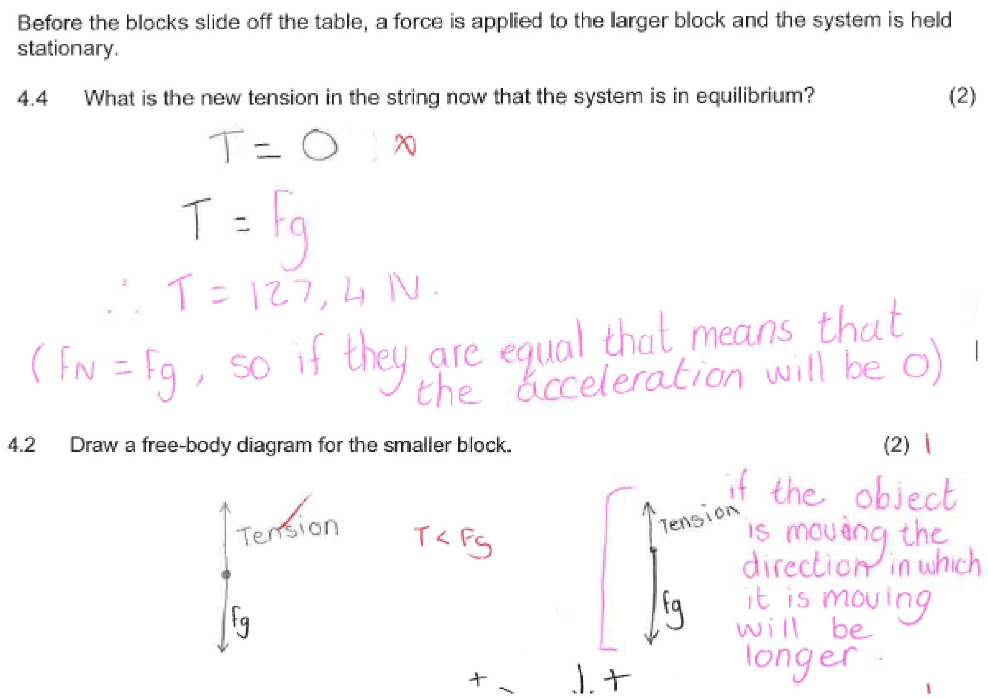
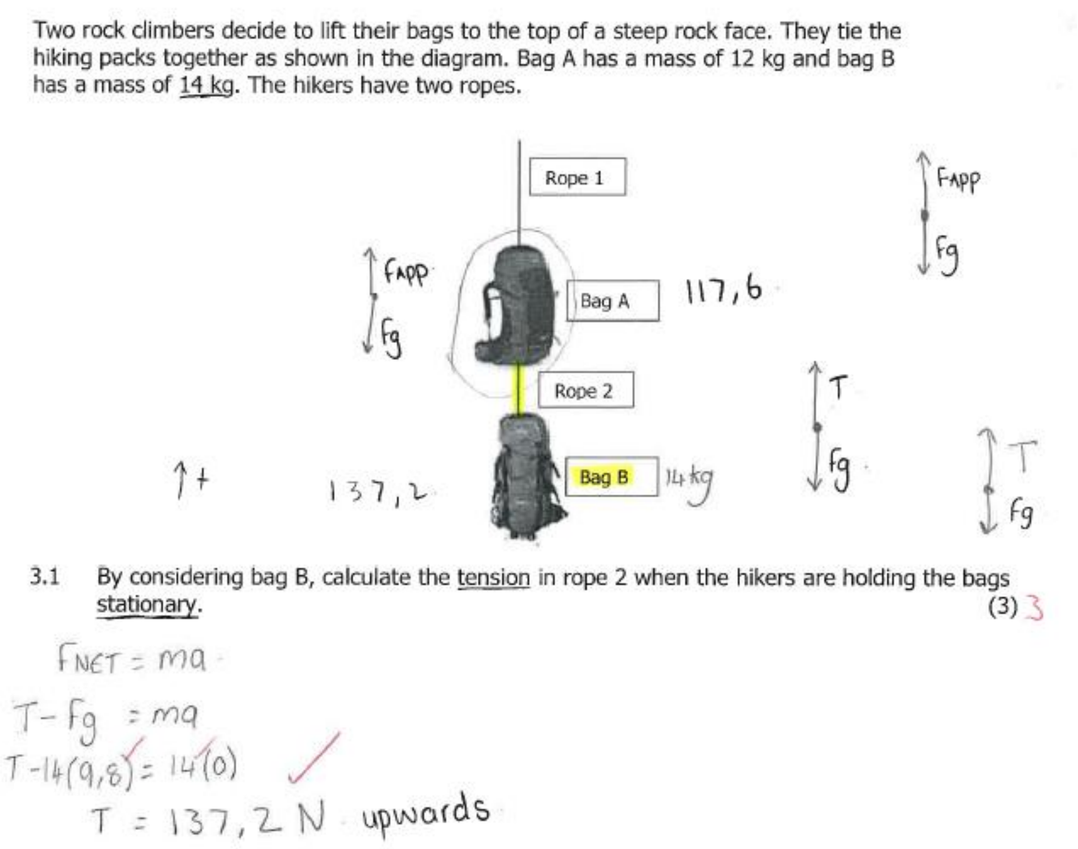



**Figure 7.29:** The corrections and reflection on the pre-test shown by Grade 11 Student Z.

In the actual test, Grade 11 Student Z was able to correctly answer a question similar to the one from the pre-test shown in Figure 7.29, as shown in Figure 7.30. Grade 11 Student Z's result improved from the pre-test (53%) to the actual test (76%) on the applications of Newton's second law. She correctly answered a similar question to the one asked in the pre-test and also used free-body diagrams in thinking about the physics involved, without prompting. Using representations such as free-body diagrams without prompting suggests that she has adopted the behaviour that we value (Maries and Singh, 2017).


Two rock climbers decide to lift their bags to the top of a steep rock face. They tie the hiking packs together as shown in the diagram. Bag A has a mass of 12 kg and bag B has a mass of 14 kg. The hikers have two ropes.



3.1 By considering bag B, calculate the tension in rope 2 when the hikers are holding the bags stationary. (3) 3

FNET = ma
T − Fg = ma
T − 14(9,8) = 14(0)
T = 137,2 N upwards

**Figure 7.30:** Grade 11 Student Z's answer in the actual test.

For the majority of students, doing corrections improved their result from the pre-test to the actual test. However, in the small sample of students who submitted reflections or generalisations, there did not seem to be a marked improvement in their marks, over and above the improvement evidenced by the corrections. Chang and Chou (2011) showed there to be a correlation between the quality of reflection, and learning. Modelling by the teacher and encouraging *effective* reflection may see an increase in the number of students who use reflection to improve their understanding and their learning.

Students who completed at least one pre-test ($n$ = 147; F = 79; M = 68); reported a range of benefits to completing the pre-test. There were a number of perceived benefits that were reported in student surveys, which were coded inductively from the student responses and are represented in Figure 7.31.

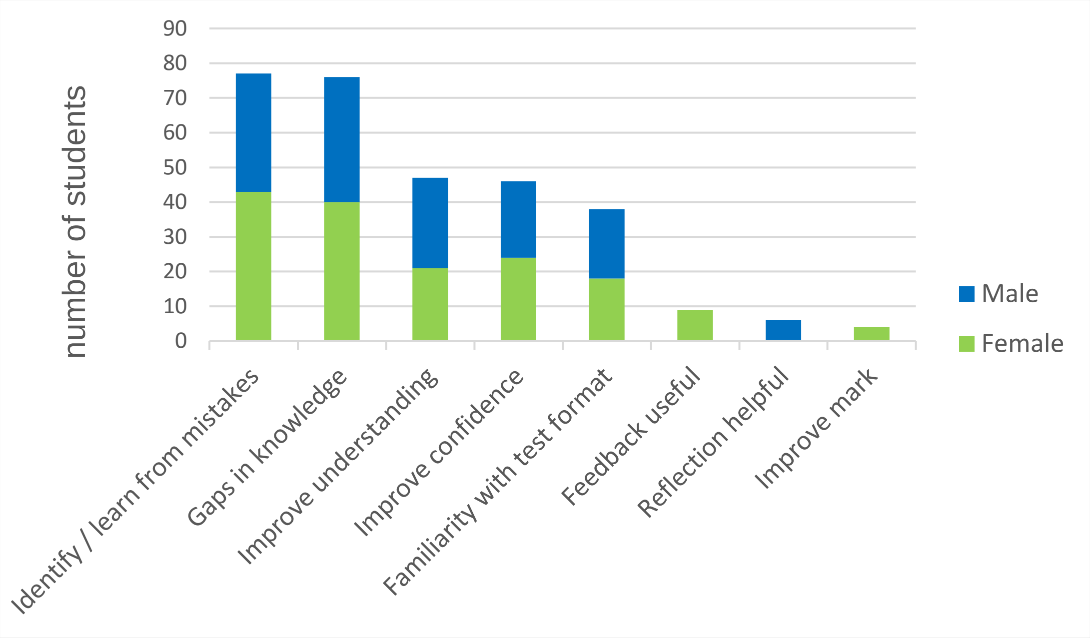



**Figure 7.31:** Student responses in surveys to identify the benefits that they saw in completing a pre-test (*n* = 162, 83 female, 79 male).

Each of these reported benefits is discussed below, by category. I have grouped the first three codes together because they all involve the student working with their pre-test and improving their knowledge and understanding through the process of grappling with the concepts that the pre-test tested, and fixing their initial application of these concepts.

I. Identifying mistakes and gaps in knowledge to improve understanding.

The most commonly mentioned benefits were that the pre-test helped the students to identify and / or learn from their mistakes on the pre-test (*n* = 77, F = 43, M = 34) ("*It helped me see where i* (sic) *went wrong and it helped me to not make the same mistake in the real test*" (G9F, 2023 survey)), as well as identifying gaps in their knowledge of the work (*n* = 76; F = 40; M = 36) ("*It made me realise the things I actually had to work on*" (G9F, 2023 survey)).

Many students said that the pre-test offered an opportunity to improve their understanding of a concept or even fix an incorrect understanding (*n* = 47; F = 21; M = 26): "*It did improve it cause* (sic) *I would find that I understood a concept totally different than what it actually was like the Normal force on a slope which I thought was still upwards but actually was not.*" (G11F, 2023 survey)

One of the Grade 12 girls spoke in the focus group about the pre-test that they had done on photoelectric effect, saying,

> *"I find that so helpful, because when you marked it, you wrote notes for us as well. And that's the first time I really flagged that I didn't know the difference between frequency and threshold frequency. And now I know the difference. … Now, when I was practising, now I know what the difference is. And I don't think I fully would have realized that unless we did the pre-test."* (G12F, 2023 focus group)

This sentiment was shared by a student in their survey response, "*It allows you to see what you need to work on and pick up on mistakes you would not have seen before*" (G11M, 2023 survey). A Grade 11 student commented in the focus group that,

> *"I think … - especially with physics - there's more likelihood of when you don't understand it from the teacher's perspective, and you try and learn it yourself, you can learn it the wrong way. And then you have to unlearn that way and that only usually happens after the test. That's what happened with me this previous test, I think."* (G11M, 2023 focus group)

This same student had written in the survey:

> *"I didn't go over the corrections for my pre-test because I thought there would be better-studying methods in the little time I had considering other subjects that week. However, if I had made*

*corrections on the past test, the process of reflecting on my pre-test improved my understanding because I would have realized where I had gone wrong, and because I had gotten it wrong before, in the test I would have remembered to do it right."* (G11M, 2023 survey)

This student realised the importance of engaging with work to ensure proper understanding before the test. His comment that he has to 'understand it from the teacher's perspective' suggests that the student believes there is more than one perspective of physics, which is a common view held by novices. When students are unable to make connections between concepts or take into account the assumptions that are made, they often believe that certain physics only applies in certain circumstances. This results in a segmented knowledge structure.

The Grade 12 boys' focus group discussed how the use of the correct words and phrases in explanations is so important and often a shortcoming in assessments. One of the students mentioned the importance of using the right words, like a physicist, saying, "*it helps knowing what words to use, like how to explain … what the brightness effects, so it helps you to understand how to answer those questions*" (G12M, 2023 focus group). Another said that the pre-test…

> *"… helps get your wording right, because when you mark it, you see like what you saying is correct, but like the language that you use makes it wrong. … that helps a lot to be able to answer the problem correctly in the correct language so you make sure you get your right point across."* (G12M, 2023 focus group)

As much as the ISLE approach begins by encouraging students to describe their observations without using scientific terms, once these are introduced in the 'time for telling', the language that is used to describe a concept is very important and often nuanced. Students need to be trained or apprenticed to use the appropriate physics language, correctly. Pre-tests offer teachers the opportunity to alert students to incorrect use of language so that they can adjust their phrasing before the summative assessment.

There were students who commented that they saw no benefit to the pre-tests because they did not find them useful:

> *"I think that the pre-tests (if they are made compulsory) could get in the way of learning in a way that works for each student as not all students get the best out of a pre-test when they could be doing other studying that can better their understanding."* (G11M, 2023 survey)

This particular student had said in the focus group that he did not reflect on the pre-test to improve his understanding and then, having written the test, realised that this would have helped him to avoid errors. Others recognised that the pre-tests helped them in some aspects of their preparation, but not all.

A few students indicated that the pre-tests did not actually help them to improve their understanding. One of the students said, "*The presets* (sic) *just helped me work in test conditions but it didn't help me understand things better*" (G10F, 2023 survey), but she did not do corrections on her pre-test and submitted an identical pre-test to two other girls, so she did not make the most of the learning opportunity offered by the pre-test. The pre-test itself would not improve understanding of a concept, but the student's active engagement with the pre-test and their corrections would. This student (and others) perhaps did not realise the way in which they were supposed to approach the exercise and missed out on the learning opportunity. This is an example of how students need to adopt the valued behaviours that we are trying to develop in order to benefit from the activity. We also need to be explicit about the purpose of the task to help them see value in it and adopt the right attitude when they engage with it.

Interestingly, a student told me in a focus group how he did not complete the pre-test (because there was no memorandum ('memo') available, but having looked at the pre-test, he was still better prepared for the test, which was on Newton's law of universal gravitation:

> *"I did like the first page the night before the test. And then I realized that I'm struggling, but there was no memo. So, then I was like, but then I realized that the test was going to be tricky because the pre-test was tricky… Then when I wrote the actual test. I was like my mind was watching out for, make sure the distance is in kilometres, what the radius means like - just the small stuff because I saw I was struggling in the pre-test but I didn't get the memo or anything so I stopped doing it."* (G11M, in 2023 focus group)

Having seen some of the potential pitfalls in the pre-test, he knew what to look out for in the actual test. Again, perhaps if we are more explicit about *why* we do not hand out solutions to the pre-test, students may embrace the activity without the feeling that they *should* be given solutions.

Some students expressed that the pre-tests allowed them the opportunity to see what they knew and what they did not know so that they were able to focus their studies on what they did not know well, rather than needing to study everything with equal focus: "*It highlighted areas I struggled with and gave me an opportunity to focus on.*(sic) *them more*" (G10F, 2023 survey).

One of the Grade 12 students articulated how he used the pre-tests (which he referred to as 'mock tests') not only to identify gaps in his knowledge, but also to see the underlying physics in different problems:

> *"I think it makes studying easier, because you know, what you know and what you don't know, And then also, lots of questions are … quite predictable, in the sense and that you often see the same question just with different numbers and stuff. So, you can easily apply where you made mistakes from the mock test into the normal test. And I think that helped a lot."* (G12M, 2023 focus group)

This idea that the questions are predictable came up in a number of responses and students also stated that the pre-test helped them to know how questions would be asked or 'what the test would look like'. Many of these students missed the point that pre-tests were intended to improve their learning, as they were focused on performance outcomes instead of learning goals. This is discussed in the next section (II, below).

The pre-test offered students the opportunity to improve understanding, be made aware of misplaced understanding, address gaps in knowledge and take stock of what they knew. Previously, when students were offered re-tests, many of them would often only realise these problems after writing the test, as this was the first time that their work was formally assessed, while pre-tests offered students the chance to identify before the test if they truly understood a concept correctly. Pre-tests also gave teachers the opportunity to flag misconceptions among students before the test, which meant that students could fix them before the test.

II. Effect of pre-tests on confidence

Many of the students (*n* = 46; F = 24; M = 22) indicated in the survey that completing the pre-test improved their confidence or made them feel more comfortable in the actual test ("*it made me feel more comfortable and ready to write the actual test.*" (G9F, 2023 survey)), although interestingly this was far more common amongst the responses from Grade 9 (*n* = 20) and Grade 10 (*n* = 17) students.

The students' improved confidence was in some cases attributed to an improved understanding ("*Felt more confident and understanding of different types of questions*" (G10M, 2023 focus group)). The pre-tests also empowered the students to fix their own understanding of the concept, which built confidence: "*I knew what I was getting wrong and could fix that*" (G10M, 2023 survey). Sometimes, just because they had been exposed to a pre-test before writing the actual test, they felt more confident: "*it made me feel more at ease because i* (sic) *knew more or less what to expect*" (G9M, 2023 survey) and, "*It made me feel more prepared and less stressed*" (G9F, 2023 survey).

When asked whether the pre-test changed the way that they felt about the actual test, 83 students (F = 45; M = 38) indicated a positive change in the way they felt ("*definitely ! It made me feel more ready for the test*" (G10F, 2023 survey)), while 34 students (F = 17; M = 17) felt it had no effect on how they felt ("*no it was the same, the questions were never exactly the same."* (G10M, 2023 survey) and "*No I was still anxious about it*" (G10F, 2023 survey)).

Struggling in the pre-test could increase anxiety for the actual test if it did not go well and revealed gaps in their knowledge ("*I was very nervous [in the physics test] as I did really badly in the pre test*" (G10F, 2023 survey)) and this can negatively affect confidence *("it just made me feel bad that i* (sic) *got a bad mark while during the time we could've done and experiment or learned more on that topic*" (G9F, 2023 survey)).

However, the majority of responses certainly suggested that the pre-test activity enhanced confidence and well-being, with students responding that, "*It made me enjoy more*" (G9M, 2023 survey), and, "*it made me believe I could do physics*" (G9F, 2023 survey). Confidence grows as a result of the familiarity that comes through practice:

> *"I think it showed like how much practice can help … it doesn't help like often if you're just teaching, teaching, teaching, and you think you understand, because until you actually practice* (sic) *and doing a lot of practice, like helped you understand and be like, comfortable with what you're doing. So, you're not as nervous for tests."* (G10F, 2023 focus group)

The scheduling of the pre-test encouraged students to start preparing for their test earlier than they normally would do, and also modelled for them how they should prepare. If there were students who were not already actively engaging with past tests in their preparation, they may have been prompted to start earlier.

Analysis of the focus-group discussions highlighted the use of pre-tests as a motivation to study and prepare earlier. However, this theme did not come through in the survey responses, In the focus groups, there were a number of students who shared this sentiment: "*It's a way to get me to start studying earlier, it's also a good indication to myself of what I need to pay more attention to*" (G10F, 2023 focus group) and, "*Like they forced you to learn, maybe earlier than some people would*" (G11F, 2023 focus group). Some students leave studying until the day before the test. However, the pre-test had to be submitted at least 2 physics lessons (2-3 days) before the test to give enough time for the teacher to assess and return to the students. A Grade 10 student was honest in the focus group, telling me, "*I procrastinate a lot. … if we have a pre-test to do and we're forced to have it by a due date, it'll force me to start like studying earlier*" (G10F, 2023 focus group).

Some students were prompted to study harder after their experience of the pre-test: "*I realized I needed some more preparation after struggling with the pre test*" (G10F, 2023 survey) and, "*I felf* (sic) *like I needed to study way more because I felf* (sic) *unprepared*" (G9M, 2023 survey). The pre-test motivated some students to improve: "i *(sic) did bad* (sic) *in the pre-test so I wanted to do better ion* (sic) *the actual test*" (G9F, 2023 survey).

The pre-test process guided students towards good practice in how and how much they should prepare for an actual test: "*it definitely showed me that i* (sic*) should do prac tests in preparation*" (G9F, 2023 survey) and, "*Made me realise how much i* (sic*) needed to study*" (G10M).

As previously mentioned, time is constrained in our context and students also have at least six other subjects (seven, if you count chemistry as a separate subject) and students often feel pressured by the volume of work that they need to do. One of the Grade 11 girls told me in the focus group that the pre-test, being a concrete task, unlike studying for a test, was easier to prioritise. She said, "*because we so often … have quite a lot of other homework. So, it just forces you … it becomes that homework, ... so it becomes a priority, because I always try to get my work done first … and then I study for tests.*" (G11F, 2023 focus group)

Prompting students to begin their test preparation sooner will give them more time to engage and grapple with the concepts as students complete the pre-test. One of the primary aims of ISLE is to enhance student well-being (Etkina, Brookes and Planinšič, 2019) and the pre-tests appear to have done this for many of the students by improving their confidence.

III. Familiarity with test layout

The students commented on the use of pre-tests in modelling what the test would look like (*n* = 38; F = 18; M = 20). While this may seem a bad thing, this information is available to anyone who seeks out a past test and they are available for students to use in their revision. Coaching and scaffolding problem solving is part of the learning process (theory of cognitive apprenticeship - (Collins, Brown and Newman, 1987)) and it is also important that we are explicit and transparent about the contents of the test so that students can prepare themselves appropriately.

In a focus group, one of the Grade 9 boys commented that the pre-test allowed him to focus on what is most important for the assessment. This supports literature that says that assessment drives learning (Bezuidenhout and Alt, 2011; Schell and Butler, 2018; Fischer et al., 2024).

About half the students in each of Grade 9, 10 and 11 mentioned familiarity with the structure of the test as a benefit of completing the pre-test because it helped their confidence and also reduced test anxiety: "*it made me feel more* *at ease because i* (sic) *knew more or less what to expect*” (G9M, 2023 survey) and, “*It helped me know the set up and type of questions for the actual formal test*” (G9F, 2023 survey).

This does seem to reduce anxiety (“*it gave me an idea about what the test would be like, which made the experience easier*” (G9F, 2023 survey)) and one of the goals of the re-test was to enhance student well-being, so this is appropriate. A Grade 11 student said in the focus group that it…

> *“… is also a lot more comforting going into the test, knowing what you're going to be tested on; what it's gonna look like. if I go into a test not really knowing what's gonna, what's going to greet me when I get there, then it's a bit frustrating, almost, but then it's a lot more comforting now we've done a pre-test. So, we know what to expect on the day.” (G11M, 2023 focus group)*

The question is whether students are learning the *physics* if the problems that they answer are always similar. From anecdotal experience, students often say that the test was completely different from the past tests that they had practised, which suggests that they are looking at surface features, rather than the underlying physics principles which will always be the same for each concept (Chi, Feltovich and Glaser, 1981). The emphasis on surface features over underlying physics did not come through in the survey responses or in the focus-group discussions, perhaps because students are unaware of this distinction. However, there were a few comments made where I saw this theme emerging. One of the Grade 12 girls mentioned the fact that there are always unfamiliar questions, commenting, “*I also feel like, with physics, … you can get a really good mark, if you do like loads and loads of past papers, because some of the things are repetitive. But I mean, some of the things you've just never seen before*” (G12F, 2023 focus group). This was reiterated by one of the Grade 12 boys in their focus group, who said, “*There's also there's like, obscure questions where it's like, like, I can't describe them.*” (G12M, 2023 focus group)

The format of the questions is usually the same across assessments, which is a conscious decision to make the goal explicit and put students at ease: "*it helps you understand the format of test questions better but they are basically the same in the book"* (G11M, 2023 survey). In fact, the exit examination always uses the same font and layout for this reason, and we mimic this in our assessment at the schools so that students know what to expect. One of the Grade 12 students commented on this in the boys' focus group:

> *"it's understanding and also getting used to the exam because they always, they always the same, you always know like Question 2 is kinematics, all that stuff. So, … it's as much understanding as like, just knowing what you going to see on the day, like, to help yourself, just relax, and knowing that there are only so many, like, situations they can create out of the curriculum. So, if you do enough, you will like you see something, you're like "oh I know exactly what to do".* (G12M, 2023 focus group)

In our assessment-driven context, students saw the pre-test as a means to become familiar with the way in which questions were asked. The repetition of questions (never the same, but similar) and the predictability of assessments is peculiar to high school and our context, and students are still not all able to apply the physics correctly. This is a potential code clash between the nature of assessment, and our efforts to teach students sufficiently coherent and robust concepts so that they can transfer their knowledge to new contexts.

Those who have developed the valued behaviour of seeing beyond the surface features to apply the physics are more likely to say that the questions are 'all the same' and, interestingly, all those students who pointed out the similarities ('basically the same', 'repetitive', 'always the same') were competent physics students who display most of the behaviours that we value. Those who struggle tend to say that every assessment looks different and perhaps they have yet to develop the valued behaviour of seeing the physics rather than the surface features in order to transfer concepts.

Despite the availability of memoranda and the emphasis on preparing for assessments, one of the students commented that he did not feel that we just teach to the exam:

> *"Just like a general note, like, I really do enjoy that like teachers for well, at least, like our classes' teachers are really good at not just spoon-feeding us to pass the exam, and are really good at like, giving us an overall background because in subjects where teachers are just exam driven, you end up losing sight of what you actually need to know for the exam and you just end up being completely focused on the exam, even though the exam is the end goal, having overall knowledge you're not going to need to, like cram study as much."* (G12M, 2023 focus group)

As students practise past papers, they should be taking a step back to see the underlying physics concepts, rather than the surface features of the problems, reflecting to see patterns and abstracting their thinking to see the physics concepts in their guises of different concrete contexts. The goal of practising past papers is not to 'learn how to solve' to pass, but rather to understand concepts more deeply, through exposure to multiple contexts as a means to see the 'big picture' or the patterns of physics across many questions. To do this effectively, students need to actively engage and reflect, not just mindlessly or passively solve problems. They need to look for the connections between concepts. The structured and guided process of pre-tests was intended to model how the process should be approached.

IV. The role of the teacher and feedback given on the pre-test

The assessment of the pre-test was done without indicating marks (just ticks, no marks awarded) and without extensive comment, as it was expected that the students were to do corrections as part of the process. This had the desired effect, in some cases, of encouraging students to actively engage with the concepts and with their mistakes, and these students made the effort to address the problems discovered: "*I went out of my way by going to a* *teacher or a friend to better understand my mistakes*" (G10F, 2023 survey). For some, this also increased effort and motivation in completing the task: "*It helped as it was going to be marked by a teacher so I wanted to do well, so I put lots of effort into it to try and understand to get the questions right.*" (G11F, 2023 survey)

Some students expressed an appreciation for the teacher input on the tasks: "*It is very nice and beneficial to have a teacher marks* (sic) *because things that you wouldn't notice as errors when marking by yourself are picked up and then corrected.*" (G12F, 2023 survey)

The intention was for students to correct their mistakes by engaging with their notes, peers or asking the teacher. However, although the pre-test is intended to build independent, active engagement with the concepts with minimal teacher input, there were a few responses from students indicating that they would like more teacher input: "*I wish it had more corrections. Some of the things I got wrong I did not know what was the correct answer - what I was meant to do. Although I was able to ask my peers for help"* (G12F, 2023 survey). A number of students wanted the teacher to work through the pre-test in class and give the answers, "*I would really like to go through each question in the pre-test after we have written it and you have marked it to ascertain how and why I got a question wrong.*" (G11F, 2023 survey)

As previously mentioned, a few students expressed frustration that there was no memorandum for the pre-test:

- "*I wanted to do it in class and study it for the test however I could bot* (sic) *find it's memo on the drive so I'm not sure how I did in it*" (G11M, 2023 survey)
- "*i* (sic) *think the memo should be on classroom the night before the test so that you can mark the corrections*" (G11M, 2023 survey) and
- "*I didn't see much benefit in doing the pre-test before studying much of the work, and without a memo*" (G11M, 2023 focus group).

Students need to know that they are expected to grapple with the concepts as part of the pre-test learning process. However, in addition to explicitly explaining the objectives of the pre-test, students may need further guidance and modelling to see how to find the answers when solutions are not provided.

V. Comments on the reflection process

In addition to correcting any mistakes on their pre-tests, students were encouraged to reflect on anything that they had answered incorrectly. The reflection aspect of the pre-test (Appendix 3: ISLE approach and ISLE-inspired activities; p. 372) is important as it is a means of stimulating conceptual change (Posner et al., 1982). To bring about conceptual change, students need to encounter a conflict in their understanding to prompt them to interrogate an alternative understanding: "*That's where you realize that like, I don't know, like something you didn't know, or you understood it in a different way. And often in the test, you kind of remember, oh, yeah, I've corrected something. I now know what to do here*." (G10F, 2023 focus group)

Reflecting on their work allows students to take ownership of their learning and to improve or deepen their understanding, as described by this student:

> *"I did the pre-test and there were a few concepts I struggled with and after them, I reflect on them and then I go, I go look over the section again, and then see where I went wrong and I'd try and reteach it to myself in a way that I can remember how it works."* (G11M, 2023 focus group)

Such learning, where the student engages with the concepts and grapples with them (particularly when they experience an 'aha! moment') is more likely to lead to long-term learning, such as,

> *"when you're like doing a past test or a past paper, and then you like, correct yourself, like with the memo, and you're like, actually… and then you're like, '**oh'**, and then it will stay with you, you know, like, if*

> *you're doing corrections, it'll like, stay with you for longer"* (G11F, 2023 focus group)*, to which her peer responded, "And when you see that same question, in a test, you're like…. 'I remember this!'"* (G11F, 2023 focus group)

Simply correcting answers without reflection can lead to fixing the answer to just that question, whereas reflection can elevate the learning to more generalised understanding, beyond the specific context of that question:

- "*It helped me to understand my mistakes instof* (sic) *just correcting my answers*" (G10F, 2023 survey)
- "*Doing this forced me to find the reason why I did the question wrong and then I understood afterwards*" (G11F, 2023 survey)
- "*The reasoning of why I made the mistake and the explanation of the right way to do something helps me to understand properly and learn from my mistakes*" (G10F, 2023 survey).

Writing reflections on paper also requires the student to think about the problem well enough to describe what went wrong and how they can fix it in future, which is helpful in diagnosing the problem to fix it. This can also be done verbally:

> *"Talking about the process and the ways of learning has taught me a lot and like articulating what you've done wrong and understanding how to do it better and how you don't make the same mistake has really helped me."* (G10F, 2023 focus group)

Only by identifying what went wrong, can the conceptual problem to be addressed: "*If you don't recognize why you made s* (sic) *mistake, it wont* (sic) *be fixed"* (G9M, 2023 survey).

Physicists reflect and look to improve their thinking. ISLE wants students to 'think like physicists' (Etkina and Planinšič, 2014b). Students are expected to reflect on their pre-tests, in order to improve their understanding through grappling, to deepen their knowledge.

VI. Emphasising learning goals over performance goals

Despite our efforts to reduce an emphasis on marks in the pre-test process (by not writing a mark on the test), to encourage learning goals over performance goals (Yeager and Dweck, 2012), some students still focused on the marks. When students received their pre-tests back, many took out a calculator, added up the sub-totals and wrote a mark at the top of the test paper.

One student's response to whether the pre-test changed the way they prepared for a physics test was, "*Yes because I knew what to expect and where i* (sic) *could loose* (sic) *marks so i* (sic) *focused on that*" (G9F, 2023 survey), suggesting that marks remain a focus. The fact that it did not count for marks, also offered students the opportunity to focus on their understanding without the emphasis on marks.

Students in the Grade 10 focus group embraced the shift from performance goals to learning goals and found freedom in this to grapple with the concepts:

> *"So, for the pre-test when you first complete it, like when you just kind of doing it, there's no pressure to perform or anything, which is really nice, because you can kind of experiment and just try and see, you know, you test yourself without any pressure. And then when you get your tests back, it's really nice that there isn't like a mark on it to be like judged or anything but rather to focus on fixing mistakes and learning from them."* (G10F, 2023 focus group)

Another participant in the focus group responded to emphasize how downplaying marks in the formative assessment allowed students to focus on their learning, rather than their performance, which meant that they did not take short cuts to try and please the teacher or 'get the mark':

> *"And it's nice to know that you don't care about the marks on our pre-test either because that also makes a difference to how we work hard*

> *for ourselves. Instead of just copying off each other. We actually talk about it and go through it. So that makes a difference."* (G10F, 2023 focus group)

Although there is no conclusive evidence to show that not writing a mark on the test changed all students' mindsets, it does seem that this has shifted the focus for some students from performance goals to learning goals, which is a goal of the ISLE approach (Etkina, Brookes and Planinšič, 2019).

### VII. Comment on the pre-test process

In the survey, students were offered the opportunity to comment further on the pre-test and some used the opportunity to suggest changes. In particular, the timing of the pre-test was mentioned: "*The test was handed out quite late resulting in me not having enough time to complete it as I had a very hectic week with many tests*" (G11F, 2023 survey). This is a valid concern as the students need to have enough time to engage with the pre-test and do it properly, preferably having prepared before they do it. Not giving enough time for the pre-test to be done properly can lead to shortcuts: "*I did not put much effort into it and used a lot of my friends for help but without trying to understand, rather to get the pre-test done*" (G11F, 2023 survey).

One of the students in the Grade 10 focus group spoke about how she made sure that the pre-test was a true account of her understanding, rather than taking short cuts to complete it:

> *"I left out some questions that I really couldn't do, okay, because I didn't want to … just copy it down from the book. So, I'd rather not know and then get like an average thing of how I would actually have done and then say, I actually do need to study a bit more."* (G10F, 2023 focus group)

It would have been better for her to seek help to improve her understanding of the concepts, rather than leaving questions out. She could have sought help from teachers or her peers.

An unanticipated positive outcome of the pre-test was encouraging students to collaborate and discuss physics, as described by this student:

> *"I think my confidence spiked from being able to like, chat to friends about it, and get ideas of how they work out things. And that helped a lot with doing the pre-test, because we could kind of chat about it. Whereas when we used to rewrite our tests, we couldn't like, you know, like test conditions, so you couldn't chat about it and stuff."* (G10F, 2023 focus group)

This was mentioned in the Grade 11 boys' focus group as well:

> *"it was like really learning some stuff and then just learning from each other. Like we'd get the pre-test done, you will be engaging with the work that you assume you'd have to study for the test."* (G11M, 2023 focus group)

This unanticipated outcome of the pre-tests align them further with ISLE activities, as collaboration is highly valued in the ISLE approach and was not as integral in our physics lessons as it would be in an ISLE classroom (Etkina and Planinšič, 2014b).

Another student speculated on how he thought students were approaching the pre-test:

> *"I think most people looked at what they did wrong and then went over that. Not the ones they got wrong in the test, but they would see what they need. Like if it's average speed they got wrong, they would go and do examples of average speed, they wouldn't just do the one in the test, though."* (G11M, 2023 focus group)

This was one of the ideals that the pre-test hoped to achieve: for students to take their specific learning from one question on the pre-test and generalise or abstract it so that they could apply it in various contexts. These students are not only grappling with the concepts that they needed to improve their understanding, but they are also practising the transfer of concepts as they apply them to other problems.

The Grade 9s wrote their pre-tests in class, under test conditions to ensure that they each completed the task based on their own understanding, the task was completed, and to acclimatise them to the anxiety of writing under test conditions. They had to prepare for the pre-test just as they would for their test, but it did not count for marks and they had the opportunity to have it marked, to do corrections and to reflect on their mistakes. One of the Grade 9 girls commented that this reduced the stress of a test situation: “i (sic) *think it is an extremely good way to practice* (sic) *under test conditions without having the stress of the marks counting for anything*.” (G9F, 2023 focus group)

The Grade 12 group in 2023 completed a ‘mock prac’ before the practical assessment for the final, school-leaving assessment. This was a special case of a pre-test where an investigation was given to students to complete in their own time and to submit. We assessed this ‘mock prac’ without giving a mark, but marking questions correct and indicating incorrect answers, as we had done with the pre-tests. 47 students responded to say that they had completed the mock prac (F = 25; M = 22) and only two respondents said that they did not complete it (both M). About half the students (*n* = 23; F = 13; M = 10) felt that this offered them the opportunity to identify and correct mistakes or incorrect concepts, with many specifically naming these in the survey. In answer to ‘What did you learn from looking through the mock prac?’, one of the students answered,

> *“The mistakes that I made and when studying for the final prac. I was able to see these mistakes and ensure I didn't make them again. It definitely helped me understand where I went wrong and prepared me well for the final prac.”* (G12M, 2023 survey)

Students felt that the mock prac helped them to identify gaps (*n* = 19; F = 6; M = 13): "*Yes it did because it made me more aware of places that I need to focus on in my Physics prac"* (G12M, 2023 survey) and helped them improve their understanding of the skills that were assessed in the practical (*n* = 14; F = 8; M = 6): "*I saw where I had made my mistakes and how to go about answering the question I didn't initially Understand* (sic)" (G12F, 2023 survey).

Others commented on how the mock prac (essentially a pre-test for the final prac) improved their confidence:

> "*I actually got some of this right! Like, I actually know what I'm doing! So, it made me feel a lot better because I was like, you know, if I can do this, I can, I'm sure I can do the actual prac.*" (G12F, 2023 focus group),

and

> *"For me it helped with like anxiety wise, because you kind of have an idea of what to expect. Yeah, because when you sit there and you've actually like, done it before, … then when you actually get to the prac, … 'I'm going in with a little bit of preparation so that I can know what to expect.' It helps anxiety."* (G12F, 2023 focus group)

The mock prac was a different task, modelled on the pre-test, which seemed to work in much the same way and see the same benefits.

#### *7.1.13* *Examination reflection tool*

This task was inspired by the ISLE reflection task (May and Etkina, 2002), but was applied specifically to assessment and had students classify their mistakes on a previous examination. Students were given the opportunity to work through their previous physics examination with an 'examination reflection tool', which I designed as an ISLE-inspired activity. It was intended to encourage students to reflect on their previous assessment, to categorise problems by topic (to check knowledge coherence and structure) and to assist the student in preparing for their next assessment.

This table (Appendix 3: ISLE approach and ISLE-inspired activities; p. 366) was to be used by the student alongside their examination script to help them to categorise the types of error that they made in each question as conceptual, learning-based or functional. Once they had worked through the activity, they would have a very visual summary of their performance in each section of work and the types of errors that they made in each section. A sample of part of a completed examination reflection tool, where students wrote notes to themselves and generalised the problems that they had in the examination (July 2023), is shown in Figure 7.32.

The reflection tool was mentioned in the Grade 12 focus group:

> *"I really liked that like, table thing. You know? Like, when we were looking over our prelims[4], then you can see exactly… that was very, very, very helpful for me, because, as I said, I'd given up on the subject, but to see like, exactly, okay, well, this section is like a common pattern. I'm just not getting this thing. When you can visualize, and you can see, okay, well, it's not just a test that I got, like, a really bad mark for, it's actually like a section that I just didn't get …. So that helped me visually see that. So, because then you can just go and work on it... And you can actually see it, because if you just look at the column or what it was, … Okay, same thing, same thing, same thing, same thing. Then I've split my entire exam to four things that I need to work on. It's just so much more, like, manageable." (G12F, 2023 focus group)*

This task seemed to enhance well-being as it made the students' errors and problems in the examination seem more manageable and surmountable by classifying them: "*I have a gaps in my understanding of some sections but I think it's very fixable*" (G12M, 2023 survey). Another Grade 12 commented in the focus group: "*I think a lot of us, like thought, gosh, 'like, do I have to like go through it.' But it's so worth it.*" (G12F, 2023 focus group)

[4] 'prelims' is short for preliminary examinations, which are the Grade 12 July examinations. These are also often referred to as trial examinations as they are written a few months before the final set of examinations.

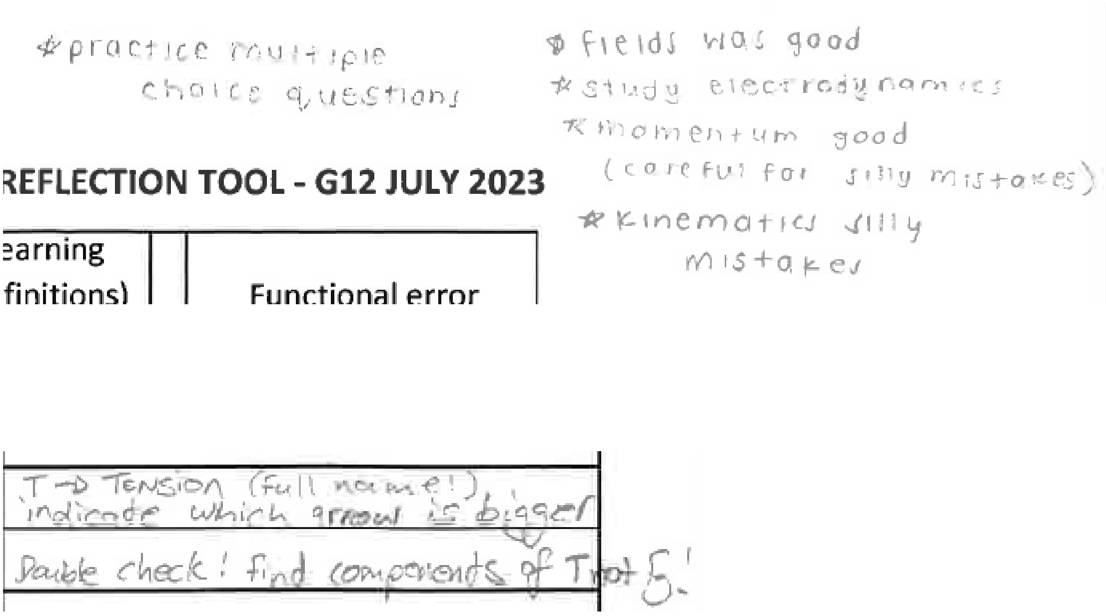



**Figure 7.32:** A sample part of two students' Grade 12 examination reflection tool.

Arising out of this, in 2024, I developed a similar (simplified) version of this tool for reflection on tests, which is included in Appendix 3: ISLE approach and ISLE-inspired activities on p. 367. Even though this tool did not form part of the study, it was developed from the implementation of the ISLE approach in our context.

## 7.2 How the student experience of the ISLE approach demonstrates the extent to which the students have developed the behaviours that are valued.

In Section 7.1 of this chapter, I have presented and discussed student responses to understand how they have experienced the ISLE approach. In this section, I will look at how these responses demonstrate the extent to which the students have developed the behaviours that we value in the physics classroom and beyond. I have organised this section by valued behaviour, so I will discuss

- active engagement,
- grappling with concepts,
- making connections, and
- transfer of knowledge from one context to another.

### *7.2.1 Active engagement*

Some students certainly recognised that physics requires active engagement with comments such as: "*Physics requires a lot of active learning that takes a lot of time, especially when you are not the best at it*" (G10F, 2022 survey). Some adopted more active learning practices, which they recognise: "*My approach has changed from more passive to active*" (G9F, 2023 survey).

A Grade 11 student commented in the survey that he had learnt concepts through the investigations, "*from paying attention and being forced to be active while doing the exercise as its different it makes me enjoy my time a little more in class because im* (sic) *not on autopilot*" (G11M, 2023 survey). This suggests that he was previously 'on autopilot' and requiring his participation meant that he gained more from the lesson.

Active engagement was not only required in student participation in lessons, but also by the level of engagement expected with activities which may be completed outside the classroom. A Grade 11 explained that, "*actively* *reflecting on my original test indeed improved my understanding of physics as it required me to actively dissect each question and each concept until I understood how to get to the answer.*" (G11M, 2022 survey)

Students' level of engagement can affect their confidence, as this student explains: "*I question my ability only when I have not put in the right kind of effort. For example not taking the time to really engage with certain sections.*" (G12M, 2022 survey)

One particular student spoke extensively in the Grade 12 focus group about how she had changed the way that she approached her learning in physics and how this had helped her to improve her understanding and her confidence. She had been reliant on looking at the memorandum when she was stuck on a question, but did not engage with the memorandum to work out what she did not understand through active engagement and grappling. She said,

> *"I went back after I had prepared, like literally the day or two before the physics prelim. And I looked back and I tried to redo everything I got wrong, because I didn't actually realize in grade 11 what I was doing wrong. Like I didn't realize, 'oh, this is actually, like, I have no idea.' I thought I was doing the right thing. And after it scared me that I didn't even realize that I had the wrong approach. And then when I did it again, I could do it. And I was like, Oh, this is so easy. And it was so nice to look back at my mistakes and be like, 'This caught me out.' So, let's make sure this doesn't catch me out again. Like the tension things. I kept getting that wrong. I practised it specifically in the past papers. And then I got it right, I got it right in prelims. So, looking back was very useful, because you forget what you struggled with."* (G12F, 2023 focus group)

Being an active learner encourages grappling, which is important when learning to apply physics concepts, which can be difficult and require time and effort to master.

### 7.2.2 *Grappling with concepts*

Students are expected to grapple with concepts in order to assimilate new knowledge and to fit this coherently to their existing knowledge structure. Students were required to grapple in the experiments. where they needed to reconcile what they saw with their understanding of the world, and in solving problems.

In the focus-group discussions about the investigations, it was apparent that many students are uncomfortable when they do not know the right answer or are not sure that they are correct. The ISLE approach recognises the value of learning from mistakes (Etkina, Brookes and Planinšič, 2019) and the activities that I have developed (pre-tests and reflection tools) encourage students to reflect on their work, grapple with what they do not understand and to work through their mistakes. This will not be comfortable for students, but learning is often not comfortable, as students re-evaluate what they know, face their incorrect reasoning and challenge their perceptions (Etkina, Brookes and Planinšič, 2019). One of the ways in which students seek comfort when they are solving problems is to look at the memorandum when they get stuck, to see how to go about solving the problem.

Working through past papers was a strong theme that came through in the survey responses and the focus-group discussions. This approach can help students to see the different applications of physics concepts, which could help them to transfer their knowledge, but students often look for procedures (such as which formula to use) to solve the problem, rather than considering the physics principles that are applicable. Working through past papers can also build understanding and is certainly an effective way for students to evaluate their understanding and ability to apply their understanding, but completing these papers mindlessly, without engagement or grappling, does not help students to see the physics across problems. When the paper has been written and corrected, the process of correcting mistakes and reflecting on these mistakes should further encourage grappling with the concept and reinforce learning. Repetition and practise of the procedures of solving problems does also assist in automating these procedures, allowing students to focus on assimilating new concepts and constructing understanding (Paas, Renkl and Sweller, 2004; Schell and Butler, 2018). However, mindlessly working through problems, without effective engagement, does not facilitate learning:

> *"I was trying, but I don't know if my practising was actually getting to like the problem because I would do a lot of past papers, but maybe not effectively. And then this year, I like really shifted the whole way I did it and my confidence started going up and I started getting the marks. And now like it's not this big negative thing in my mind anymore."* (G12F, 2023 focus group)

Learning to complete past papers 'effectively' is part of learning the behaviours that will enable success in physics. In our context, the students do learn that past papers are a means to practise their application of the concepts: "*I have learned that you should always do as many past papers as you can*" (G11F, 2023 survey) and, "*I've realised I need to put more emphasis on past papers*" (G12M, 2023 survey). However, *how* they use the past papers is important. This student refers to 'learning for understanding', which is the mindful practise that I have described above:

> *"I think before in like Grade 10 and Grade 11, I'd just studied to pass the test time, I just do lots and lots of past papers and I could probably set a test if I wanted to, that's how many I'd done. But after that you sort of just forget the concept. And then you just have to do it all over again. You never really learn the... it's not learning for understanding, which is what I'm trying to do now. Which I think will hopefully help me in the exam, more than just doing lots of past papers."* (G12M, 2023 focus group)

Working through past papers exposes students to many problem contexts and provides them with opportunities to grapple, which is a behaviour that is valued in physics knowers. As they work through past papers and problems, it is not enough to mechanically follow procedures; students need to be looking for patterns and physics concepts across problems and making connections between the physics concepts.

### *7.2.3 Making connections*

Students learnt the importance of drawing diagrams, to help them visualise the situation ("*when you draw a diagram on the side, like you encourage us to draw a diagram that helps a lot.*" (G11M, 2023 focus group) and "*It lets you like, visualize, like how to do it properly.*" (G11, 2023 focus group)), and also to make sense of the 'story' in the question ("*that common sense factor also applies in a diagram compared to when you read it. Yeah, if it stops against the wall, you say it might not make sense. But if you draw the wall, it's like, ja*" (G11M, 2023 focus group)). Often students make errors that could be avoided had they drawn the picture to better understand what is happening in the description.

In the other Grade 11 focus group, a student recognised how important it is that information is written down when problem solving:

> *"I definitely think just drawing it out helps ... If you're trying to just do everything in your head, you sometimes get mixed up. But if you just put it on paper, and see what's going on, it's easier to understand."* (G11M, 2023 focus group)

Information is held and processed in the working memory, which has a finite capacity (Johnstone, 2009). Drawing a diagram or writing down information can reduce the amount of information held in the working memory, which can increase processing capabilities (Larkin et al., 1980; Maries and Singh, 2013). Free-body diagrams are particularly useful when solving problems and our emphasis on the importance of drawing them has developed this valued behaviour in many of the students:

> *"If you could see my prelim paper… you will literally see like stickmen like on a skateboard and I draw the path of where they are going and I*

> *circle where they want me to calculate … like the picture, or like free-body diagrams, even if the section doesn't need a free-body diagram, I will use a free-body diagram because it's going to show me where what forces and where they want me to look at."* (G12F, 2023 focus group)

I examined the Grade 11 pre-tests (two) and tests (two) that were handed in for evaluation (*n* = 114; F = 47; M = 67) for the unprompted drawing of diagrams and found that 60 of the students (F = 19; M = 41) drew at least one unprompted diagram, with 44 of those 60 scripts showing more than one unprompted diagram. The proportion of scripts showing unprompted diagrams increased for each test and pre-test, with only 3 scripts (out of a total of *n* = 34) showing none. This suggests that students developed the valued behaviour of drawing diagrams to help them solve problems, even when they were not prompted to draw a diagram. This is a valuable habit in physics and assists students as they make connections between the domains (or representations) of a problem.

#### *7.2.4 Transfer of knowledge from one context to another*

Consulting the memorandum for help with a specific problem can help a student solve *that* problem, but only if they take a step back and look for the physics in the problem, rather than the surface features, can they solve any problem in that family of problems. So, in the case of the pre-test (or re-test), doing corrections can help with *that* test, but the reflection process should hopefully help them to apply that understanding more broadly, to any similar example.

Many of the ISLE activities develop a concept, which then needs to be transferred to – and applied in – new contexts. Sometimes the focus of the activity and the behaviour that the activity develops are not the same. For example, when we ask students to do corrections and reflect on what went wrong in their pre-test, they may think that the focus is on the corrections, but there is an additional goal to this activity, which is to encourage them to look for the physics principles in each question and to critically examine the way in which they applied these principles. Another example of how the desired outcome of the activity might not be evident in the focus of the task, is the observational experiment which asked students to design an experiment to test whether the statement that current was depleted by components in a series circuits. In this activity, students learn to design an experiment and learn to disprove a statement by proving it untrue. The activity may assist in reinforcing the concept that the current in a series circuit remains the same throughout the circuit, but the focus is on the task of designing the experiment, rather than content. Most of the ISLE activities focus on developing valued behaviours and the content is learnt through the task, rather than being explicitly taught.

The teacher's approach and how they scaffold the learning process can also affect student confidence. Teachers should apprentice their students, guiding and scaffolding their learning to model the correct strategies so that students adopt them and develop valued behaviours:

> *"I think sometimes, especially in Grade 10, or stages with a question, I wouldn't understand this straightaway, and then I'll get a bit flustered and maybe panic a bit because I didn't really see how I was going to figure it out. But I think what's helped me is, is in class when you break down like exactly how to, to kind of structure a question, so you can label what the mass says what the acceleration is, what the velocity is, and then taking it step by step, rather than trying to get the answer straight away. I think definitely more confident now. Because even if there's a question I'm not quite sure of initially, I know I can go through the process of saying like, Okay, what do I know? And then trying to use formulas to, well use my understanding – I'm definitely more confident."* (G11M, 2023 focus group)

Despite the emphasis on learning goals over performance goals, responses from students about their experiences of re-tests and pre-tests showed that marks remain a significant focus. The re-test was viewed by many students as a means to improve their mark ("*you learn from your mistakes and you up your mark from the previous*" (G10F, 2022 survey)). Students still gauge their capability in physics on their marks, largely because that is how our system evaluates understanding. A Grade 12 articulates this feeling:

> *"I used to feel close to incapable of doing physics because I would work hard and it wouldn't pay off in my marks but in Term 2 I received amazing test results and a huge improvement in my exam marks and so my hard work finally seems to be paying off and my confidence has grown in the subject."* (G12F, 2023 focus group)

Students' confidence remains closely tied to their performance and their marks.

In this light, pre-tests were seen as a means to improve marks, rather than an opportunity to improve understanding. This suggests a code clash between the *students' focus* on the outcome of the activity as being to improve their result (performance goal) and the *intended focus* of the pre-test activity on learning goals and the process of learning. As was evident from the student responses, the majority of students feel pressure to do well in physics and so their mindset is influenced by this pressure.

## 7.3 Overview of the student experience of the ISLE approach

This chapter has described and discussed the students' experience of learning physics through ISLE and ISLE-inspired activities. Most students felt pressure to do well and about half the students surveyed were positive about their ability to do well in physics. Students were made to feel comfortable in class by the teaching, their teacher, the class environment as well as their peers. This reiterates the importance of a learning community, which is an aspect of ISLE that I did not explore in depth in this study. In this regard, more than 75% of students commented that group work had a positive impact on their learning.

Students feel comfortable in class when they feel able to do the work and when they have the freedom to ask questions. They indicated that they learn new concepts predominantly from doing questions and practising examples. This became a core theme of the discussion in this chapter, particularly in exploring the extent to which this practice develops the behaviours we value. The Grade 10 to Grade 12 students noticed a change in their understanding of how they learn and their approach to learning over the time that they had studied physics.

A large proportion of students reported that they need to be convinced of a concept by seeing it or by proof. This could be through an experiment or demonstration or independent investigation. Some of the ISLE experiments were found to need tighter boundaries to be effective in our context, but others were impactful. A large number of students developed the habit of drawing diagrams to solve a problem, even when they were not prompted to do so.

Students were generally positive in their responses to reflections on learning, re-tests and pre-tests. These activities helped many students to adopt active learning strategies and to improve their ability to solve problems in future, but it emerged that many students are reliant on full solutions and unwilling to grapple with their understanding of concepts on their own. There was insufficient evidence to show that more than a few students learnt to abstract their knowledge through these activities.

The ISLE and ISLE-inspired activities that were implemented in this study value the behaviours that enable physics knowers to access, apply and transfer knowledge. The student experience of the ISLE approach has shown that many students value these behaviours, but some need training or apprenticeship to develop them. Drawing attention to these valued behaviours and coaching students to adopt them may help those students for whom they are not innate to develop them.

# CHAPTER 8: SUMMARY OF RESEARCH AND CONCLUSION

> *"Learning in her classroom occurs when students struggle to make connections from what they know in relation to the more complex and larger world. Ms. Blake has set in motion a fertile environment in which to stimulate her students' growth as emerging thinkers who trust and value their own and each others' questions and answers."*
>
> (Applefield, Huber and Moallem, 2001, p. 45)

In this final chapter, I present a brief overview of the research process before giving a summary of the findings. On the basis of these findings, I draw conclusions and highlight the new knowledge emerging from the study, as well as the consequent implications and significance for the field of physics teaching. Next, I describe the limitations of the study and suggest future work. Lastly, I conclude with a brief personal reflection on my research journey, which includes some ideas for my own teaching practice that have emerged from this study.

## 8.1 Introduction

In the South African high-school context, physics is considered a 'gateway' subject, offering access to various future paths of study. The physics classroom can also expose students to activities that may develop critical thinking and shape their reasoning. Students need to grapple with concepts that may be in conflict with their experience of the world and they need to interrogate their understanding until they can reconcile their experience with new knowledge (as described by the theory of conceptual change in Section 2.3.3). Physics is perceived to be a difficult subject (Ekici, 2016) with a knowledge code (Adendorff and Blackie, 2022). In this study, the Investigative Science Learning Environment (ISLE) approach (Etkina and Van Heuvelen,

2007) was introduced to shift the students' focus from the *outcomes* of teaching to the *process* of learning, with explicit emphasis on valuing particular behaviours.

These valued behaviours require students to

- actively engage with concepts while learning;
- transfer knowledge from one context to another (which LCT refers to as cumulative learning);
- Make connections between the concrete, mathematical and conceptual representations of a concept (or problem), often aided by a visual representation;
- grapple with concepts.

Various ISLE and ISLE-inspired activities were introduced in Grades 9-12 in a South African high-school physics classroom. The Specialization code of Legitimation Code Theory (LCT) (Maton, 2014) was used as an analytical framework to consider data that were collected in a mixed-methods approach, using surveys, focus-group discussions, interviews and student assessments. The data were also coded using an inductive approach (Creswell, 2013) to discover emerging themes and to answer the research questions:

1. To what extent do ISLE activities legitimate the behaviours that we value in physics knowers?

2. How does the student experience of the ISLE approach demonstrate the development of behaviours that we value in physics knowers?

These questions guided the study, and the findings are summarized below.

## 8.2 Summary of research findings

I will summarise the findings of the study as they answer each of the research questions.

### *8.2.1 The legitimation of valued behaviours through ISLE activities*

The Specialization code of LCT recognises that activities legitimate the knower or the knowledge of a practice to varying degrees (Maton, 2014). Each of the ISLE and ISLE-inspired activities was coded using the translation devices that were developed (Section 6.2) through engagement with the theory and the data (Maton and Chen, 2015). These translation devices evaluated to what extent knowledge was legitimated in each activity and to what extent the valued behaviours that were identified in this study, were validated in each activity. Based on the coding according to the translation devices, the activities were plotted on the Specialization plane, which offered a visual depiction of the emphasis of the activities and helped to show patterns.

Physics is considered to have a knowledge code in which knowledge is legitimated. However, the ISLE approach requires active engagement from students and the nature of the activities shifts the emphasis from legitimating knowledge, to valuing the knower and the behaviours that we want to legitimate. Often teachers expect students to develop into knowers, but without explicitly coaching these behaviours. Students should reflect on their learning and not only correct their work, but grapple with what went wrong in their thinking to change or improve their understanding of concepts (Section 2.3.3). They should look for the underlying physics concepts across problems, connecting these concepts into a coherent knowledge structure. However, unless these expectations are made explicit or students are trained in how to learn effectively, they are unlikely to develop these behaviours by chance. We want students to become lifelong learners through activities that develop these behaviours.

The ISLE approach is underpinned by the principles of sociocultural theory and social constructivism (Vygotsky, 1978) in its emphasis on collaboration, active learning and the negotiation of meaning through dialogue. However, the role of the teacher as curator of the learning environment is also important, with the student being trained or apprenticed into becoming a physics knower, as described by the cognitive apprenticeship model (Collins, Brown and Newman, 1987) in Section 2.3.2. Many of the ISLE activities and most of the ISLE-inspired activities that were developed as part of this study, model valued behaviours.

The ISLE approach emphasizes both learning physics through doing physics (mirroring the behaviour of physicists) and enhanced student well-being. The emphasis of this study has been on the development of valued behaviours in the students alongside their conceptual development, rather than on their well-being, although a consideration of the students' well-being has underpinned all pedagogical decisions. As such, this study has not fully evaluated the effect of the ISLE approach in the South African high-school context on student well-being, specifically, but considered the overall experience of the students in the physics classroom.

Two translation devices were developed and used; one to look at which knowledge was legitimated in each ISLE and ISLE-inspired activity and one to look at which behaviours were legitimated by these activities. The majority of activities that introduced new concepts to students turned out to represent knower codes (ER–, SR+) because no prior knowledge was necessary to complete the task successfully. All the other ISLE activities that this study considered represented élite codes (ER+, SR+) with varying degrees of stronger epistemic relations and stronger social relations. Those activities that model behaviours that we value had the strongest social relations, as they require students to be a particular kind of knower. This is in contrast to the usual idea that physics is a knowledge code. The ISLE and ISLE-inspired activities legitimate the behaviours that we value and so could be effective in developing these valued behaviours in our students.

### *8.2.2 <u>Student experience of the ISLE approach</u>*

In order to evaluate how the student experience of the ISLE approach demonstrated the development of behaviours that we value in physics knowers, a mixed methods approach (Creswell and Creswell, 2017) was used, considering both quantitative and qualitative data through an action-research process. Data were gathered through student surveys and reflections, interviews and focus-group discussions and the research-validated CLASS. The students' tests, re-test applications, re-tests, pre-tests and examinations were also studied to gather further data. An inductive approach was used to code the responses to surveys and quotes from the interviews, and then focus-group discussions were used to triangulate the quantitative data that the coding offered. Students' reflection and corrections on the re-test applications and pre-tests were noted, as well as the marks scored by students on these, in comparison to the actual test on a section.

Through the ISLE activities, students learnt behaviours that are valued in the physics classroom, and which will enable them to better access physics knowledge. ISLE-approach activities encourage active engagement, the transfer of knowledge between contexts (Section 2.2.1), the use of representations, which assist students in making connections between the domains of a problem or scenario (Section 2.2.3) and grappling with concepts.

From the responses and quotes from students, it was evident that students also value these behaviours and that many students are developing them. Student responses indicate that they have actively engaged in learning. The

ISLE approach advocates experiments rather than demonstrations. However, in our context, where time is constrained, demonstrations were adequate to convince students of phenomena, to visualise the physics, and to help them connect concepts. A number of students also adopted the behaviour of drawing diagrams without prompting to help them visualise the physics. Many students saw benefit in using representations to help them understand the concepts, whether those representations were diagrams or practical investigations and demonstrations.

Some students began to look for the underlying physics principles when faced with a problem, although it was evident that many still practised problems without considering the physics - looking for an equation to apply or doing past papers without looking for patterns across the questions. Working through examples is necessary to practise the skill of solving problems and can assist students in constructing a coherent knowledge structure, including connections between concepts (Section 2.2.5). Continued emphasis on looking for the underlying physics and making these connections while solving problems may help students to apply concepts, and to see the patterns across problems, rather than learning *how to* solve one particular problem in isolation. This requires modelling and engaged practice, which the structured pre-test reflection process facilitates, but perhaps students need to initially verbalise their reflection to a peer or teacher to build the habit of appropriate reflection, which I will encourage in future.

The ISLE activities also encourage students to grapple with concepts and to interrogate how they know something. Grappling with a concept can be achieved through reflection, which leads to generalisation and then to transfer. We valued reflection by explicitly making this the gateway to re-tests through the application process and then valuing the role of reflection as part of the pre-test process. The ISLE approach did not change all students' views on where knowledge comes from, nor persuade them to always question how they know what they know. This may be because we did not do enough activities that required this or because we did not value this explicitly enough. Many students remained performance-orientated, struggling to shift their mindsets from ‘learning to perform’ to building understanding. In many students’ minds, marks seemed to validate knowers. Unfortunately, time constraints limited the extent to which we could use exploratory activities in the development of the sort of knowers who will be life-long learners. Students enjoyed getting problems right and the sense of achievement that this gives, but many did not yet find joy in the satisfaction of achieving understanding through grappling.

Students also disliked making mistakes, particularly if they had a performance-orientated mindset, and so were not comfortable with our expectation that they grapple and make mistakes in order to learn. Many also chose not to engage properly with tests, particularly when they had done badly, as this was uncomfortable. This represents a code clash (see Section 4.3) between the philosophy of the ISLE approach which values learning from mistakes and the performance-orientated mindsets of our students. Although this study has not focused on the well-being aspect of the ISLE approach, this is relevant here, as fostering a learning environment where students feel safe to make mistakes and ask questions, can support their learning.

It has been acknowledged that when applying the ISLE approach, less content can be covered, as building knowledge takes longer (even though it means that concepts are better understood) (Etkina, Brookes and Planinšič, 2019). In South Africa, the externally examined curriculum dictates what is taught and teachers have a responsibility to their students and other stakeholders (parents, school management) to teach their subject thoroughly and completely to prepare the students as best they can for the high-stakes examination. This means that any activities that develop additional skills and deepen understanding need to be over and above the stipulated curriculum. Any tasks that would reduce time for teaching in preparation for assessments would have to be carefully planned and efficient in their goal, so as not to disadvantage the students. If we were to make time for more design experiments, which build critical thinking skills, these would need to assist conceptual understanding. There is conflict between the aspirations of the South African National Curriculum Statement, which aims to produce students who are capable of ‘critical and creative thinking’ (Department of Basic Education, 2012, p. 5) and the reality of a time-constrained learning environment, where there is little time for exploration of concepts or extensive engagement to develop these thinking skills.

There is also a code clash between our expectations that students develop the behaviours that we value and the student focus on assessment and performance goals. One way to navigate this code clash is to be explicit with students about the desired outcome or goal of each activity: is it assisting them in their preparation to write an examination on the content, or is it assisting them in learning physics or deepening their understanding? While these are often seen as one and the same thing, sometimes they are not aligned.

The ISLE experiments and many of the activities expect students to self-scaffold. This proved challenging for most students, which may be owing to the level of maturity of the students or to the novelty of the approach to experiments. Perhaps, with more frequent exposure to similar activities, students would gain confidence as well as familiarity with the expectations and process of these experiments.

## 8.3 Conclusion of study

The ISLE-approach activities were found to legitimate the behaviours that we value in physics students to a varied extent and, with continued use, would develop these behaviours in students. All ISLE-approach activities required students to actively engage in the learning process, which is critical to learning. The ISLE activities also legitimated grappling with concepts, making connections between the abstract, concrete, conceptual and symbolic domains with the aid of representations and being able to transfer knowledge to new contexts. The students' experience confirmed that these behaviours were valued and were being developed.

Two ISLE activities that were particularly effective were the Newton's third law observational experiment and pre-tests. Many students mentioned the activity where they discovered Newton's third law as being a powerful learning moment. This is an example of an activity that can induce conflict so that students interrogate their understanding to achieve conceptual change (Posner et al., 1982).

The pre-tests were also successful in improving student well-being, developing valued behaviours, as well as improving achievement in some cases, which may indicate an improvement in conceptual understanding and transfer. The pre-tests were ISLE-inspired and based on the theory of conceptual change (Posner et al., 1982) and the importance of reflection, self-assessment and making the basis of achievement clear to all. The pre-tests helped students to identify gaps in their knowledge and to approach the assessment with greater confidence.

Some students retained a performance-orientated mindset, and this inhibited their development of some of the valued behaviours, such as the ability to grapple with concepts. Students who were pursuing the 'right answer' were often reluctant to problem solve and try approaches that might not take them straight to the answer and they missed learning opportunities when they looked up the answer or bypassed the grappling in some other way. This code clash may be resolved in time by explicit modelling of grappling, discussing the benefits of this behaviour and continually encouraging it through many activities.

The time constraints and demands of the curriculum would most likely hinder a full-scale implementation of the ISLE approach in South African high schools. However, there are many ISLE activities which can be incorporated into the South African physics classroom, which not only assist students in constructing physics knowledge, but also validate and develop the behaviours that we value in physics students. That said, this study showed the relative success of these activities in a well-resourced, independent school, with teachers who were well-qualified in physics and still found the implementation of the ISLE approach to be challenging. Careful scaffolding of the ISLE activities and extensive teacher training and mentoring would be necessary to implement the ISLE approach in a wider range of schools.

Legitimation Code Theory (LCT) offered an appropriate lens and analytical framework to study the implementation of ISLE, as both emphasize the importance of access to knowledge for all students and being explicit about the objectives of the activities.

While the focus of this study has been on the process of learning physics, student well-being is an important consideration in the physics classroom, as emphasized by the ISLE approach. Students who feel comfortable, safe and confident are empowered to actively engage in the learning experience, and have the courage to grapple with concepts and problems. Students who feel uncomfortable or fearful in the learning environment are more likely to experience a narrow focus of ‘survival’ and will struggle to see the connections between concepts which facilitate transfer and deep learning.

Curating a learning environment that values and supports students, and enhances their well-being, impacts students’ capacity for physics learning.

## 8.4 Contribution to new knowledge

In this study, I have implemented the ISLE approach in a South African high school and explored the experience of students. A key difference between our context and other contexts in which the ISLE approach has been implemented is that we are constrained by an externally determined curriculum, and our students write set an externally set exit examination.

Legitimation Code Theory (LCT) provided a novel and fitting lens and framework with which to view the ISLE approach. Both ISLE and LCT advocate for enabling access to learning and emphasizing the process of building knowledge structures.

I have implemented the ISLE approach, using the activities that the ISLE research group has developed, but also developed two novel ISLE-inspired activities in adapting re-tests to pre-tests and designing an examination reflection tool.

## 8.5 Limitations of study

There are always aspects of a study that could be improved. In this study, not all the cohorts had the same time or extent of exposure to the ISLE approach because the approach was implemented in Grades 9-12 over a three-year period. Different classes were also taught by different physics teachers and not all teachers implemented the ISLE approach in the same way. The time frame between pre- and post-CLASS surveys and the time of exposure to physics also varied. While this is a consideration in looking at the results, this study needed to fit in with the curriculum and the school timetable and this was a necessary compromise. All changes in student belief (as indicated by CLASS) cannot be attributed to instruction, which agrees with Adams et al. (2006).

The South African context constrained the extent to which we could include ISLE activities. The significant emphasis on summative assessment by the schools, universities, and colleagues across all subjects at high school and, consequently, the students, also posed a challenge to the implementation of the ISLE approach. The ISLE approach values learning from mistakes and also requires class time for tasks which might not directly impact students' preparation for assessment.

The impact of the pre-tests was analysed by comparing a student's mark for the pre-test and their mark for the test. It would have been insightful to ask students to talk through their test, so that a teacher could determine the student's understanding, which is not always reflected in the marks. This would have been helpful in unpacking why students who appeared to have prepared thoroughly, done corrections on their pre-test and reflected extensively, did not see the expected improvement in the summative test.

The data collection for this study relied on student participation. The students were conscientious in responding in the surveys, but the post-lesson reflection responses tapered off within a few weeks, as the students forgot to reflect, and the teachers forgot to remind them. The post-lesson reflection task did not offer sufficient responses over a long enough time to draw conclusions.

One last limitation was the novelty of the ISLE approach in our context. I implemented the ISLE approach as I was learning about it myself and this study was conducted during this introductory period. Buggé et al. (2023) found that instructors who have had exposure to ISLE, are better able to guide students to developing the scientific abilities that the course intends developing. From the findings of her study and my own experience of trying to implement the ISLE approach, I believe that teachers need to be apprenticed into teaching ISLE, working alongside other teachers who have experience in implementing the ISLE approach. The students' experiences may have been different, had I already been an experienced ISLE teacher. However, I grew in my practice and this study describes the process of the implementation. As an outsider to the ISLE community and also an outsider to the LCT community, I have had to build knowledge in both frameworks, as well as developing the behaviours that they value. This has not been easy and has highlighted the importance of apprenticeship. There were online workshops which I attended in both LCT and ISLE, but both required active participation, which was uncomfortable initially in particular, when I knew very little. This gave me empathy for students who are immersed in unfamiliar physics and expected to participate in lessons, even when they do not know what is going on and it is uncomfortable.

## 8.6 Suggestions for further research

The ISLE approach was implemented and researched for the first time in a South African high-school physics context and evaluated the extent to which the activities legitimated and developed certain valued behaviours, as well as the student experience of the approach. There is much more, beyond this introduction, that can be explored. In this section, I will describe some ideas for expansion of the use and exploration of ISLE in the South African high-school context.

The introduction of the ISLE approach was tailored for the schools where it was implemented, as well as for the prior knowledge expected and the desired outcomes. 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, which would be particularly important in our South African context, where schools and students are not all home-language English speakers.

This study implemented the ISLE approach over a period of three years to various classes. A comparative study could use ISLE activities with just one cohort, from Grade 9-12. This longitudinal study could allow the researcher to evaluate more conclusively how repeated exposure to ISLE activities develops behaviour. It may also offer insights on how students of different ages respond to ISLE activities.

This study did not interrogate the student experience based on student (or teacher) gender, although the gender of the students whose responses were used was recorded in the presentation of data. This could be of interest for future study. It would also be interesting to ask colleagues to implement aspects of the ISLE approach and to research the experience of the teacher(s) rather than the students' experience.

I believe that the Legitimation Code Theory dimensions of Semantics and Autonomy would offer interesting insights into the ISLE approach and a further study could employ these to look at classroom practices.

Lastly, the ISLE approach values both physics learning and student well-being. The emphasis of this study has been predominantly on the students' physics learning experience. However, a consideration for student well-being has underpinned all aspects of the implementation of the ISLE approach in this context. Future work could look at student well-being and particularly what causes an improvement or decline in student confidence and student motivation.

## 8.7 Researcher's reflections and implications for teaching

This study has provided me with the opportunity for professional development and has impacted my ideas on learning and teaching. I speak to my students about valued behaviours and am explicit about the importance of developing them. I have four ideas for future change to my own practice, which have grown out of this study and which I will record here.

### *8.7.1 Include more design experiments*

Design experiments have been shown to strengthen conceptual learning (Hmelo, Holton and Kolodner, 2000) and are commonly used by physicists in their everyday work (Van Heuvelen, 2001). They also usually require students to integrate and apply knowledge, which supports the task of constructing a coherent knowledge structure (Van Heuvelen, 2001). However, I did not include as many design experiments as I would have liked to, due to time constraints. I would like to review the concepts that we cover and see where I can incorporate more of these activities, perhaps earlier in the course, where the time pressure is a little less. Unfortunately, there is no mention of the falsification of theories in the curriculum. Thus, any activities that focus on this are taking time away from the examinable content, unless the activity is designed to teach content.

### *8.7.2 Encourage students to self-explain*

Students need to be encouraged to self-explain concepts, perhaps even working through activities in a think-aloud setting. Asking students to explain their thinking encourages deeper, more effective engagement (McDermott, 1991; DeVore, Marshman and Singh, 2017) and students who engage in think-aloud learn more than those who do not (Chi et al., 1994). It was hoped that the pre-test reflection task would prompt students to explain their reasoning, but perhaps an additional step needs to be added to the process where students pair up and explain their thinking to a peer, once they have had a chance to do corrections and reflect. Not only would this ensure that all students did corrections and reflected, but students would have the opportunity to articulate their thinking, which should clarify their understanding.

### *8.7.3 Initiate study groups*

It was clear from the Grade 12 focus group that the students enjoyed talking about how they learn physics and found it beneficial to hear others' ideas and to articulate their own thoughts on learning, knowledge and physics. It is also an important underpinning of ISLE that collaboration and community should be valued.

Initiating or encouraging study groups could be helpful to students if the focus is on building collective understanding by finding connections between topics, rather than memorisation (Willson-Conrad and Kowalske, 2018).

### *8.7.4 Structure activities that validate behaviours*

Many of the ISLE activities that I introduced had the feeling of add-on tasks. For example, the reflection task was often done as students were leaving the class. Incorporating an opportunity for students to reflect on their learning ('Reflection Points') in the student workbook at strategic points may emphasize the value that we place on reflection and will also give students the opportunity to reflect.

Another activity that could be included either on a wall in the classroom or in the workbook is a mind map of concepts, which we could construct collaboratively as we cover concepts to encourage a coherent knowledge structure. Another activity that encourages reflection and linking concepts

would be ending each lesson by pairing students up and having them summarise the lesson for one another.
To encourage students to see the value in an activity and to ensure that they are clear what the purpose, the focus and the desired outcome of a task is, each activity should perhaps begin with an aim or an explicit purpose. While I did describe this verbally, having it in writing may assist students in aligning their efforts with the purpose of the activity.

Although I want to promote learning goals and to legitimate the learning process and the behaviour that we value in the physics classroom, my responsibility as a teacher necessitates that I legitimate performance goals to prepare my students for the external examination based on a very full curriculum. In our context we are challenged to prepare our students to pass a high-stakes exit examination that will determine their access to future study, while encouraging active learning and student participation to develop deep understanding and learning. By developing valued behaviours, we assist students in deepening their understanding to prepare for the examination while also equipping them with the tools and behaviours that will enable them to be lifelong learners.

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# APPENDICES

**Appendix 1:** Waves investigation

[Only used with a few classes, but illustrates 'need to know'.]

(Link back to text)

***Motivating Question: How do sound cancelling headphones work?***

**Observe and explain**

a. Go to [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-11-6-1]. Observe and describe what happens. What do you see when two pulses coming from opposite directions meet?

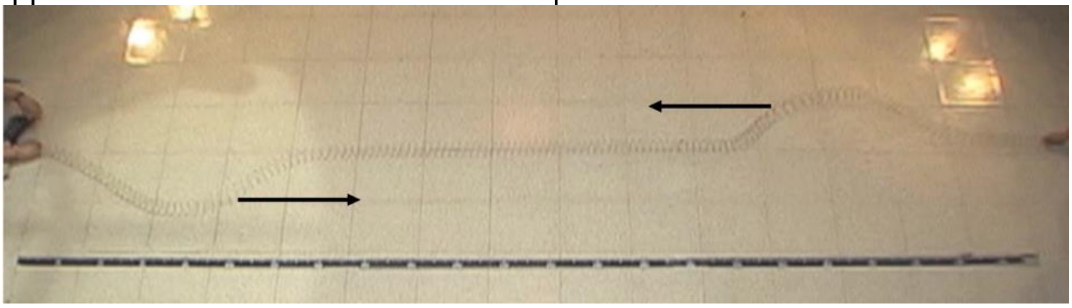
b. Brainstorm one or two ideas to explain what is happening when the two pulses meet each other.

c. If you come up with two competing ideas as to what happened, brainstorm ways in which you could conduct a testing experiment to decide which of these two ideas is correct.

**Test your ideas**

*Before* you watch the video, answer the following questions:

In this video, two oppositely oriented pulses approach each other from opposite directions as shown in the snapshot below:



Use *each explanation* you developed in part b. above to make a prediction about what the Slinky will look like just *after* the two pulses meet. (One prediction based on each explanation.) Sketch them on the whiteboard and paste them into the slide for your team..

Now that you have sketched out your predictions, watch the following video [ALG 11.6.2] to see which explanation best predicts the behavior in this video. (Which prediction was consistent with the actual outcome of this experiment?)

How can it be that two pulses arrive to the same place at the same time and the spring appears to be flat? Where did the energy of the system go in the instant when the spring is flat?

Watch the following video at [https://youtu.be/XUPHgm9dLIE]. Is the outcome consistent with the explanation you chose in part b?

How might everything that we did help us explain how noise canceling headphones work?

These activities were developed from a number of resources from:
PUM | Kinematics

**Appendix 2:** Ethical clearance

**Documents pertaining to ethical permission to conduct this study:**

- Appendix 2.1: Ethical clearance letter (I)
- Appendix 2.2: Ethical clearance letter (II) updated to include permission to interview teachers.
- Appendix 2.3: Request for consent from parents
- Appendix 2.4: Introduction to ISLE for teachers to read to students
- Appendix 2.5: Request for assent from students
- Appendix 2.6: Request for consent from participating teachers

## Appendix 2.1: Ethical clearance letter (I)

RHODES UNIVERSITY
*Where leaders learn*

**Rhodes University Human Ethics Committee**
PO Box 94, Makhanda, 6140, South Africa
t: +27 (0) 46 603 7727
f: +27 (0) 46 603 8822
e: s.manqele@ru.ac.za
**NHREC Registration number: RC-241114-045**

**https://www.ru.ac.za/researchgateway/ethics/**

23/07/2021

Kate Cobbing

Email: g00b0010@campus.ru.ac.za

Review Reference: 2021-5074-6199

Dear Dr. Jennifer Williams

**Title:** Implementing the Investigative Science Learning Environment (ISLE) approach in high school physics teaching

Principal Investigator: Dr. Jennifer Williams

Collaborators: Mrs. Kate Cobbing, Mrs. Joyce Sewry

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Human Ethics Committee (RU-HEC). Your Approval number is: 2021-5074-6199

Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying when the annual report is due.

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 the 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 cataloging number allocated.

Sincerely,

Arthur Webb

**Prof Arthur Webb**

**Chair: Rhodes University Human Ethics Committee, RU-HEC**

cc: Mr. Siyanda Manqele - Ethics Coordinator

[Link back to text]

## **Appendix 2.2: Ethical clearance letter (II) updated to include permission to interview teachers.**

Rhodes University Human Research
Ethics Committee
PO Box 94, Makhanda, 6140, South Africa
t: +27 (0) 46 603 7727
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za
**NHREC Registration number: RC-241114-045**

**https://www.ru.ac.za/researchgateway/ethics/**

29 July 2022

Dear Mrs Cobbing,

Re: Protocol amendment for *Implementing the Investigative Science Learning Environment (ISLE) approach in high school physics teaching.*

This letter confirms that the RU-HREC has reviewed the proposed changes to your research protocol and approved your request to employ an additional research instrument during your research.

Approval has been granted for 1 year. An annual progress report will be required to renew approval for an additional period. You will receive an email notifying you when the annual report is due.

Approval number: 2022-5074-6932

Sincerely,

Janet Hayward

Dr Janet Hayward
Chair of Rhodes University Human Research Ethics Committee

[Link back to text]

## Appendix 2.3: Request for consent from parents

Dear parents

I am emailing to request your consent for your [*Grade 10 daughter*] to participate in a study which will be conducted in their Physics classes, beginning next term. Please read the information in the attached form (Parents' Consent Form) and, if you have no objection, please complete and return the form. If you do not wish to allow us to use the responses given by your daughter, please could you indicate this when you complete the form or simply respond to this email with "no" or a similar negative response. I will then not contact you again when I follow up on non-respondents in future. Please feel free to contact me if you have any questions or concerns.

In brief, we are trialing a more investigative approach to learning physics, with collaborative tasks to develop scientific abilities. One of the primary goals of the approach is to improve student confidence and well-being in the classroom. I am going to use quantitative and qualitative research methods to evaluate this approach, but need your consent to use your [*daughter*]'s responses. The larger sample that we can evaluate, the better we can assess the approach, so please consider giving your consent.

All physics students from Grade 9 – 11 in all classes (not just my classes) will participate in investigations run within our normal teaching schedule, regardless of your consent for me to use their responses. The activities and investigations will not involve any tasks that we do not believe will have direct benefit to the students. We are trialing this new approach to test its effectiveness. Your consent will just allow me to study your [*daughter*]'s responses to evaluate the effectiveness of the approach.

I appreciate your time in completing the form and please do get in touch if you have questions or concerns.

Should you request feedback, I will make this available when the longitudinal study is completed in 2024/5.

Thank you so much.

Regards

Kate

[Link back to text]

# Consent Request for Parents

This form is to replace a letter requesting consent that was previously sent out. My hope is that this will be easier and more efficient to complete and return.

* Indicates required question

## PARENT AND GUARDIAN'S INFORMED CONSENT DECLARATION

Implementing the Investigative Science Learning Environment (ISLE) Approach in High School Physics Teaching.

The students that we teach are exposed to a continuous flow of information, which they are expected to decode and evaluate. In their future workplaces, they will also be expected to be adaptable problem-solvers. The Investigative Science Learning Environment (ISLE) approach has been shown to promote a way of thinking that encourages students to question and critically evaluate the information that they are presented with. In addition, one of the primary goals of ISLE is to enhance each student's well-being in the Physics classroom.

Mrs Kate Cobbing will investigate the impact of this new teaching approach (ISLE) on students' confidence, attitude to Physics and their development of scientific abilities. All students will participate in the same activities in class and complete the reflections, self-assessment tasks and surveys, but Mrs Cobbing will only use the responses from those students who give assent and whose parents have given consent.

In addition to these written responses, Mrs Cobbing will use audio and / or video recording of group work activities in the Physics classroom so that she can evaluate some of the discussion while managing the classroom as a teacher, rather than a researcher. These recordings will be made with the students' assent and knowledge and the contents of the recordings will be viewed only by Mrs Cobbing and only for the purpose of capturing the discussion about the Physics task.

Mrs Kate Cobbing from the Department of Physics and Electronics, Rhodes University has requested my permission to allow my child/ward to participate in the above-mentioned research project.

The nature and the purpose of the research project, and of this informed consent declaration have been explained to me in a language that I understand.

## Declaration

1. The purpose of the research project is to investigate the impact of the Investigative Science Learning Environment (ISLE) approach on students' confidence, attitude to Physics and their development of scientific abilities.

2. The Rhodes University has given ethical clearance to this research project [2021-5074-6199] and I have seen/ may request to see the clearance certificate from Mr. Siyanda Manqele (s.manqele@ru.ac.za).

3. By participating in this research project my child/ward will be contributing towards the evaluation of a new way of teaching which should benefit students. The collection of rich and extensive data will allow a better evaluation of the impact of this approach and will provide evidence for other teachers on the benefits of its implementation.

4. My child/ward will participate in the project by completing activities, surveys, self-assessment rubrics and reflection tasks related to the Physics curriculum.

5. My child/ward's participation is entirely voluntary.

6. Should I or my child/ward at any stage wish to withdraw from participating further, we may do so without any negative consequences.

7. My child/ward may be asked to withdraw from the research before it has finished if the researcher or any other appropriate person feels it is in my child/ward's best interests, or if my child/ward does not follow instructions.

8. Neither my child/ward nor I will be compensated for participating in the research.

9. There may be risks associated with my child/ward's participation in the project, such as feelings of awkwardness and embarrassment. Every effort will be made to minimise these feelings.

10. Mrs Cobbing intends publishing the research results in the form of an academic thesis with possible papers written thereafter. However, confidentiality and anonymity of records will be maintained and that my or my child's/ward's name and identity will not be revealed to anyone.

11. I will not receive written/verbal feedback regarding the results obtained during the study unless specifically requested in the form of a phone number or email address provided at the end of this form.

12. Any further questions that I might have concerning the research or my participation will be answered by Mrs Kate Cobbing . or g00b0010@ ru.ac.za).

13. By returning this informed consent declaration I am not waiving any legal claims, rights or remedies that I or my child/ward may have.

14. Record of the return of this form will be stored electronically (in a spreadsheet) by the researcher.

1. Please tick the appropriate boxes to indicate your consent: *

*Mark only one oval.*

- ( ) I agree to Mrs Kate Cobbing's request to take photographs, take audio recordings or videos of my child/ward during Physics activities as part of this research project (identifying features on any published photographs will be obscured).
- ( ) I DO NOT AGREE to Mrs Kate Cobbing's request to take photographs, take audio recordings or videos of my child/ward during Physics activities as part of this research project (identifying features on any published photographs will be obscured).

2. Please tick the appropriate boxes to indicate your consent: *

*Mark only one oval.*

- ( ) I agree to Mrs Kate Cobbing's use of voice recording of my child/ward's comments and opinions during interviews, should my child/ward participate in an interview on Physics learning.
- ( ) I DO NOT AGREE to Mrs Kate Cobbing's use of voice recording of my child/ward's comments and opinions during interviews, should my child/ward participate in an interview on Physics learning.

CONSENT DECLARATION:

I have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of the contents of this document. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of my child/ward during the research. I have not been pressurised in any way to let my child/ward take part. By signing below, I voluntarily agree that my child/ward, named below, may participate in the above-mentioned research project.

3. Name of parent/ guardian: *

_______________________

4. Name of child: *

_______________________

5. I consent to my child's participation in this research. *

*Check all that apply.*

- [ ] Yes
- [ ] No

6. I request feedback on this research to be sent to me at:

______________________________

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This content is neither created nor endorsed by Google.

Google Forms

[Link back to text]

**Appendix 2.4: Introduction to ISLE for teachers to read to students**

- This survey must be completed in class and only students in class should have access to the form. Please remove the post from your Classroom once students have had the opportunity to complete the form. This is because it is based on a survey which has restricted access and I have had to agree to not sharing this with students in an environment that is not carefully controlled.

**Please read the following to your class before giving them the opportunity to complete the Google Form.**

- We are testing a new approach to teaching physics, which we hope will improve your learning experience.
- The new approach is called ISLE (*pronounced like a small island*) and is thought to develop 21st century skills, enhance learning, build confidence and encourage a growth mindset (when students believe that intelligence is not fixed, but can be developed).
- Mrs Cobbing is collecting data to evaluate the effectiveness of this new approach.
- While everyone will be participating in the new activities and the whole class will reflect on their learning (as this is considered a valuable activity), Mrs Cobbing can only use and study the responses of those students who have given their assent and whose parents have given consent.
- There is no benefit to you for giving Mrs Cobbing permission to use your responses nor will there be consequence for not giving Mrs Cobbing permission to use your responses. However, the more responses she can use, the richer and more valuable the study will be.
- Should you give permission, you may withdraw at any time.
- You will be completely unaware of the use of your responses for the study, they will be anonymized and no one else (other than Mrs Cobbing) will know what your answers were.
- Your answers in surveys and reflections will have no effect on your marks at all.
- The potential risks to this approach are that you may feel uncomfortable and challenged by this new approach. All students may experience this regardless of whether they allow their responses to be used or not. "If you're comfortable, I'm not teaching and you're not learning." (*David Brookes; 2019*) This is because transforming your view of the world is uncomfortable.
- If you have any questions about the study, you are welcome to contact Mrs Cobbing or come and see her during the Physics Support opportunities that are advertised.

[Link back to text]

## Appendix 2.5: Request for assent from students

[Link back to text]

# Consent for Participation in Study

This form requests your permission for Mrs Cobbing to use the responses that you give in tasks, reflections and possible interviews to assess the effectiveness of a new approach to teaching.

The second part of the form will ask you some questions related to your understanding of Physics and scientific skills. Your answers to these questions are just for my information and will have no impact at all on your Physics mark in class. They will allow me to see if and how your understanding and attitude change.

* Indicates required question

---

PARTICIPANT INFORMED ASSENT DECLARATION

Implementing the Investigative Science Learning Environment (ISLE) Approach in High School Physics Teaching.

Mrs K. Cobbing, conducting research through the Department of Physics and Electronics, Rhodes University has requested my permission to participate in the above-mentioned research project.

Declaration

The nature and the purpose of the research project and of this informed assent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to investigate the impact of the Investigative Science Learning Environment (ISLE) approach on students' confidence, attitude to Physics and their development of scientific abilities.

2. Rhodes University has given ethical clearance to this research project (2021-5074-6199) and I have seen/may request to see the clearance certificate by contacting Mr Siyanda Manqele (s.manqele@ru.ac.za).

3. By participating in this research project I will be contributing towards the evaluation of a new way of teaching which should benefit students.

4. I will participate in the project by completing activities, surveys, self-assessment rubrics and reflection tasks.

5. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.

6. I will not be compensated for participating in the research.

7. The following risks are associated with my participation: feelings of awkwardness and discomfort when learning in a different way.

8. The research results will be published in the form of an academic thesis and possible academic papers thereafter. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone other than the researcher.

9. I will receive feedback in the form of class discussion regarding the results obtained during the study.

10. Any further questions that I might have concerning the research, or my participation will be answered by Mrs Cobbing in person or via email: , or g00b0010@ru.ac.za

11. By returning this assent declaration, I am not waiving any legal claims, rights or remedies.

12. The responses to this form will be kept on record in a spreadsheet.

1. Please tick the appropriate boxes to indicate your consent: *

*Check all that apply.*

- [ ] I agree to Mrs Cobbing's request to take photographs, take audio recordings or videos of me during Physics activities as part of this research project (identifying features on any published photographs will be obscured and audio and video recordings will be for Mrs Cobbing's reference only).
- [ ] I DO NOT AGREE to Mrs Cobbing's request to take photographs, take audio recordings or videos of me during Physics activities as part of this research project (identifying features on any published photographs will be obscured and audio and video recordings will be for Mrs Cobbing's reference only).
- [ ] I agree to Mrs Cobbing's use of voice recording of my comments and opinions during interviews on Physics learning, should I participate in an interview (these recordings will be for Mrs Cobbing's research only and will not be available to anyone else).
- [ ] I DO NOT AGREE to Mrs Cobbing's use of voice recording of my comments and opinions during interviews on Physics learning, should I participate in an interview (these recordings will be for Mrs Cobbing's research only and will not be available to anyone else).

CONSENT DECLARATION:

I have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of the contents of this document. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

2. My first name *

______________________________

3. My surname *

______________________________

4. I am currently in *

*Mark only one oval.*

- ⬭ Grade 8
- ⬭ Grade 9
- ⬭ Grade 10
- ⬭ Grade 11

5. I agree to allow Mrs Cobbing to use my responses in her research. *

*Check all that apply.*

- ☐ Yes
- ☐ No

---

[Link back to text]

## Appendix 2.6: Request for consent from participating teachers

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### PARTICIPANT INFORMED ASSENT DECLARATION

**Implementing the Investigative Science Learning Environment (ISLE) Approach in High School Physics Teaching.**

Mrs K. Cobbing, conducting research through the Department of Physics and Electronics, Rhodes University, has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to investigate the impact of the Investigative Science Learning Environment (ISLE) approach on students' confidence, attitude to Physics and their development of scientific abilities.

2. Rhodes University has given ethical clearance to this research project *(*2022-5074-6932*)* and I have seen/may request to see the clearance certificate by contacting Dr Janet Hayward (j.hayward@ru.ac.za).

3. By participating in this research project I will be contributing towards the evaluation of a new way of teaching which should benefit students.

4. I will participate in the project through voluntary reflections on my experience of activities run in my Physics class, as well as voluntary interviews and / or focus groups.

5. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.

6. I will not be compensated for participating in the research.

7. The following risks are associated with my participation: feelings of discomfort when reflecting on an unfamiliar approach to teaching.

8. The research results will be published in the form of an academic thesis and possible academic papers thereafter. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone other than the researcher.

9. I will receive feedback regarding the results obtained during the study, should I request it.

***Please tick the appropriate boxes to indicate your consent:***

□ I **agree** to Kate Cobbing's request to provide feedback on my experience of using activities based on the ISLE approach during Physics activities run in my classroom as part of this research project (audio recordings and written feedback will be for Kate Cobbing's reference only)

10. Any further questions that I might have concerning the research, or my participation will be answered by Kate Cobbing in person or via email: or g00b0010@ru.ac.za

11. By signing this informed consent declaration, I am not waiving any legal claims, rights or remedies.

12. A copy of this informed consent declaration will be given to me, and the original will be kept on record.

I, …………………………………………………………………………., have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of the contents of this document. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

…………………………………. …………………………

**Participant's signature** **Date**

Rhodes University, Research Office, Ethics
Ethics Coordinator: ethics-commitee@ru.ac.za
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[Link back to text]

**Appendix 3:** ISLE approach and ISLE-inspired activities

## Activity I: Representations: introduction to motion (bean bags)

An investigation of moving objects

Watch the video clips showing four different rolls of a ball. Rolling bowling ball. Pause the video after each experiment and use the data from the video to sketch the position of the bean bags by representing them as dots.

Slow bowling ball:

Faster bowling ball:

Bowling ball on carpet:

Ball pushed with a board:

What patterns did you notice in the placement of the dots?

How can you use the distances between the dots to describe the motion of thebowling ball?

[Link back to text]

## Activity II: Representations: motion diagrams

[Link back to text]

A **hypothesis** is a general belief, pattern, model, or rule developed from observations. Hypotheses can be used to develop predictions.

A **prediction** is a statement that describes the outcome of a specific experiment (prior to conducting the experiment). Predictions must be based on the hypothesis being tested.

A **testing experiment** is an experiment whose outcome you should be able to predict using the hypothesis being tested. The experiment tests the hypothesis, not the prediction. A testing experiment cannot prove the hypothesis to be correct (if its outcome matches the prediction) but might disprove it (if the outcome does not match the prediction).

An **assumption** is some factor in the physical situation you choose to ignore or assume to be true, that simplifies a calculation or a model, or an experiment.

For example, you might say that when you apply brakes while riding a bicycle, *your stopping distance depends on the speed at which you are cycling* (**hypothesis**). If you cycle fast at different speeds and apply the brakes (**testing experiment**), your stopping distance will be larger for greater speeds and smaller for slower speeds (**prediction**). This will be true when the braking conditions are the same in each test (assumption).

---

Place a ball on a flat surface. Practice rolling the ball along the surface.

Describe the motion of the ball as best as you can. Is the ball moving at a regular pace? Is it speeding up? Slowing? How do you know?

**Test Your Idea**

Think what it means to test an idea. In physics, experimental testing consists of the following steps:

1) you accept the idea (the hypothesis) being tested as true;
2) you design an experiment whose outcome you can predict using this idea;
3) you make the prediction of the outcome (here you also need to think of what you assume to be true in addition to the idea you are testing—these are called *assumptions*);
4) you perform the experiment and compare the outcome to the prediction, and based on the comparison, you make your judgment concerning the idea being tested.

In the previous activity you observed the ball and came up with an idea – a hypothesis – about how the ball is moving. Let us test this idea by performing a new experiment.

The goal is for your team to follow the ball as it travels in detail, the same way a real physicist would.

With your teammates, think of a way to keep the clock reading and mark the location of the ball for each second as it rolls. You can use any marking method you think is appropriate. Describe your method and practice until you are comfortable.

To practice your counting, you can look at a second hand on a stopwatch while tapping on a desk or shouting a word.

If you use a word to keep count, make sure that when you say your counts for each second, they are brief; for example "now". Always practice enough so that you are comfortable keeping a consistent counting method going.

---

a) Now that you have a method for marking the location of the ball for each second as it rolls, design an experiment to test the idea of how the ball rolls.

b) Predict what the marks would look like if the ball ***were moving according to the hypothesis*** you came up with in the previous activity.

c) Conduct the experiment.

d) Explain how you can use the marks to describe the motion of the ball.

e) Remember that after every testing experiment you must compare the actual outcome to your predicted outcome.

How did yours compare?

Did the outcome match your prediction?

Explain how the evidence supports or disproves your hypothesis.

f) What assumptions did you make when writing your prediction?

---

**Assumptions** are issues we take for granted in an experiment. They can help us explain why the results weren't exactly as we expected or could be something that wasn't taken into account when we designed the experiment. Despite the outcome of the experiment, it's important to consider the assumptions that may have been made.

---

If the ball rolled faster than in (c), how would the marks be spaced? Use dots to represent the location of the ball and draw this dot diagram below.

Much like the experiment you just conducted, motion can be represented by marks or dots. We refer to this as a **dot diagram.**

---

Imagine that you have a wind-up toy that first moved slowly and then faster and faster. How would the dot diagram look?

If you had another toy that first moved fast and then slower and slower, how would the dot diagram look?

**Exercise:**

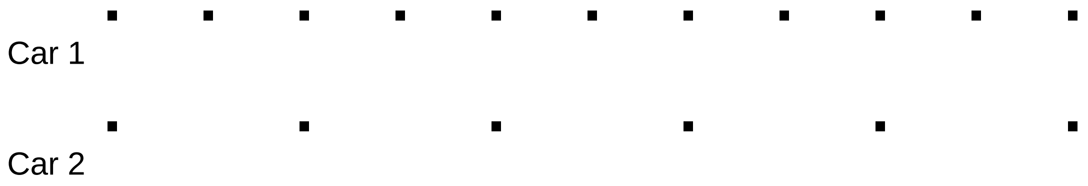
1. Imagine you are in a car that is coasting on a flat road at constant pace. Draw a dot diagram for it.

2. Now imagine the same car moving at the same constant pace only uphill. Draw a dot diagram for it. How are the diagrams the same? How are they different?

3. Now imagine that you are in a car speeding up from a street light. Draw a dot diagram for the motion of the car.

4. Now imagine the same car rolling downhill and speeding up. Draw another dot diagram. How are these two diagrams the same? How are they different?

5. You have two battery-operated toy cars that you can release simultaneously on a smooth floor and a metronome set to 1-second intervals. You and a friend each walk next to one of the cars, and at every “blip” of the metronome, you place a sugar packet at your car’s location. The dots in the figure below represent the locations of the sugar packets for the two cars. The cars start simultaneously at the dot on the left and move to the right.




5.1 Were the cars ever next to each other? If so, where?

5.2 Measure the distances between dots with your ruler, using the mm scale, and record the distance between dots:

Car 1: ___________________ Car 2: ___________________

These activities were developed from a number of resources from: PUM | Kinematics


[Link back to text]

**Activity III: Observational experiment: relative motion**

[Link back to text]

# Relative Motion Investigation:

### 1.1 Observe and Find a Pattern

In this activity you will use a tube "telescope" to follow an object.
During the first two experiments you will be THE OBSERVER. The observer must always keep the object in sight through the telescope. Consider the following situations:

a) In the first experiment, the teacher holds a ball and is standing still. **You are the observer**. Take note of the initial direction that the telescope points in order to see the ball through it.

**This is the original orientation of the telescope.**

b) Next, the teacher travels from one corner of the classroom to another. Make sure that you see the ball through the telescope at all times. What happens to your telescope as you follow the object?

c) For the next experiment, carefully observe your teacher. The teacher holds the ball the same way, but this time, **the teacher is the OBSERVER** and looks at the object through the telescope while traveling from right to left. What happens with the orientation of the teacher's telescope during the experiment?

d) Based on your experiences in part (a) through part (c):
- Can you say whether the ball was moving during the experiments in a) and b)? Explain your answer. (Hint: Compare what happened to the telescopes for the different observers.
- Based on this idea, is there anyone else that would observe the ball as not moving?
- In general, how do you know whether something is moving or not?

e) For the c) experiment, once again observe the orientation of the teacher's telescope. The teacher points the telescope at a classmate and looks through it. The teacher travels in the same way.

- Does the orientation of the telescope change?

- Does your classmate move? How do you know?

**1.2 Describe**

1. Consider the following situation:

- A blue car travels along a street with two passengers. One passenger sits in the front passenger seat of the car and the other passenger sits in the back seat.

- A red car travels in the same direction and is passing the blue car.

- There is a sidewalk along the road the cars are traveling and a pedestrian is standing on the sidewalk.

**Choose four students from your class to play the roles of the four people and recreate the situation.**

**Describe the movement of the front passenger in the blue car as seen by each of the following observers:**

| **Observer** | Motion of the passenger in the blue car |
|---|---|
| a) The person sitting in the backseat of the blue car. | |
| b) The pedestrian standing on the sidewalk as the blue car passes. | |
| c) The driver of the red car moving in the same direction and passing the blue car. | |

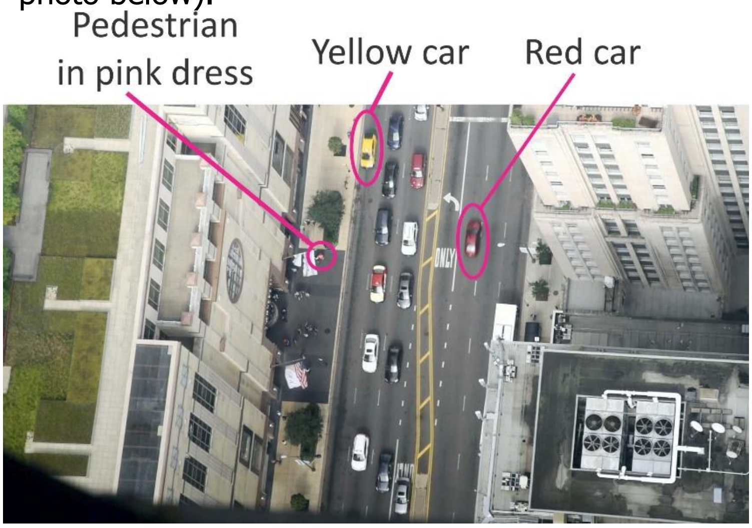
Review your analyses and answer the questions that follow.

d) Do any of the observers say that the front passenger in the blue car was moving? Explain.

e) Do any of the observers say that the front passenger in the blue car was **not moving**? Explain.

f) Based on your answers in parts (a) through (e) and activity 1.1, explain what it means when someone says an object is "moving".

2. Watch the video of cars moving on a street.
Use the comma and period keys on your keyboard to play the video frame by frame. Notice the yellow and red cars and a pedestrian in the pink dress on the street (see photo below).




**a.** Describe how a passenger in the yellow car sees the motion of the driver of the yellow car, the driver of the red car, the pedestrian on the sidewalk.

**b.** How does the pedestrian describe the motion of the driver of the yellow car?

**c.** Why would the passenger in the yellow car and the pedestrian disagree about the motion of the driver of the yellow car?

**d.** Based on your answers in parts a. through c., explain what it means when someone says an object is "moving" and what it means when we say "motion is relative".

---

**Motion:** An object is in *motion* with respect to another object (observer or reference object) if, as time progresses, its position is changing relative to the reference object.

**Reference frame:** A *reference frame* includes three essential components:

1. An object of reference with a point of reference selected as the origin of the coordinate system;
2. A clearly defined coordinate system. The coordinate system includes the direction of the axis, such as north, south, east, west, or positive and negative direction. The reference frame also includes a unit for measuring distances.
3. A zero clock reading that serves as a reference for future clock readings.

---

### 1.3 Test Your Idea

At this point you may have concluded that,

*"Different observers see the same motion differently".*

Another way of saying this is that,

*"Motion is relative".*

Consider the following experiment: Your friend carries an object and walks in a westerly direction.

a) Based on what you know about relative motion, **predict** what you would need to do to make the object appear stationary (not moving). Write your prediction and explain your thinking.

b) Use the idea of relative motion to **predict** what you need to do to see the object as moving in the easterly direction. Write your prediction and explain it.

c) Perform the experiment.

d) Make a judgment about whether the idea that motion is relative was supported or disproved by your experiment. Explain.

**1.4** **Relate** Use toy cars, marbles, and any other toys available in class. Come up with the observers who will see a car parked on your desk moving. Come up with observers who will see the car parked on your desk stationary. Repeat for another toy.

**1.5** **Design an experiment** Design an experiment in which one observer sees a toy car or a marble moving 1.3 m along a straight line in the direction left to right, another observer sees the same car (marble) not moving at all and the third observer sees the same car (marble) moving 1.0 m left to right. Describe your experiment in words and draw a picture so a person who did not see you perform the experiment can repeat it.

## *Homework*

### 1.6 Describe

Consider the following situation.

- A person stands near a bus stop.
- Another person is in an approaching bus.
- A person riding in a car travels away from the bus stop.
- Another person stands at the bus stop.

a) Describe the motion of the person standing near the bus stop as seen *by the following observers*:

| **Observer** | Motion of the person standing near the bus stop |
|---|---|
| The person sitting in the approaching bus. | |
| The person riding in the car moving away from the bus stop. | |
| The person standing at the bus stop. | |

b) Do any of the observers say that the person standing near the bus stop was moving? How do you know?

c) Do any of the observers say that the person standing near the bus stop was not moving? How do you know?

This activity was taken from the Kinematics 1 module from the Physics Union Mathematics (PUM) resources developed by Rutgers, The State University of New Jersey.

[Link back to text]

**Activity IV: Observational experiment: introduction to forces**

[Link back to text]

# Investigation 1: FORCES AS INTERACTIONS

1.1 Observe and describe:

a) Pick up a tennis ball and hold it in your hand. Now pick up a different ball and hold it. Describe the difference.

b) Think of a word that describes what your hand had to do to the tennis ball in order to hold it. Write possible words below:

*In Physics, we use the word **interaction** to describe what the hand does to the ball. It interacts with the ball. In any interaction, there are always 2 objects involved.*

c) Give two examples of other interactions, indicating the 2 objects:

1.2 Represent and reason:

a) Choose the tennis ball as your object of interest.

- The dot represents the tennis ball. Label it "ball".
- Think of how your hand had to push on the ball.
- Draw an arrow on your diagram (dot) to show how your hand pushes the ball.

*The tail of the arrow should be connected to the dot.*
*The arrow should point in the direction of the force that your hand exerts.*

b) How could you label this force arrow to show that it is the force that your hand exerts on the ball?

- Add this label to the representation alongside.

To show that the force arrow represents the push that the hand exerts on the ball, we can use a symbol $F$ with two little words at the bottom on the right. These are called subscripts. You can then write the force that your hand exerts on the ball as $F_{\text{Hand on Ball}}$.

c) Why don't we add the force arrow for how the ball interacts with the hand?

In part (a), we chose the tennis ball as our object of interest, or "system". A ***system*** is an object or group of objects that we are interested in analyzing. When we draw force arrows, we only consider the forces that are *exerted ON the system object(s).*

d) What do you think would happen to the ball if your hand (pushing just as hard as before) were the only object interacting with it?

e) What does this tell you about other objects interacting with the ball?

Name/list any other objects interacting with the ball.

In physics the word ***force*** is only used to note the physical quantity that describes how hard one object pushes or pulls another object. For a force to exist there must be two objects involved. **One object does not carry or possess a force.**

1.3 Represent and Reason

a) In activity 1.2 (e), did you say that gravity interacts with the ball? Gravity is not an object; you cannot hold or touch it. So, when we use the word gravity to note the downward pull on all objects on Earth, what is the object that exerts this downward pull?

b) Add another Force arrow on your diagram in 1.2(b), and draw it here: Label the Force arrow with the appropriate subscripts.

c) What do you notice about the length of the arrows on your diagram?

What do you think would happen to the ball if the arrow representing the interaction with your hand were *longer* than the arrow due to the interaction with the Earth?

What if it were the opposite --- *shorter*?

d) Now, draw a diagram for the second ball. How are the force arrows different from the arrows on the diagram for the tennis ball?

The diagrams that you created in activity 1.3 are used to represent the forces exerted on an object of interest (system) by other objects. Objects may be represented by a dot. The length of each arrow should correspond to the relative amount of force. (more force = longer arrow, etc.), and the direction of the arrow shows the direction of the force (push or pull). Draw the arrows coming outward from the object even when some objects are pushing on the object.

1.4 Test your idea

a) In part 1.2 (e), did you say that air interacts with the ball? How do you think air interacts with the ball?

b) Experiment: *A sealed 2-L plastic bottle is suspended from a spring inside a bell jar. A vacuum pump is connected to remove the air from the bell jar surrounding the bottle. A mark is made to indicate the suspended position of the bottle. What will happen when the air is removed from the jar?*

Before watching the video, write a prediction of what should happen to the bottle, based on your hypothesis about how air interacts with an object.

Prediction:

c) Watch the video:

**d)** Summarize the effect the air has on the ball.

**Note:** We often simplify situations in physics by ignoring air resistance. ***So, unless stated otherwise, air resistance is not considered.***

**Activity V: Observational experiment: Newton's third law**

[Link back to text]

# Investigation 2: NEWTON'S THIRD LAW

2.1 Observe and Explain

Both student A and student B sit on office chairs with wheels.

Student B pushes student A (or the chair that student A is sitting on) abruptly.
Draw force diagrams for both students. *What do you think the length of the force arrows should be on the diagrams?*

Perform the experiment. Use the diagrams to explain the observations.

*Give examples of three situations where two interacting objects exert forces on each other (for example, a tennis racket hits a ball, a person pushes a vacuum cleaner, the Earth pulls a leaf). Draw force diagrams for both objects separately and use the labels to find the forces that those objects exert on each other.*

What can you say about the forces that they exert on each other?

What can you say about the accelerations of those two objects?

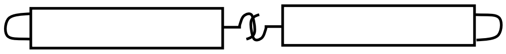
2.2 Test Your Idea

Student A and student B are both on rollerblades. The mass of student A is smaller than the mass of student B. Use what you learned in activity 2.1 to predict what will happen if students A and B start throwing a heavy medicine ball back and forth to each other.

Check whether your prediction matches the outcome in this video.

What do you notice?

2.3 Observe and Find a Pattern



You and your friend each hold a spring scale and you hook the scales to each other.
Observe what your friend's spring scale reads if you pull yours, exerting a force of 3 units. Record here.

Observe what your spring scale reads if she pulls, exerting a force of 5 units. Record here.

What can you say about the forces that the springs exert on each other?

*This is your "rule".*

2.4 Test Your Idea

Consider the following experiment: You and your friend hold a spring scale and you hook the scales to each other. You pull with 5 units of force and your friend tries to pull with 3 units of force.

Use your rule (from your observation above) to predict whether it is possible to achieve this.

Perform the experiment. Revise your hypothesis if your prediction did not match the outcome.

2.5 Observe and Explain

Student A and student B are on rollerblades. They each have one end of a rope tied around their waist. Student B pulls on the rope, which in turn pulls on student A.

Watch the video at:

Use your revised hypothesis [from 2.4 above] to explain what you observed.

---

You have just developed the idea of Newton's third law: go back to the front of the book and try some exercises.

---

## Activity VI: Testing experiment: water in a glass

[Link back to text]

In the investigations that follow, we are not going to ask you to answer questions based on your life experience or what you think will be the right answer.

We are going to ask you to predict an outcome for an experiment based on the hypothesis that we are testing.

**SOME TERMINOLOGY THAT WE NEED:**

An **explanation** is a statement of a possible reason for why something happened in the experiment or why we observed what we observed.

A **hypothesis** is a synonym for an explanation. There are multiple hypotheses that can explain what happened. A hypothesis is a general belief, pattern, model, or rule developed from observations. A hypothesis should be experimentally testable and can be used to develop predictions.

A **prediction** is a statement that describes the outcome of a specific experiment (before you conduct it) based on the hypothesis being tested. It says what should happen in a particular experiment if the hypothesis under test is correct. Without knowing what the experiment is, one cannot make a prediction; a prediction is not a guess. A prediction is based on the hypothesis being tested, not on intuition.
A hypothesis is something that we TEST experimentally. The prediction is something that we COMPARE to the outcome of the testing experiment. Thus, a prediction that does not match the outcome of the experiment shows a mismatch and makes us think whether we need to revise the hypothesis or to examine additional assumptions that went into the prediction. Predictions are not right or wrong, but they tell us whether our explanation (hypothesis) can be rejected or not.

A **testing experiment** is an experiment whose outcome you should be able to predict using the hypothesis being tested. The experiment tests the hypothesis, not the prediction. A testing experiment cannot prove the hypothesis to be correct (if its outcome matches the prediction) but might disprove it (if the outcome does not match the prediction).

An **assumption** is some factor in the physical situation you choose to ignore or assume to be true, that simplifies a calculation or a model, or an experiment.

---

***REMEMBER!* –** Your predicted outcome must be based on your hypothesis.

[Taken from the PUM resources (http://pum.islephysics.net/)]

# Design Experiment

## Hypothesis-prediction-testing rubric (used for testing experiments)

| Scientific Ability | Missing | An attempt | Needs some improvement | Acceptable |
|---|---|---|---|---|
| **Is able to distinguish between a hypothesis and a prediction** | No prediction is made. The experiment is not treated as a testing experiment. | A prediction is made but it is identical to the hypothesis. | A prediction is made and is distinct from the hypothesis but does not describe the outcome of the designed experiment. | A prediction is made, is distinct from the hypothesis, and describes the outcome of the designed experiment |
| **Is able to make a reasonable prediction based on a hypothesis** | No attempt to make a prediction is made. | A prediction is made that is distinct from the hypothesis but is not based on it. | A prediction is made that follows from the hypothesis but does not have if-and-then structure | A prediction is made that is based on the hypothesis and has if-and-then structure. |
| **Is able to make a reasonable judgment about the hypothesis** | No judgment is made about the hypothesis. | A judgment is made but is not consistent with the outcome of the experiment. | A judgment is made and is consistent with the outcome of the experiment but assumptions are not taken into account. | A reasonable judgment is made and assumptions are taken into account. |

**TASK 1: CAMERAS**

**1. Observe, explain, and test your ideas**

Watch the video at https://youtu.be/HYpgBLKB-pA .

a. Come up with at least 3 explanations (crazy ideas) for why the person living in this house has 12 cameras.

b. Make a list of the explanations. How can you decide which one is correct? You can conduct additional experiments but you cannot talk to the person. Describe the experiments you plan to perform.

c. What outcomes of these experiments might convince you that certain explanations (or all of them) are not correct?

c. Do you think there is a way to know with absolute certainty why the person living in the house has 12 cameras?

---

**Test an Idea**

a) While over at you friend Scott's house, you notice that he has 20 television sets. You formulate the hypothesis that your friend Scott must be a secret television thief. Think of a way to test this hypothesis. Then write a prediction using the *if/and/then* format.

b) A classmate writes, "*If Scott is a secret thief then he will steal my TV too."* Can we call this statement a prediction? Why or Why not? See the rubric below for help.

c) What are the assumptions that your classmate may have been making?

| **Rubric to self-assess your prediction** | | | | |
|---|---|---|---|---|
| **Scientific Ability** | **Missing** | **An attempt** | **Needs some improvement** | **Acceptable** |
| **Is able to distinguish between a hypothesis and a prediction.** | No prediction is made. The experiment is not treated as a testing experiment. | A prediction is made but it is identical to the hypothesis. | A prediction is made and is distinct from the hypothesis but does not describe the outcome of the designed experiment. | A prediction is made, is distinct from the hypothesis, and describes the outcome of the designed experiment. |

## 2. Observe, explain and test your ideas

*Equipment: glass or transparent plastic cup, ice cold water, additional materials to test your ideas.*

Take a glass (or a transparent plastic cup) and pour ice cold water into it.

- **a.** Carefully observe the glass for a few minutes. Describe what you observe in simple words.

- **b.** Think of different explanations (crazy ideas) for the observed patterns. Try to devise as many explanations as possible.
- **c.** How can you find out which explanation is correct? In science we conduct testing experiments. A testing experiment is an experiment whose outcome you predict before conducting it using the explanation under test. You do not need to agree with the explanation, but the prediction of the outcome must be based on it. After you design the experiment and make predictions based on all explanations that you devised, you conduct the experiment and compare the outcome to the prediction. Think about what testing experiments you can run to test the proposed explanations. Try to propose as many as you can by writing each one with a brief description.
- **d.** For *each* testing experiment, make a prediction for its outcome based on *each* explanation that you proposed in b. Indicate any of your additional assumptions when making the predictions. (Note: The best testing experiments are those that give different predictions for different explanations).
- **e.** Perform as many testing experiments as you can.
- **f.** Compare the outcomes of the testing experiments with the predictions that you made in c. What can you say about the explanations under test now? Can you reject some explanations?
- **g.** One of the testing experiments suggested by other students is as follows: you take a glass, put it on a scale, pour ice cold water into it and record the mass. If the explanation that water on the outside of the glass comes from the outside air is true, then the reading of the scale will increase as the glass becomes wet. If the explanation that water on the outside of the glass comes from the water inside the glass is true, then the reading of the scale should not increase but should stay the

same or even decrease a little bit. Watch the experiment https://youtu.be/x6bNApNaeQA and compare the outcome to the predictions. What can you say about those two explanations? Which one can you reject? When answering the last two questions you are making a judgment about the explanations. A judgment if the decision to accept or reject an idea/explanation under test, it needs to be back up with evidence.

**h.** Think of the explanation that you were not able to reject as a new piece of knowledge. Can you think of any application of this knowledge?

| Testing experiment / Explanation for original observation | **Testing experiment 1:** | **Testing experiment 2:** | **Testing experiment 3:** |
|---|---|---|---|
| **Explanation 1:** | | | |
| **Explanation 2:** | | | |
| **Explanation 3:** | | | |
| | **Outcome of testing experiment 1:** | **Outcome of testing experiment 2:** | **Outcome of testing experiment 3:** |
| **Accepted explanation:** | | | |

**Activity VII: Testing experiment: How fast do you walk?**

[Link back to text]

## Activity 3: TESTING EXPERIMENT: HOW DO YOU WALK? [IN GROUPS OF 3]:

Goals:

a) learn how to test an idea;
b) learn how to make a prediction based on an idea under test.

Equipment: distance measuring device, stopwatch, bean bags or any other materials you might need.

**a.** Design an experiment to test whether or not you walk across a room in your house at constant speed. Think what it means to test an idea. In physics, experimental testing consists of the following steps:

1) you accept the idea (the hypothesis) being tested as true;
2) you design an experiment whose outcome you can predict using this idea;
3) you make the prediction of the outcome (here you also need to think of what you assume to be true in addition to the idea you are testing—these are called *assumptions*);
4) you perform the experiment and compare the outcome to the prediction, and based on the comparison, you make your judgment concerning the idea being tested.

***REMEMBER!* –** Your predicted outcome must be based on your hypothesis.

**b.** Describe the experiment and the materials you will need to conduct it. If you do not have a meterstick or bean bags, use available materials to improvise. Make a prediction of the outcome of the experiment based on the idea under test (not your intuition). Write it here.

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------------------------------------------------------------

**c.** Collect, record and analyze your data here. Did the outcome match the prediction? What is your judgment about the idea under test?

**d.** If you determined that you walk at approximately constant speed, what is your speed? What assumption(s) did you use to make this estimate (Hint: think of what happens when you just start your motion.)

These activities were developed from a number of resources from: PUM | Kinematics

**Activity VIII: Testing experiment: current in a circuit**

[Link back to text]

# Design Experiment: Current

**Your friend says that as current flows through a circuit, it is used up by the elements of the circuit. Design an experiment to test your friend's idea.**

**Available equipment: a voltage source, resistors, light bulbs of different ratings, ammeter and a voltmeter.**

State the hypothesis that you will test.

Design an experiment to test this hypothesis. Write an outline of your design and procedure and include a circuit diagram to show your set up.

List the assumptions you are making.

Make a prediction of the outcome of the experiment based on the hypothesis you are testing and your assumptions.

Perform the experiment. Record your data in an appropriate format.

Did the experimental outcome support the prediction?

Based on the prediction and the outcome of the experiment, what is your judgment about the hypothesis you were testing?

## Activity IX: Modelling behaviour: our physics workbooks

[Link back to text]

**Space for drawing diagrams was included and students were prompted to draw them wherever appropriate:**

5. A child drops a ball of mass 0,1 kg. The speed of the ball just before it strikes the ground is 5 $m.s^{-1}$ and it rebounds, leaving the ground with a speed of 4 $m.s^{-1}$.

   (a) Determine the magnitude and direction of the impulse exerted on the ball **by the ground**.

*Draw a diagram:*

**Summaries of the activities were included in the notes so that learning could be recorded:**

**Complete Investigations 4 and 5 on page 64:**

When two objects interact, what do you notice

- about the direction of the forces that they exert on one another? ____________________
- about the size of the forces that they exert on one another? __________________

**Answers were included in the book instead of sharing full solutions to encourage students to grapple when they calculated an incorrect answer, instead of copying out the solution:**

## Answers:

1a) $6,7 \times 10^{-8}$ N    b) $1,7 \times 10^{-8}$ N    c) $6,7 \times 10^{-8}$ N

2a) $1,68 \times 10^{-13}$ N    b) $6,7 \times 10^{-15}$ N

3. $5,3 \times 10^{24}$ kg    4. $1,47 \times 10^{23}$ kg

5a) $3,5 \times 10^{5}$ m/350 km    b) 2,45 N/kg    c) 1,09 N/kg

6. $2,27 \times 10^{6}$ m    7. distance from centre **only**

**Activity X: Modelling behaviour: post lesson reflection task**

[Link back to text]

# Lesson Reflection

Thinking about what you are learning and how you are learning it is an important habit - and a skill that we hope to develop.

It is really helpful to knowledge retention to review what you learned within 24 hours of learning it. We hope that this exercises will help you to develop this habit. It should also mean that you never allow a lesson to go by without learning something!

The second question will hopefully encourage you to think about how you learn - you can then apply this when you study.

The third question is to inform my teaching, to give you a voice in every lesson and to help you stay up to date with concepts.

---

My first name: *

Your answer

My surname *

Your answer

I am currently in *

- ○ Grade 8
- ○ Grade 9
- ○ Grade 10
- ○ Grade 11
- ○ Grade 12

In today's Physics lesson I learned *

Your answer

I think that I learned this concept by / through: *

Your answer

This still remains unclear / I want to ask:

Your answer

## Activity XI: Modelling behaviour: examination reflection task

[Link back to text]

**PHYSICS EXAM REFLECTION TOOL - G11 JULY 2023**

| | Conceptual problem | | | | | Learning (definitions) | | | | Functional error | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Did not understand the question | Did not answer the question | Misapplied the concept | Did not understand the concept | | No attempt (no idea) | Did not know it | Inaccurate wording | | Wrong units | Left out units | Maths error | Incorrect value (incorrect copying) | CONCEPT (notes) |
| 1.1 | | | | | | | | | | | | | | |
| 1.2 | | | | | | | | | | | | | | |
| 1.3 | | | | | | | | | | | | | | |
| 1.4 | | | | | | | | | | | | | | |
| 1.5 | | | | | | | | | | | | | | |
| 2.1 | | | | | | | | | | | | | | |
| 2.2 | | | | | | | | | | | | | | |
| 2.3 | | | | | | | | | | | | | | |
| 2.4 | | | | | | | | | | | | | | |
| 2.5 | | | | | | | | | | | | | | |
| 2.6 | | | | | | | | | | | | | | |
| 2.7 | | | | | | | | | | | | | | |
| 2.8 | | | | | | | | | | | | | | |
| 2.9 | | | | | | | | | | | | | | |
| 2.10 | | | | | | | | | | | | | | |
| 3.1 | | | | | | | | | | | | | | |
| 3.2 | | | | | | | | | | | | | | |
| 3.3 | | | | | | | | | | | | | | |
| 3.4 | | | | | | | | | | | | | | |
| 3.5 | | | | | | | | | | | | | | |
| 3.6 | | | | | | | | | | | | | | |
| 4.1 | | | | | | | | | | | | | | |
| 4.2 | | | | | | | | | | | | | | |
| 4.3 | | | | | | | | | | | | | | |
| 4.4 | | | | | | | | | | | | | | |
| 4.5 | | | | | | | | | | | | | | |
| 4.6 | | | | | | | | | | | | | | |

**This is the test reflection tool that developed from the examination reflection tool:**

## <u>Learning from a test</u>

1. Look over your test broadly to see where your errors were.
2. Start at the beginning of the test and classify your errors. Using the phrases from the table below might help you. You can use a key to capture these types of problems.
3. Do corrections on your test in a different colour. As you do the corrections, try to articulate (describe) *what* the problem was so that you can remember to approach the problem differently next time.
4. Make notes to yourself that will help you learn from your mistakes.
5. Hand in your corrections.
6. When the test is returned to you, file it so that you can look through your lessons before the next assessment on this section.

| **CONCEPTUAL PROBLEM** | **LEARNING (usually definitions)** | **FUNCTIONAL ERROR** |
|---|---|---|
| Did not understand the question | No attempt (no idea) | Wrong units |
| Did not answer the question | Did not know it | Left out units |
| Misapplied the concept | Inaccurate wording | Maths error |
| Did not understand the concept | | Incorrect value (incorrect copying |
| | | No direction for a vector quantity |

[Link back to text]

**Activity XII: Well-being: Expertise Activity**

[Link back to text]

**I used this PowerPoint presentation to guide the Expertise Activity.**

What are you good at?

- In your group, talk about what you're really good at.
- Maybe it's a sport, playing a musical instrument, juggling, cooking, a game, drawing… anything!
- Write down your areas of expertise on the whiteboard.

Regroup in areas of expertise.

How do you become an expert?

- Construct a diagram that shows the rest of the class how to move from novice to expert in your field of expertise.
- The diagram should be a learning cycle that illustrates a repeatable process that can be engaged in to progress from novice to expert.

Share your ideas with the class.

What has this to do with physics?

**Activity XIII: Well-being & modelling behaviour: re-tests**

[Link back to text]

# Test Resubmission Policy

The ISLE approach emphasises student well-being and encourages a growth mindset. It proposes that students' intelligence is not fixed, but rather that some everyone can learn physics.

With this in mind, students are offered more than one opportunity to master a concept. However, effort and engagement needs to be rewarded and this process needs to be fair to all students – including those who did their best on the first try.

We want students to engage with work and to be motivated to improve their understanding of concepts.

**Matt Blackman's Strategy:**
**Core features of a successful assessment correction/retake system**

1. Student accountability
2. Requires metacognition
3. Reasonable time requirement
4. Minimal teacher effort
5. Consistent with course philosophy

Students have one week to fill out correction forms for questions they missed. I skim forms and give each a check/no check. Forms with a check act as a ticket to reassess with a similar question for full credit. Students all reassess at the same time with questions that are quick to grade. Students cannot keep reassessments, and minimal feedback is provided. One chance for reassessment (for accountability and my sanity)

- Rewrite problem, solved correctly.
- What mistakes did I make on my first try?
- Why did I make these mistakes?
- How did I learn to do these parts correctly?

https://rutgers.zoom.us/.../tlUYoqsbsv3Skb3J-BxckesO...
Password: yXnK4+=7
Watch from 1:29:00

# <u>Re-test Application form:</u>

NAME:__________ DATE: __________ TEST: __________

QUESTION: __________

*Please complete a form for each question that you did not score full marks for. You may include all sub-questions on one page, if there is space to do this.*

Application successful: □ YES □ NOT YET

Rewrite the problem, solved correctly:

What reasoning led me to the answer that I wrote in the original test?

What part of my physics understanding did I need to change to correct this reasoning?

How did I learn to do these questions correctly?

# Guide to completing the reflection form

The goal of this exercise is to encourage you to engage with your errors and fix them. The process is designed to help you master a section of work that you have struggled with.

We will be assessing your level of engagement with the exercise and a sufficient amount of effort is required in order to qualify for the rewrite. Simply handing in anything does not guarantee you a chance to redo the test.

<u>How to answer the questions in the form</u>:

"Rewrite the problem, solved correctly"

We want to see the right answer, showing that you have figured out how to solve the question.

"What reasoning led me to the answer that I wrote in the original test?"

Where did it go wrong in the test? What prevented you from getting the answer correct? What do you think your misconceptions were in solving this problem?

"What part of my physics understanding did I need to change to correct this reasoning?"

What was behind the reasons given in the answer to the question above? You need to identify the cause of the errors that occurred.

"How did I learn to do these questions correctly?"

In order to write out the correct answer, you needed to correct the errors that led to the wrong answer. How did you do this? How did you determine what the right answer was?

<u>How many forms to fill in</u>:

Fill in one form for each question you got wrong.

Tests are broken down into long questions with multiple parts.

You only need to fill in one form per long question and include any part you got wrong for that question.

E.G

*If we have a question with four parts:*

Question 2

2.1 ✓

2.2 x

2.3 x

2.4 ✓

*And we got 2.2 and 2.3 wrong but the rest correct.*

*We would fill in a single form for Question 2 and answer the reflection questions for 2.2 and 2.3 on this form.*

**Activity XV: Well-being & modelling behaviour: pre-tests**

[Link back to text]

**This overview of the pre-test process was shared on Google Classroom with each class when the pre-tests were given out:**

**Pre-test Learning Reflection**

The purpose of activity is for you to engage with your work and identify what went wrong, think about it and fix any mistakes and misunderstandings. By working through your answers carefully, we hope that you will not make the same mistakes in the "real" test and that you will improve your understanding of concepts.

The process:

- You will complete and hand in a past test.
- We will mark the test, but not assign a mark for the test or do your corrections for you.
- When you get the test back, you need to:
  - Write corrections on your test in a different colour pen to the one that used to write the test.
  - Briefly articulate (explain) what you did wrong (e.g. "forgot that velocity is a vector and needs direction" or "did not know that current through a series circuit is the same all round")
  - Hand this test (with corrections and reflection) in when you come to write your test.

What you stand to gain:
A deeper understanding of physics concepts.

## Appendix 4: Data collection and analysis tools



### Appendix 4.1: Semi-structured interview and focus group questions

[Link back to text]

**Proposed student interview & focus group 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.*

**General questions:**

1. Describe a favourite physics lesson? (*Ice breaker question*)
2. Why did you enjoy this lesson?
3. What is your favourite aspect of physics?
4. What do you like least about physics?

*Icebreaker questions 1 – 4 changed to "*What will you remember from physics?*" in 2023*

5. Is your experience in the physics classroom different to your experience in other classes?
6. Is there anything that you would like to change about the way the physics class is taught?

**Epistemology:**

7. How are you convinced of a concept?
8. Tell me how you learn new concepts.
9. Do you learn differently in Physics to other subjects?
10. Have you changed your view of learning since doing Physics?
11. Do you reflect on what you have learnt?

**Confidence and well-being**

12. Has your attitude and feelings towards Physics changed over the past year?

**Re-test (2022) / pre-test (2023) opportunities**

13. Tell me about your experience of re-tests (2022) / pre-tests (2023) in Physics.

**Learning in class**

14. What do you think about the way concepts are introduced in Physics?

**Self-Assessment (only if there is time)**

15. How do you go about checking your work in Physics?
16. How do you use the memo in Physics?
17. When you mark your own work, how do you use the process to improve your understanding?

**Appendix 4.2: Colorado Learning Attitudes about Science Survey (CLASS)** (Adams et al., 2006).

[Link back to text]

Science Attitude Survey

Here are a number of statements that may or may not describe your beliefs about learning physics. You are asked to rate each statement by choosing between the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose "neutral".

---

Each statement was set up so that students could select just one option from the Likert scale. Question 1 is shown is it appeared on the form, but, for space considerations, the rest of the questions are just listed in this appendix.

The CLASS categories (Adams et al., 2006) are given in Appendix 4.3.

1. A significant problem in learning physics is being able to memorize all the information I need to know.

*Mark only one oval.*

- ⬭ Strongly disagree
- ⬭ Disagree
- ⬭ Neutral
- ⬭ Agree
- ⬭ Strongly agree

---

1. A significant problem in learning physics is being able to memorize all the information I need to know.
2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.
3. I think about the physics I experience in everyday life.
4. It is useful for me to do lots and lots of problems when learning physics.
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.
6. Knowledge in physics consists of many disconnected topics.
7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.
8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.
9. I find that reading the text in detail is a good way for me to learn physics.
10. There is usually only one correct approach to solving a physics problem.
11. I am not satisfied until I understand why something works the way it does.
12. I cannot learn physics if the teacher does not explain things well in class.
13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.
14. I study physics to learn knowledge that will be useful in my life outside of school.
15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.
16. Nearly everyone is capable of understanding physics if they work at it.
17. Understanding physics basically means being able to recall something you've read or been shown.
18. There could be two different correct values for the answer to a physics problem if I use two different approaches.
19. To understand physics I discuss it with friends and other students.
20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.

21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.
23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.
24. In physics, it is important for me to make sense out of formulas before I can use them correctly.
25. I enjoy solving physics problems.
26. In physics, mathematical formulas express meaningful relationships among measurable quantities.
27. It is important for the government to approve new scientific ideas before they can be widely accepted.
28. Learning physics changes my ideas about how the world works.
29. To learn physics, I only need to memorize solutions to sample problems.
30. Reasoning skills used to understand physics can be helpful to me in my everyday life.
31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.
32. Spending a lot of time understanding where formulas come from is a waste of time.
33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.
34. I can usually figure out a way to solve physics problems.
35. The subject of physics has little relation to what I experience in the real world.
36. There are times I solve a physics problem more than one way to help my understanding.
37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
38. It is possible to explain physics ideas without mathematical formulas.
39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.
40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.
41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.
42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

**Appendix 4.3: CLASS questions listed by category** (Adams et al., 2006).

**CATEGORIES**

| | |
|---|---|
| **Personal Interest** | 3. I think about the physics I experience in everyday life.<br>11. I am not satisfied until I understand why something works the way it does.<br>14. I study physics to learn knowledge that will be useful in my life outside of school.<br>25. I enjoy solving physics problems.<br>28. Learning physics changes my ideas about how the world works.<br>30. Reasoning skills used to understand physics can be helpful to me in my everyday life. |
| **Real World Connection** | 28. Learning physics changes my ideas about how the world works.<br>30. Reasoning skills used to understand physics can be helpful to me in my everyday life.<br>35. The subject of physics has little relation to what I experience in the real world.<br>37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed. |
| **Problem Solving (PS) General** | 13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.<br>15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.<br>16. Nearly everyone is capable of understanding physics if they work at it.<br>25. I enjoy solving physics problems.<br>26. In physics, mathematical formulas express meaningful relationships among measurable quantities.<br>34. I can usually figure out a way to solve physics problems.<br>40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.<br>42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented. |
| **PS Confidence** | 15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.<br>16. Nearly everyone is capable of understanding physics if they work at it.<br>34. I can usually figure out a way to solve physics problems.<br>40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own. |

| | |
|---|---|
| **PS Sophistication** | 5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.<br>21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.<br>22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.<br>25. I enjoy solving physics problems.<br>34. I can usually figure out a way to solve physics problems.<br>40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own. |
| **Sense Making / Effort** | 11. I am not satisfied until I understand why something works the way it does.<br>23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.<br>24. In physics, it is important for me to make sense out of formulas before I can use them correctly.<br>32. Spending a lot of time understanding where formulas come from is a waste of time.<br>36. There are times I solve a physics problem more than one way to help my understanding.<br>39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.<br>42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented. |
| **Conceptual Understanding** | 1. A significant problem in learning physics is being able to memorize all the information I need to know.<br>5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.<br>6. Knowledge in physics consists of many disconnected topics.<br>13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.<br>21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.<br>32. Spending a lot of time understanding where formulas come from is a waste of time. |
| **Applied Conceptual Understanding** | 1. A significant problem in learning physics is being able to memorize all the information I need to know.<br>5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.<br>6. Knowledge in physics consists of many disconnected topics. |

8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.
21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.
40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.

## Appendix 4.4: Post-physics learning survey

**Each grade had a slightly nuanced survey, as the classes had written different pre-tests and there were other subtle differences. However, all the questions asked, and the codes used in all the surveys are given in Appendix 4.4. The Grade 11 physics learning survey is given here as an example.**

# Grade 11 Physics Learning Survey

These questions have been approved for use by the Rhodes University Human Ethics Committee (Approval number: 2022-5074-6932)

Please answer the questions as honestly and as fully as you can. Your rich feedback will help me to improve the way that we teach physics and the experience that students have in class. Most of the questions are not "required", but I ask you to answer all the questions that you feel comfortable answering.

All responses will be kept strictly confidential. I will be the only person who will see your responses to these questions. The reason why we ask you to put your name on the survey is so that we can link your responses to this survey to your responses on other surveys.

Thank you.
Mrs Cobbing

Your surname: _________________
Your first name: ______________

I agree to allow Mrs Cobbing to use my responses in her research: **YES / NO** (please circle)

**Exploratory Learning**

This term we have not done any exploratory tasks. I have just taught concepts. These questions ask you to compare your learning experience this term to your experience in the first term when we used exploratory learning tasks at the back of the book.

Briefly describe any investigations that you remember doing.

Did this investigation change your understanding of a concept? **YES / NO** (please circle)

If yes, please explain how your understanding changed.

Write down one thing that you learned in these investigations.

How do you think you learned this?

Describe how working in groups in physics class affects your learning experience.

We have not had time for investigations this term. Describe how this has impacted your learning experience in physics.

**Confidence and well-being**

How do you feel about your ability to do physics?

Has your answer to the question above changed this year? (Explain, if you like.)

What makes you feel comfortable in your physics class?

**Pre-test opportunity**

You were given the opportunity to complete a pre-test and hand it in for feedback. This was a test that you completed as an open book exercise and handed in to be marked before writing a formal test on a section. These questions are about this task to see whether it benefited your learning process or not.

To remind you, these pre-tests were offered for
- Applications of Newton's 2nd Law in Term 2
- NLUG & Chapter 5 and then Work & Energy this term

The questions below refer to the recent pre-test on NLUG and Chapter 5, but there is a general question at the end, if you can remember your experience of the previous pre-test.

Did you hand in the recent "pre-test"? This was a test that you completed as an open book exercise and handed in to be marked before writing a formal test on a section. **YES / NO** (please circle)

If you did not take the opportunity to hand in the pre-test, why not?

What benefit (if any) did you see in completing the pre-test when you did a pre-test?

How did you approach the pre-test? Tick all options that applied to you.

- ☐ Worked on it alone
- ☐ Worked with a friend / friends / peers
- ☐ Asked an adult for help
- ☐ Asked a student in another grade for help
- ☐ Used my book
- ☐ Looked at memos of other past tests
- ☐ Other (please explain below)

Please tell me about your approach to pre-tests if the options above do not cover it.

Did you do corrections on your pre-test? **YES / NO** (please circle)

Did you identify and explain your corrections on your pre-test (the WHY of the mistakes you made, not just correcting the mistakes)? **YES / NO** (please circle)

Do you think that the process of reflecting on your pre-test improved your understanding? **YES / NO** (please circle)

Please elaborate on your response above.

Did the pre-test change the way that you prepared for a physics test? Please explain.

Did the pretest change the way that you felt about the physics test? Please explain.

Any further comments about the pre-test opportunities:

Describe your experience of the previous pre-test in Term 2 and its impact on your learning.

**Epistemology - your thoughts about your learning**

(Epistemology is the study of how people learn.)

How do you learn a new concept?

How are you convinced that a new concept is true?

Has your understanding of how you learn changed in any way over the time that you have done physics? Please explain.

Has your approach to learning changed in any way over the time that you have done physics? Please explain.

Any further comments on your experience of learning physics:

Would you be willing to discuss the process of learning Physics and your experience of learning physics in a small focus group (4 - 5 people) in the next week? This will take 20 - 40 minutes, depending on how much you have to say and here will be cupcakes, hot chocolate and biscuits to make up for your time commitment!

**YES / NO** (please circle)

## Appendix 4.5: Survey questions and analysis codes

[Link back to text]

| Question | Type of question | Options / Theme / code |
|---|---|---|
| Do you feel pressure to do well in physics? | Binary | Yes / no |
| Where (who) does this pressure come from? | Open-ended | No pressure (from previous) |
| | | Self |
| | | Parent(s) |
| | | Peers |
| | | Future study |
| | | Teachers / school |
| How do you feel about your ability to do well in physics? | Open-ended | Positive |
| | | Neutral / in between |
| | | Proviso |
| | | Negative |
| Has your answer to the question above changed? (Explain, if you like.) | Open-ended | Yes (improved) |
| | | Yes (no explanation) |
| | | Yes (deteriorated) |
| | | No |
| What makes you feel comfortable in your physics class? | Open-ended | Teacher / teaching |
| | | Friends / peers |
| | | Ability / understanding |
| | | Freedom to ask questions / questions / no judgement |
| | | Class environment |
| | | Practice / pre-tests |
| | | Class discussions / examples |
| | | Help / support available |
| | | Marks / getting it right |
| | | The notes / book |
| | | Pace of teaching |
| | | Repetition |

| | | |
|---|---|---|
| | | I don't feel comfortable |
| | | Taking notes |
| Does working in groups in physics class affect your learning experience? Explain. | Open-ended | No effect |
| | | Positive effect |
| | | Neutral / pros and cons |
| | | Negative effect |
| How do you learn a new concept? | Open-ended | Doing questions / applying . practising |
| | | Reading notes |
| | | From the teaching / lesson |
| | | Working to understand |
| | | Writing notes |
| | | Learning / studying |
| | | Repetition |
| | | Visual examples |
| | | Ask questions |
| | | Watch Videos (YouTube) |
| | | Teaching others |
| How are you convinced that a new concept is true? | Open-ended | External / taught |
| | | Self / discovered |
| | | Both |
| | | Not convinced |
| Has your understanding of how you learn changed in any way over the time that you have done Physics? Please explain. | Open-ended | Yes |
| | | No |
| Has your approach to learning changed in any way over the time that you have done Physics? Please explain. | Open-ended | Yes |
| | | No |
| If you did not complete the reflection exercise after each lesson, what were your reasons for not completing it? | Open-ended | Forgot |
| | | Rushed to next lesson |
| | | Did not know about them |
| | | Other priorities |

| | | |
|---|---|---|
| What benefit (if any) did you see in the reflection exercise that you are asked to complete? | Open-ended | No benefit |
| | | Summary of learning |
| | | Think back / reflect on lesson |
| | | Helps retain info / remember |
| | | Find gaps in understanding |
| | | Structure understanding |
| | | Improved well-being |
| Have you applied for a rewrite? | Binary | Yes / No |
| If you did not take the opportunity to apply to rewrite, why not? | Open-ended | |
| Did you apply and your application was unsuccessful? | Binary | Yes / No |
| If your application was unsuccessful, do you understand why it was unsuccessful? | Open-ended | |
| If you did take the opportunity to apply, please comment on your experience of the reflection process. | Open-ended | |
| If you applied to rewrite, would you like to make any suggestions to improve the process or the reflection document? | Open-ended | |
| Do you think that the process of reflecting on your original test improved your understanding of the physics concepts involved? | Open-ended | saw benefit |
| | | Indifferent |
| | | No benefit |
| | | Too much effort (application) |
| | | Test format |
| | | Feedback |
| | | Learn from mistakes |
| | | Gaps in knowledge |
| | | Improve understanding |
| | | Confidence |
| | | Improve mark |

| | | |
|---|---|---|
| Did the knowledge that there would be a rewrite change the way that you prepared for the test? | Binary | Yes / No |
| Please elaborate on your response above. | Open-ended | |
| Did the knowledge that there would be a rewrite change the way that you felt during the test? | Binary | Yes / No |
| Please elaborate on your response above. | Open-ended | Positive |
| | | Neutral |
| | | Negative |
| | | No effect |
| Any further comments about the rewrite opportunities: | Open-ended | |
| Did you hand in a "pre-test"? This was a test that you completed as an open book exercise and handed in to be marked before writing a formal test on a section. | Binary | |
| If you did not take the opportunity to hand in a pre-test, why not? | Open-ended | |
| What benefit (if any) did you see in completing a pre-test? | Open-ended | |
| How did you approach the pre-test? Tick all options that applied to you. | Multiple options | Worked on it alone |
| | | Worked with a friend / friends / peers |
| | | Asked an adult for help |
| | | Asked a student in another grade for help |
| | | Used my book |
| | | Looked at memos of other past tests |
| | | Other (please explain below) |
| Please tell me about your approach to pre-tests if the options above do not cover it. | Open-ended | |

| | | |
|---|---|---|
| Did you do better in the pre-test or the actual test? | *These questions were asked in the very first survey and then removed to de-emphasize marks. They were not coded.* | |
| What do you think the reason is for your answer to the previous question? | | |
| Did you do corrections on your pre-test? | Binary | Yes / No |
| Did you identify and explain your corrections on your pre-test (the WHY of the mistakes you made, not just correcting the mistakes)? | Binary | Yes / No |
| Do you think that the process of reflecting on your pre-test improved your understanding? | Binary | Yes / No |
| Please elaborate on your response above. | Open-ended | Didn't complete pre-test |
| | | saw benefit |
| | | Indifferent |
| | | No benefit |
| | | Identify / learn from mistakes |
| | | Gaps in knowledge |
| | | Improve understanding |
| | | Improve confidence |
| | | Familiarity with test format |
| | | Feedback useful |
| | | Reflection helpful |
| | | Improve mark |
| Did the pre-test change the way that you prepared for a Physics test? Please explain. | Open-ended | |
| Any further comments about the pre-test opportunities: | Open-ended | *Used codes above* |
| Did the pre-test change the way that you felt about the Physics test? Please explain. | Open-ended | Positive |
| | | Neutral |
| | | Negative |
| | | No effect |
| Do you mark your work? If so, | Open-ended | |

| | | |
|---|---|---|
| how do you go about the process? | | |
| Do you look at the memo / solutions when you get stuck on a question or when you don’t know how to do a question? | Binary | Yes / No |
| When you get a question wrong, do you | Multiple options | Mark your answer wrong and move on |
| | | Copy the right method off the memo |
| | | Study the memo and trace the steps to see where you went wrong |
| | | Go back to the question and try it again with a different approach |
| If you are only given answers only to a revision or homework exercise (not full solutions), what will you do if your answer does not match the answer given? | Open-ended | |
| Describe anything that we have seen in class that changed your original understanding of a physics concept. | Open-ended | Students remembered investigation |
| | | Changed understanding due to visual |
| If yes, which investigation/s changed your understanding? | | Changed understanding due to practical |
| If yes, please explain how your understanding changed. | | Could (correctly) identify concept learnt |
| Write down one thing that you learnt in these investigations. | | Learnt by visual |
| How do you think you learnt this? | | Learnt by practical |
| Did you have questions after these investigations that you would like to ask? | | Learnt by engagement |
| | | Teaching / teacher |
| | | Learnt by book |
| We have not had time for investigations this term. Describe how this has impacted your learning experience in | Open-ended | Negative impact |
| | | Demos are enough |
| | | More time for exercises / |

| | | |
|---|---|---|
| Physics. | | concepts |
| | | No impact |
| | | Unrelated comment |
| | | Had to focus more to understand |

*It always seems impossible until it is done.*
Nelson Mandela (1918 – 2013)