Link Maps and Map Meetings: A theoretical and experimental case for stronger scaffolding in first year university physics education

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

by

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Dedicated to my grandfather

Hans Richard Pedersen (1932 – 2010)

Thank you for taking those first steps with me.

Declaration of originality

To the best of my knowledge, this thesis contains no copy or paraphrase of work published by another person, except where duly acknowledged in the text. This thesis contains no material that has been previously presented for a degree at the University of Sydney or any other university.

Christine Lindstrøm

Included papers and attribution

The following refereed papers and presentations arose from work related to this thesis.

Publications

Lindstrøm, C. and Sharma, M. D. (in press). Development of a Physics Goal Orientation survey. *International Journal of Innovation in Science and Mathematics Education.*

Lindstrøm, C. and Sharma, M. D. (2008). Initial development of a Physics Goal Orientation survey using factor analysis. Proceedings from the UniServe science symposium, Sydney, Australia, 1st – 3rd October, 2008.

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Lindstrøm, C. & Sharma, M.D. (2008). From idea to reality: The integration of Map Meetings into first year physics. *National Australian Institute of Physics Congress.* Adelaide, Australia, 30 Nov-5 Dec, 2008.

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Abstract

This thesis is a result of my lifelong passion for learning and reflection on my own learning experiences. It has three parts: development of theory, development of a learning environment that is consistent with theory, and the naturalistic trial of this environment. Together these three parts extend and critique the current trends in both physics education specifically and the wider field of education generally.

Physics education research does not rest on a solid theoretical framework, at least not as theory is understood by physicists. In my work I integrate some of the theoretical foundations of neuroscience, cognitive psychology and education, and argue that, at a fundamental level, they all agree on the basic tenet of human learning: each individual constructs her own knowledge; there is no alternative. I subsequently discuss how this informs teaching, arguing for stronger scaffolding for physics novices, and I emphasise the importance of prior knowledge and explain *why* this is essential. A discussion of the nature and structure of physics knowledge itself also features prominently. Empirical findings from Physics Education Research are included; practical knowledge about physics education is important for the implementation and development of new pedagogies regarding aspects where the theoretical underpinnings are not well understood. Self-efficacy, an area of motivation, is also considered; students' beliefs in their own ability to learn physics represent a necessary but not sufficient first step towards learning, and are particularly important for novices. I conclude that *all* of these fields should be considered in physics education, and future work should continue the integration and refinement of these different elements.

Based on the theoretical understanding of human learning, I developed a learning aid for first year physics students: Link Maps. Link Maps resemble concept maps and knowledge maps, but are developed specifically for physics based on its characteristic integrated knowledge structure. Link Maps focus on the relatively few, but frequently occurring, core concepts that are covered in first year physics *and* the myriad of links between these. Temporal consistencies in the presentation of concepts across Link Maps result in strong links not only occurring within maps, but also between them. Thus, *together* the Link Maps form an abstract knowledge network, reflecting the integrated nature of physics knowledge. However, once created, detailed analysis of the set of Link Maps further illuminated the knowledge structure of physics, which allowed for a deeper understanding of the characteristics of the first year curriculum and students' interaction with it.

To test the pedagogical effectiveness of Link Maps, they were implemented in Map Meetings, which are relatively scaffolding tutorials. First year students in four different physics courses (two each semester) were allocated to either Map Meetings or the standard physics tutorials, which are inquiry based. Link Maps were developed for each course, which differed in levels of assumed prior knowledge. Data on students' tutorial attendance, self-efficacy and examination performance were collected, and qualitative feedback was obtained through interviews and focus groups, short answer questions in questionnaires, tutorial observations by physics education experts and student-staff liaison committee meetings. Triangulation of results revealed that Map Meetings were considered more valuable by the students, both in terms of student attendance and qualitative feedback, had a more positive effect on students' self-efficacy, and resulted in fewer students at risk of failing the course with the lowest assumed prior knowledge – a result that was borderline significant (p = 0.056).

This thesis demonstrates that the theory underlying physics education can be made more coherent than it currently is. Against popular beliefs, a more scaffolding educational environment improved the learning and motivation of first year physics students – especially the novices with the lowest prior knowledge. The thesis concludes with a reflection on the fields of Physics and Education based on my experiences with these fields during my PhD.

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1 Introduction

1.1 *The origin of thesis*

This thesis is the product of a complex interaction between Physics, Education and me. The interaction is not easily mapped, understood or described, but I will try nonetheless.

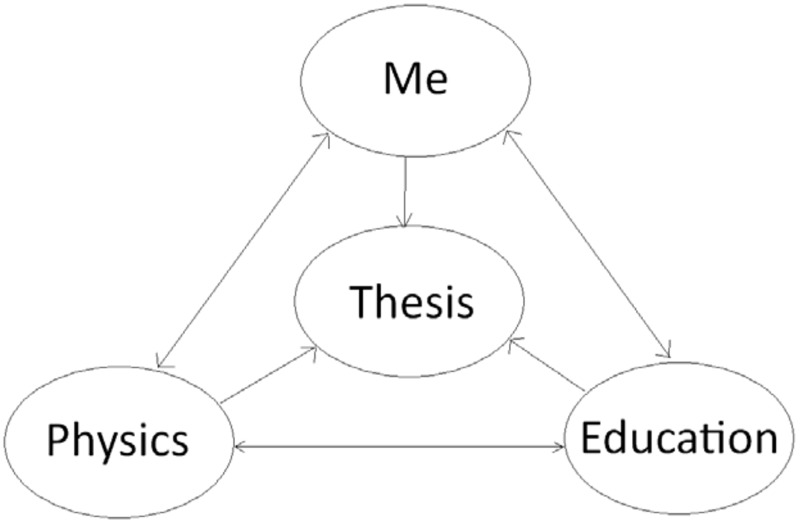


Figure 1.1: Schematic of the three main areas that contributed to the thesis.

As a thesis within Physics Education Research (PER), both Physics and Education represent corner stones in the final product. However, literature does not beget new literature without the intervention of an individual – in this case: me.

The focus of this thesis is a result of my own passion for physics and interest in both learning and teaching it. Allowing curiosity to guide my path, I chose to pursue PER in my Honours and PhD projects. Essentially, I wanted to understand how I and others learn physics and consequently how it best can be taught. From my own experience of both good and not-so-good physics teaching and more or less efficient ways of studying physics, by my Honours year I had developed a relatively comprehensive and coherent personal view of physics learning and teaching. I had reached the stage where I needed to test the value and validity of my ideas and decided to make it my Honours project. With incredible support and freedom offered from my supervisor, the Honours project became the pilot project of my PhD (Lindstrøm & Sharma, 2009). The initial success and promise of the pilot project spawned the more comprehensive and rigorous project that is this thesis.

The focus of my project has been physics novices in a naturalistic environment. In the School of Physics at the University of Sydney, first year physics students are divided into three different courses, depending on their formal senior high school physics experience. I was particularly interested in those students who had not excelled in physics in high school or had not studied senior high school physics at all. Many of these students find physics difficult and never reach the stage where physics 'just makes sense'. In fact, a large fraction of these students are only studying physics because it is a prerequisite subject; they do not have a deep personal interest in it. The goal of first year physics is to establish most of the concepts and essential associations that have become second nature to physics instructors. However, in my experience, students often receive very little help in creating an overview of all this information, leaving many feeling completely lost in a jungle of new concepts, symbols, laws and diagrams. I believed that these students could be helped.

1.2 Delving into a complex system

Having chosen my focus of study, I acknowledged that although I had a solid foundation in physics and knew the material that was covered in first year physics, my knowledge and understanding of teaching and learning was primarily a result of reflections on my own experiences in life – observing both myself and others. Without any formal education of Education, I decided to undertake a Master of Education in parallel with my PhD, in which I was also reading extensively from the Education literature. This immersion within Education gave me the necessary grounding to pursue such an interdisciplinary enterprise as PER.

The more I learnt, however, the more aware I became of how complex human learning is and how far off we are from truly understanding it. Still, I did not find this discouraging; it simply meant that there is much work that needs to be done. The words of theoretical physicist Murray Gell-Mann were encouraging.

> Today the network of relationships linking the human race to itself and to the rest of the biosphere is so complex that all aspects affect all others to an extraordinary degree. Someone should be studying the whole system, however crudely that has to be done, because no gluing together of partial studies of a complex nonlinear system can give a good idea of the behavior of the whole. (Gell-Mann, 1994, p. xi)

By delving into such an incredibly complex system, I was well aware that I would not be able to produce elegant and accurate descriptions of nature as my final product.

This made it far from obvious how I should approach my project. However, I thought of teaching and learning as sharing many commonalities with the academic fields of Engineering and Physics. Engineering (or rather, 'building things') began long before Physics formally developed. Clearly, basic Engineering can survive without any knowledge of Physics; but with the advent and advance of Physics, Engineering became more sophisticated as new discoveries in Physics were applied. Similarly, teaching began long before the formal study of human learning. In the same way that Engineering and Physics coexist and collaborate for mutual advancement, teaching and areas concerned with learning should cooperate symbiotically. Many who have not studied these areas may well believe that they do. However, a deeper look into the relatively young area of teaching and learning reveal a rather disconcerting relationship – or lack of such.

The epistemological differences between Engineering and Physics or teaching and learning are as essential as they are profound. A physicist can allow himself to deal with special cases and ignore factors he considers irrelevant to pursue a deep and fundamental understanding of nature. An engineer, on the other hand, bases his work largely on physics (and chemistry), but the key difference is that because he constructs things in the real world he must consider *all* the relevant physics knowledge in his work. While the physicist constrains the world, the engineer is constrained *by* the world. I see a similar distinction between those who study learning and those who study teaching. When studying how people learn, although recognizing that there are many factors affecting this, we are allowed to *constrain the world* to identify individual aspects that contribute to learning (e.g., in laboratory experiments). Those who teach in a real setting, however, are constrained *by* the world and therefore *should* consider all the known aspects contributing to learning, even though these do not completely prescribe how to teach.

This thesis has a focus on teaching but draws heavily on details of what is known about learning. To do this, I consulted several fields: neuroscience, cognitive psychology, constructivism, motivation and literature on general teaching practices are the five most important ones – in addition to various fields that are concerned with the understanding of knowledge itself. Although not the most common approach, the value in drawing on such a wide variety of literature was strengthened by a recent publication in the journal *Science*; Meltzoff, Kuhl, Movellan and Sejnowski (2009) proposed integrating neuroscience, psychology, machine learning and education to form the *Foundations for a New Science of Learning* – the title of their article.

1.3 Layout of the thesis

> We need to overcome the idea, so prevalent in both academic and bureaucratic circles, that the only work worth taking seriously is highly detailed research in a specialty. We need to celebrate the equally vital contribution of those who dare to take what I call 'a crude look at the whole'. (Gell-Mann, 1994, p. xiv)

This thesis comprises seven chapters. Following this introduction, the chapter on background literature has a near-impossible aim: to tie together most of the areas that influence physics education – areas that some consider almost mutually exclusive. In Chapter 3 I describe the context of the study. Australia has a high school and university education structure that is not identical to those in either Europe or the United States, and so they need to be outlined to avoid any erroneous assumptions. Chapter 3 also contains a short introduction about me; in educational research the researcher inevitably plays an important role and cannot be completely unbiased, so an outline of my educational experience is relevant.

Chapter 4 on the intervention is the first of two core chapters in this thesis. The first goal of my project was to develop a new type of tutorial for first year university physics students, with a particular focus on helping the students with the weakest academic background get a grasp of the subject. The Intervention chapter carefully describes the tutorials – Map Meetings – and the central feature within them – Link Maps – and connects these to the literature discussed earlier; it also has a section on how the Link Maps offered new insights into the knowledge structure of physics. Chapter 5 outlines the methodology of the second part of this study, namely that in which Map Meetings were compared with the established Workshop Tutorials at the University of Sydney. This chapter also contains a discussion of aspects of the analyses used in the following Results chapter. Chapter 6 covers the results and is the second core chapter in the thesis; it reports on the findings of the yearlong study of Map Meetings and Workshop Tutorials. Four different features, all providing information about the tutorials, are investigated to allow for triangulation of results: student attendance at tutorials, the effect of tutorials on students' motivation as measured by self-efficacy, the end of semester examination results, and qualitative feedback. The last chapter discusses these findings and what they reveal not only about Map Meetings and Link Maps as educational tools but about the field of Educational in general.

2 Knowledge and Learning

Physicists are trained to solve problems. A PhD is a problem – and a very big one at that. Having chosen my research focus, I therefore approached my project in the same way that I would approach physics problems: first, I would understand what elements were part of the system I was dealing with; second, I would learn about these elements and how they interacted; and third, I would use this knowledge to design an experiment to help me improve my understanding of the system.

Figure 2.1 depicts the most general view of university education: there is the learner, the knowledge and what brings the learner to the knowledge – his motivation. There was no one book I could consult to learn what was known thus far about this situation; in fact, I was rather shocked and surprised to find that my approach – which I thought was perfectly logical – was not representative of the mainstream approach to educational projects. When the physics mind meets the education world, the road gets rocky. However, unconvinced that my approach was not sensible, I embarked on what proved to be an interesting and educational, frequently frustrating, but ultimately illuminating journey.

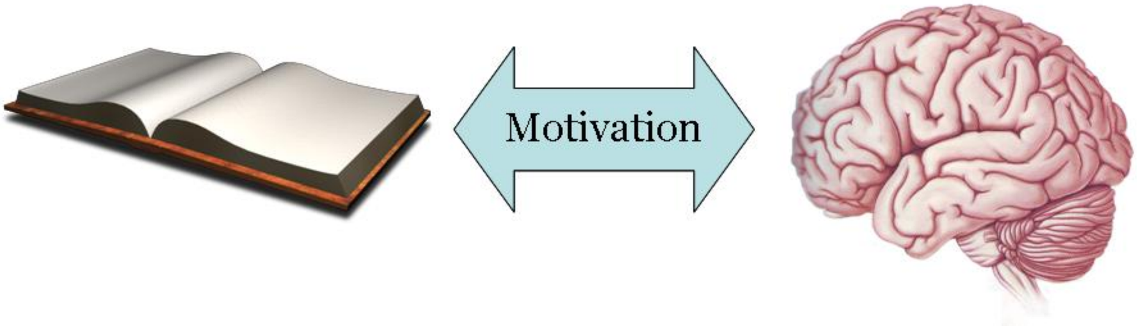


Figure 2.1: The most general view of education – the interaction between knowledge and the learner through motivation.

My literature review is an introduction to the system in Figure 2.1. It is by no means complete. The current understanding of human learning is not yet advanced enough to be simple. Some fundamental principles regarding learning are beginning to crystallize, but not even these principles are widely accepted. Because of the lack of agreement within teaching and learning, I have chosen to focus on the theoretical foundations of learning, rather than summarise a collection of somewhat contradictory empirical findings from the last few decades. The first four sections of this chapter are therefore primarily theoretical – with the aim of identifying the fundamental features of the part of the system they describe. Section one deals with knowledge itself: after a brief mention of epistemology, it delves into two different ways of classifying knowledge. Sections two to four focus on the brain: I introduce the physical brain through neuroscience, then I describe the cognitive brain using cognitive psychology, before I discuss the learning brain as viewed by constructivism – the theoretical framework underlying Education today. I argue that these three distinct academic fields in fact agree on the basic tenets of human learning. Although motivation is essential for learning, an extended account of this area was not feasible in this project. Therefore, aspects of motivation are covered within the above sections. In the fifth and last section of this chapter, I discuss the practical implementation of theory.

Note that different fields tend to use words in somewhat different ways. In particular *knowledge* and *learning* may not be understood in the exact same ways by all. In this chapter I will use words as they are used in the particular field that is being discussed.

2.1 Knowledge

Knowledge is undoubtedly a core focus of learning, but what is it? It is essential for an educator to know about *what* students learn and whether it has any characteristic features that may inform *how* it should be taught. This section will briefly discuss the philosophy of knowledge (epistemology) before three different ways of viewing knowledge is outlined.

2.1.1 Epistemology

Epistemology is devoted to the study of knowledge: what it is, what we can know and how we know what we do know (Greco, 1999). Philosophers have been active epistemologists since antiquity, and yet the question of what knowledge is has not been clearly and satisfactorily defined (Greco, 1999).

In introductory philosophy knowledge is generally referred to as ‘true belief’ (Kitcher, 2002). Zagzebski (1999) offers a more extensive definition: “Knowledge is cognitive contact with reality arising out of acts of intellectual virtue” (p. 109) where “[a]n act of intellectual virtue (…) is successful in reaching the truth” (p. 108). This is interesting because it brings human cognition and ‘external reality’ into the very definition of knowledge itself. With respect to science, and physics in particular, however, ‘successful in reaching the truth’ is contentious. How can we ever know that scientific discoveries represent the truth? ‘Truth’ may refer to reproducible physical observations and theories developed to account for these observations, but theories are dynamic constructs that are open to, and even welcome, modification in light of new, contradictory empirical evidence. Zagzebski’s definition is therefore only applicable to science if an acceptable definition of *truth* is ‘the best current understanding and representation of a physical phenomenon’.

Kitcher (2002) emphasizes the social nature of the pursuit of scientific knowledge and, with that in mind, argues that labeling something as knowledge “is to indicate that it can be depended on, used in practical activities or in further investigations” (p. 405). This is a more practical definition of knowledge. Kitcher (2002) also points out that what should be labeled as scientific knowledge is a balancing act between the conservative and liberal extremes. The conservative extreme accepts so little as knowledge as to render the idea of ‘standing on the shoulders of giants’ an impossibility. This would prevent progress by not allowing accumulation of ideas. The liberal extreme, on the other hand, places very few restrictions on what is classified as knowledge. This would lead to such a fragile knowledge foundation that minor advances would constantly experience set-backs due to flaws in the accepted knowledge, thus in fact hindering the large-scale advance of the field.

2.1.2 Types of knowledge – Bloom’s revised taxonomy

In 1956 Benjamin Bloom presented a taxonomy of knowledge for teaching and learning. This was revised 50 years later based on newer research findings, which resulted in *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom’s Taxonomy of Educational Objectives* (Anderson et al., 2001).

The revised taxonomy divides knowledge into four different categories: *Factual, Conceptual, Procedural* and *Metagognitive knowledge*. The four categories range from concrete to abstract knowledge, and each category has two or three sub-categories, which again classify knowledge from concrete to abstract. Thus, different types of knowledge form a continuum with relatively, but not perfectly, clear divisions. The following is an overview of Anderson et al.’s (2001) knowledge categories.

2.1.2.1 Factual knowledge

Factual knowledge comprises the most concrete of *what* we can know. It covers the basic elements of knowledge, which require only a minimal level of understanding. Factual knowledge is divided into two subcategories:

Knowledge of terminology refers to technical vocabulary. In physics, this means knowledge of symbols, units and numbers. The *understanding* of these, however, (i.e., their derivation and underlying meaning) is *not* part of this subcategory.

Knowledge of specific details and elements refers to knowledge that does not require any understanding, but are simply details and elements relevant to practitioners in a field, such as dates of important discoveries in physics.

2.1.2.2 Conceptual knowledge

Conceptual knowledge is the *what* of knowledge that *does* require understanding. Unlike Factual knowledge, Conceptual knowledge comprises knowledge that physicists have derived from observing nature – what we consider to *be* physics. Concepts, principles and theories represent three levels of increasing complexity within the corpus of physics knowledge, where the more complex builds on the less complex. The collective term for Factual and Conceptual knowledge is *declarative* knowledge.

Knowledge of classifications and categories encompasses, as the title indicates, subject specific definitions of groupings, generally associated with definitions of words. This type of knowledge is fundamental for practitioners in a field, but it is the most concrete conceptual knowledge. In physics, examples include the definitions of different types of physical observables (length, force, momentum, etc.) and the classification of subatomic particles.

Knowledge of principles and generalizations refers to the fundamental ideas within a subject. In physics this is often called the *natural laws*, such as Newton’s laws, conservation of energy and Maxwell’s equations.

Knowledge of theories, models and structures is the most abstract form of conceptual knowledge: it is the understanding of entire theories, such as electromagnetic theory, quantum mechanics or cosmology. Note that this type of knowledge incorporates all other types of Factual and Conceptual knowledge by integrating them into a whole that is greater than the sum of its parts.

2.1.2.3 Procedural knowledge

Procedural knowledge is the *how* of knowledge – it describes algorithms, procedures and methods for applying declarative knowledge. Procedural knowledge is the knowledge *of* the procedure, not the quality with which it is performed. For example, if a student knows the procedural steps in how to perform long division but writes 6 / 2 = 4 (which is clearly incorrect), the error is not in the Procedural knowledge but in the Factual knowledge. Procedural knowledge has three subcategories:

Knowledge of subject-specific skills and algorithms covers the most basic forms of Procedural knowledge. It generally describes simple algorithms that have fairly clearly defined steps and lead to a fixed answer. Examples are the mathematical procedures used in physics, such as how to differentiate an equation or how to perform multiplication by hand.

Knowledge of subject-specific techniques and methods contains the more sophisticated problem solving skills. As opposed to the fairly rigidly structured algorithms in the previous subcategory, this subcategory focuses on the more general techniques and methods used to solve larger open-ended problems. Anderson et al. (2001) emphasize that the main difference between these first two subcategories of Procedural knowledge is that the first is generally classified by having a fixed answer, whereas the second has a more open solution where there are many ways to solve the problem and not only one correct solution. Prime examples are ways to answer a research question and context rich problems.

Knowledge of criteria for determining when to use appropriate procedures is often required prior to using more concrete types of Procedural knowledge. It refers to knowledge of which area of a field a problem belongs to, such that the appropriate procedures may be used, and it refers to assumptions underlying certain techniques. Examples in physics would be to recognize that Newton's second law is necessary in a certain problem, or which type of statistical test to use when comparing the means of two different samples.

2.1.2.4 Metacognitive knowledge

Metacognitive knowledge focuses on students' awareness of and responsibility for their own learning. Anderson et al. (2001) define it as "knowledge about cognition in general as well as awareness of and knowledge about one's own cognition" (p. 55). This category also has three subcategories:

Strategic knowledge is knowledge of the general strategies for learning, thinking and problem solving and is itself divided into three categories. The level of understanding of knowledge that results from applying the different types of strategic knowledge increases from rehearsal (which includes memorization by repetition) via elaboration (such as using mnemonics and paraphrasing) to organization (e.g., outlining or drawing concept maps). This form of Metacognitive knowledge is not subject specific.

Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge focuses on knowledge about cognition rather than knowledge about knowledge. This type of Metacognitive knowledge describes knowledge about how different tasks and strategies can be more or less demanding on the cognitive system. Contextual knowledge refers to knowing *about* the cognitive effect of strategies; conditional knowledge refers to the *when* and the *why* of these strategies. Examples in physics include the knowledge that a good way to develop problem solving skills in mechanics is to do many problems, and how, when and why to use the problem solving strategies in, say, quantum mechanics.

Self-knowledge is knowledge of one's own strengths and weaknesses with respect to learning and thinking. Being able to identify that one lacks certain knowledge or generally exhibits an overreliance on some strategies allows the learner to take actions to change this. However, Self-knowledge also covers the learner's motivation. There are three sets of motivational beliefs: self-efficacy beliefs, which describe a student's belief that he or she can perform a certain task; goal orientations, which are a student's goals regarding the learning task at hand; and value and interest beliefs, which focus on the value the individual student places on the knowledge to be learnt and the personal interest they have in learning it. Self-efficacy is dealt with in more detail in this thesis.

2.1.3 Knowledge in physics

Having discussed the different *types* of knowledge, I now discuss *domain* knowledge – what characterizes physics knowledge as compared to knowledge in other domains.

The theoretical physicist Murray Gell-Mann (1994) describes domains or subjects by their level of complexity. He has defined *effective complexity* as “the length of the schema used to describe [the system’s] regularities” (Gell-Mann, 1994, p. 56); or, in the words of Van Gigch, “the length of the message which is required to describe certain properties of a system” (2002, p. 207). Since, in general, most theories in physics can be reduced to a few fundamental equations (e.g., electromagnetism is summarised in Maxwell’s four equations), Gell-Mann (1994) classifies physics as the simplest of all subjects. As one moves to domains that deal with the biological world, the complexity increases rapidly, with the human genome requiring some 10 million bits to be completely described.

Basil Bernstein (1996) has a different classification of domain knowledge, which forms a valuable addition to Gell-Mann’s idea of effective complexity. Bernstein discusses domain knowledge structures as being either hierarchical or horizontal. The natural sciences have a *hierarchical* knowledge structure, which has an “explicit, coherent, systematically principled and hierarchical organization of knowledge” (p. 172). This is associated with a drive to present information in a very condensed way (i.e., lowering the effective complexity if we draw parallels to Gell-Mann’s idea), which Bernstein calls ‘integrated code’. However, not all domains strive for a hierarchical knowledge structure. The humanities and social sciences have horizontal knowledge structures where the motivation is not by an integrated code but by a ‘collection code’ or ‘serial code’:

> The constraints on the production of this knowledge (a crucial feature of this code) create a series of expanding, non-translatable, specialized languages with non-comparable principles of description based on different, often opposed, assumptions. (Bernstein, 1996, p. 173)

Whereas hierarchical knowledge structures primarily develop by reducing information (or lowering the effective complexity), horizontal knowledge structures develop by “*addition* of another specialized language,” (Bernstein, 1996, p. 173) thereby increasing the effective complexity.

This fundamental difference in domain knowledge structures can give rise to heated arguments and disagreements between practitioners in different fields because their assumptions of what counts as advancement of domain knowledge are not the same. In terms of effective complexity, they are diametrical opposites. However, the question arises: is the knowledge structure of a field a reflection of the nature of the domain itself, or is it a cultural artifact?

Considering the hierarchical knowledge structure of physics, if we tie Gell-Mann's definition of effective complexity in with the different types of knowledge in the revised Bloom's taxonomy, the effective complexity becomes an expression of how deep into the realm of abstract knowledge a domain has reached, assuming that the very compact and abstract theories (such as Maxwell's laws) encompass the less abstract knowledge. For a non-trivial domain in the natural sciences to be considered simple by its practitioners it therefore needs to, by definition, be very abstract. The domain also needs to be highly advanced in terms of its development. Physics, being one of the oldest academic fields of study, was initially thought of as anything but simple because the generalized and abstract overarching theories had not yet been discovered. A good example from modern times is the Standard Model of particle physics. Richard Feynman is by many considered one of the most intelligent scientists of the 20th century. However, when he wrote his famous Lectures on Physics (Feynman, Leighton & Sands, 1963-65), physicists had a very crude understanding of the zoo of elementary particles. The description of particle physics was therefore very complex and descriptive, and many words were necessary for a complete account of the knowledge at the time: "We do not today understand these various particles as different aspects of the same thing," Feynman said (Feynman et al., 1963-65, p. 2—9). Today, however, hundreds of elementary particles are known – many more than in the 1960s – but the Standard Model of particle physics neatly describes them all in a very compact way; in fact, we now know that only a handful of different fundamental particles combine to produce all the elementary particles (Perkins, 2000).

Therefore, the effective complexity of a domain may not only be a function of the nature of the domain itself, it is also strongly interlinked with the level of our own knowledge of that domain and its classification as a hierarchical or horizontal knowledge structure. Hence, it is difficult to say whether a domain that today has a high effective complexity, such as human learning, may be considered simpler in years to come.

2.2 Neuroscience

> Clearly, the brain deserves its status as the most complex piece of matter in the universe.
> (Bear, Connors & Paradiso, 2007, p. 199)

The brain is made up of neurons and is the information processing organ of humans. Knowledge of neurons and their function is the realm of *neuroscience* – the science of the brain (Kandel, 2000a). Although neuroscience is a relatively young field, the advances it has made are remarkable and form an important foundation for the understanding and study of learning. A detailed account of the structure and function of neurons and how they communicate can be found in Appendix A; this section outlines the neuroscience that is directly relevant to learning.

Each individual has about 100 billion neurons, and each neuron is connected to up to 10,000 other neurons. The connection points are called synapses, but the strengths and number of synapses are not fixed. In fact, the plasticity of synapses is the physiological basis for learning and memory. In 2000, Eric Kandel, who is frequently referenced throughout this section, received the Nobel prize in Physiology or Medicine for demonstrating "how changes of synaptic function are central for learning and memory" (Nobel Foundation, 2000).

The large scale structure of human neuroanatomy is prescribed by our DNA, but much of the fine structure, which gives rise to individual differences in human cognition, can be attributed to a complex interaction between our unique gene expression and enormous set of experiences. However, not only does gene expression affect how we use our brain, of potentially enormous consequence is the finding that *how* we use our brain can actually *itself* alter gene expression.

> Most people assume that our genes shape us – our behaviour and our brain anatomy. Kandel's work shows that when we learn our minds also affect which genes in our neurons are transcribed. Thus we can shape our genes, which in turn shape our brain's microscopic anatomy. (Doidge, 2008, pp. 221-222)

2.2.1 Definitions

Learning and memory are generally thought of as psychological constructs, but they have a neurological basis. To avoid significant overlap, this section will discuss the characteristically neuroscientific aspects of learning and memory, whereas the psychological view is discussed later.

> Learning is the process by which we acquire knowledge about the world, while memory is the process by which that knowledge is encoded, stored, and later retrieved. (Kandel, Kupfermann & Iversen, 2000, p. 1228)

Kandel et al.'s (2000) definition highlights the relationship between learning, memory and knowledge. *Knowledge* is used in a traditional sense to refer to what we know about something – "knowledge that we have in our mind about objects, people, and events in our world" (Kandel, 2000a, p. 16). *Memory* is related to the physical storage of pieces of knowledge in the brain – "knowledge we have stored in memory" (Kandel, 2000a, p. 16). *Learning* is the process of acquiring knowledge. The word *information* is generally used when referring to bits that are too small to be called knowledge, such as sensory information (Kandel et al., 2000).

Humans can engage in two distinctly different types of learning that lead to either *implicit* or *explicit* memory (Kandel et al., 2000), associated with implicit or explicit knowledge respectively. These two forms of memory are not only psychologically different, they have evolved to exhibit identifiably different ways to be encoded and locations in the brain to be stored (Kandel et al., 2000). Implicit memory constitutes knowledge we can recall unconsciously, such as reflexive motor or perceptual skills. It generally requires repetition and practice over a longer period of time to be learnt but is not easily forgotten (Bear et al., 2007). (Once you've learnt to ride a bike, you don't forget it.) Explicit memory, on the other hand, must be recalled by deliberate, conscious effort. It is often easily learnt and easily forgotten (Bear et al., 2007). Explicit knowledge is further classified into *semantic* knowledge and *episodic* (or autobiographical) knowledge, on the basis of where memories are located in the brain (Kandel et al., 2000). Semantic knowledge is the type of knowledge acquired at school and in books and will be the focus here. Episodic knowledge relates to personal experiences, such as knowledge of family and friends and places one has been.

2.2.2 Implicit memory

Habituation and sensitization are examples of implicit memory. When an animal (or a human) repeatedly experiences a stimulus that is neither beneficial nor harmful, the response to that stimulus decreases – the animal learns to ignore it (Kandel, 2000b). This is called habituation. For example, an animal whose tail is being prodded repeatedly will initially move its tail away from the stimulus. However, with time the animal learns to ignore the prodding, if it has no adverse affects, and will eventually not exhibit a motor response. This behavioural change is associated with a change in the synaptic connection between the neurons that relay the stimulus and the motor neurons responsible for the motion of the limb (Kandel, 2000b). The opposite of habituation is sensitization where the neuronal connection is strengthened, thus amplifying the signal (Kandel, 2000b).

Although the type of knowledge we are primarily concerned with in tertiary education is far more advanced than simple motor reflexes, these examples are relevant for the understanding of explicit memory storage. The method for memory storage has been largely conserved throughout evolution, so the more complex forms of learning and memory are based on many of the same mechanisms that are found in the simplest life forms (Kandel, 2000b).

2.2.3 Explicit memory

Whereas implicit memory is very rigid and quite strongly connected with the conditions of the original stimulus, explicit memory is highly flexible and involves the association of multiple bits and pieces of information (Kandel et al., 2000). The following paragraphs outline the distinct stages of the processing of explicit knowledge.

2.2.3.1 Sensory input and attention

As humans, we receive information about the world through our senses – the five gates connecting the external with the internal. When we interact with the world, information from each sense is carried separately to the brain, and only at the later stages of cognitive processing is information from more than one modality integrated (Saper, Iversen & Frackowiak, 2000). However, "selective attention acts to limit the amount of this information that reaches the highest centers of processing in the brain" (Kandel & Wurtz, 2000, p. 504). Hence, only some of the information that impinges on our senses is actually processed. Sensory information that is not filtered out is passed on to the working memory (Saper et al., 2000).

2.2.3.2 Encoding

Working memory plays a similar role to a computer processor and has very limited capacity. Initially proposed by the psychologist Alan Baddeley, it is now also embraced by neuroscience (Saper et al., 2000). "[T]he process by which newly learned information is attended to and processed when first encountered" is referred to as *encoding* (Kandel et al., 2000, p. 1237). The quality of the encoding determines how well the learned material will be remembered (Kilgard & Merzenich, 1998); the information should be carefully attended to and associated “meaningfully and systematically with knowledge that is already well established in memory so as to allow one to integrate the new information with what one already knows” (Kandel et al., 2000, p. 1237). Research indicates that this allows for very rapid learning (Tse et al., 2007).

2.2.3.3 Memory consolidation

All knowledge that is being held in working memory can potentially be transferred to long-term memory (Kandel et al., 2000), where “[l]ong-term memories are those that you can recall days, months, or years after they were originally stored” (Bear et al., 2007, p. 727). The process of converting a memory into a permanent one is called *memory consolidation*. This may proceed via short-term memory, where memories can be stored from seconds to hours, but during this time they are vulnerable to disruption (Bear et al., 2007).

Initially, memory formation appears to involve a temporary change in the structure of existing synaptic proteins. Unless this is converted to a more permanent change, the memory will be lost (Bear et al., 2007). The temporary change corresponds to an increase in the probability of information passing through a synapse, whereas the permanent change is a structural change that is often represented by an increase in the number of synaptic connections (Kandel, 2000b). The structural change requires the construction of new proteins and sometimes new synapses, so long-term memory is associated with actual physical changes in the brain (Bear et al., 2007; Kandel, 2000b). This takes time. The transfer of information from short-term to long-term memory is therefore relatively slow; the reason for this is thought to be a mechanism that prevents new information from disrupting the already existing information (Kandel et al., 2000).

Two mechanisms that help memory consolidation are of particular interest. First, sleep has been found to play an important role in converting short-term memories to long-term memories (Stickgold, Hobson, Fosse & Fosse, 2001). Therefore, ‘to sleep on it’ may be more essential to learning than most people think. The second mechanism is that of motivation and reward, which are associated with release of the ‘reward chemical’ dopamine. Dopamine is involved in goal-directed behaviour through reinforcement (Bao, Chan, Zhang & Merzenich, 2003), where reinforcement is “the specialist term of the ‘stamping-in’ of stimulus associations and response habits that follows the receipt of reward” (Wise, 2004, pp. 1-2). The reinforcement process acts on the after-effects of a learning experience by aiding the consolidation of short-term memories to long-term memories.

Rewards subsequently give rise to motivation because “our motivations are motivations to return to the rewards we have experienced in the past, and to the cues that mark the way to such rewards” (Wise, 2004, p. 8).

2.2.3.4 Memory storage

Once new memories have become long-term memories, explicit knowledge (semantic knowledge in particular) is *stored* as different types of memories (e.g., memories of a visual image, a word and a smell of the same object) in different areas of the brain. Information associated with a certain type of sensory modality (e.g., visual or auditory) will be stored in the brain region associated with that modality. However, when memories are formed, all the information that is being processed simultaneously is stored in a way that links it all together (Bear et al., 2007). In fact, “[i]nterconnectedness is a key feature of declarative [or explicit] memory storage” (Bear et al., 2007, p. 749).

2.2.3.5 Recall

The fourth and last stage of semantic memory – after encoding, consolidation and storage – is *recall*, which again requires the involvement of working memory. Knowing that different pieces of information that constitute a memory are stored in physically different areas, recall is inherently a *constructive* process, which involves the seamless synthesis of several pieces into a coherent whole (Kandel et al., 2000). This means that recalled knowledge is far from an exact copy of the original information.

> Past experiences are used in the present as clues that help the brain reconstruct a past event. During recall we use a variety of cognitive strategies, including comparison, inferences, shrewd guesses, and suppositions, to generate a consistent and coherent memory. (Kandel et al., 2000, p. 1240)

2.2.4 Neuroscientific teaching

There is still much we don’t know about how thoughts change brain structure (Doidge, 2008), but the knowledge today is advanced enough to be practical. In the recent book *The brain that changes itself* (2008), Norman Doidge gives a remarkable insight into the neurological understanding of human learning. This understanding has, to mention a few inventions, spawned efficient techniques to help autistic children normalize their brain using a cleverly developed computer program that provides learning exercises that improves the children's hearing, language and speaking skills, further developed techniques for psychiatrists to help patients with debilitating depression and obsessive compulsive disorders, and methods to remove chronic pain in the phantom limbs of amputees.

Other studies have found that humans are hardwired to be social; for example, there is overlap in the brain between areas that are involved in perception and production of actions, and a similar overlap is observed between neural systems involved when adults experience pain and those involved when they observe others being in pain (Meltzoff et al., 2009). Further strengthening our inherently social nature is the finding that we are born to learn by observing and imitating others.

> Imitation accelerates learning and multiplies learning opportunities. It is faster than individual discovery and safer than trial-and-error learning. Children can use third-person information (observation of others) to create first-person knowledge. (Meltzoff et al., 2009, p. 285)

In summary, from the perspective of the physical brain both learning and remembering are constructive processes. We are hardwired to learn and to be motivated – and even to be social. The brain truly is nothing short of remarkable.

2.3 Cognitive psychology

While neuroscience focuses on the physiological aspect of memory, cognitive psychology emphasizes the psychological (or cognitive) aspect. However, the two fields draw on each other and ultimately try to explain the same process; they merely have different interests.

> The boundary between cognitive psychology and neural science is arbitrary and always changing. It has been imposed not by the natural contours of the disciplines, but by lack of knowledge. As our knowledge expands, the biological and behavioral disciplines will merge at certain points; it is at these points that our understanding of mentation will rest on more secure ground. (Kandel, 2000b, p. 1277)

This section covers the learning journey from a psychological perspective. Note that only the visual and auditory sensory modalities are of interest in this project.

2.3.1 Attention

Attention refers to "selectivity of processing" (Eysenck & Keane, 2005, p. 141) of incoming information. The theory that best accounts for observed features in attention is *perceptual load theory* (Eysenck & Keane, 2005). This theory proposes that all people have limited attentional capacity. With respect to visual attention, this is often described as resembling a spotlight, where only the visual field that falls within the focus of the spotlight is seen clearly (Eriksen & St. James, 1986). When a person performs a task, the amount of attentional capacity required is allocated; whatever attentional capacity remains is allocated to other tasks. There is much evidence for the validity of perceptual load theory for visual attention; validity is assumed for auditory attention as well, but this has yet to be established (Eysenck & Keane, 2005).

2.3.2 Working memory

The information attended to is processed in *working memory*. Figure 2.2 shows a schematic of its four different parts.

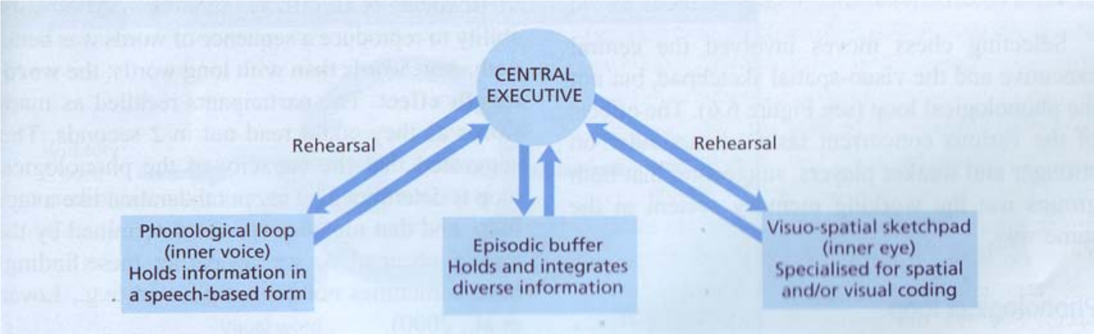


Figure 2.2: The four different parts making up working memory (Eysenck & Keane, 2005, p. 195).

The phonological loop and the visuo-spatial sketchpad are limited capacity unimodal stores for auditory and visual information respectively. Information from these stores can be integrated with information retrieved from long-term memory in the episodic buffer. The central executive resembles the attentional system and plays a vital role in the organization, planning and active use of working memory (Eysenck & Keane, 2005); it is modality-free, has no storage capacity and is the least understood component of working memory.

The limited capacity of working memory represents the bottleneck of human information processing. The capacity is most often quoted as ‘seven plus or minus two’ as determined by Miller in 1956 (Eysenck & Keane, 2005), but Redish (2004) reports that this result was an oversimplification and that more recent experiments reduce this value to as little as three plus or minus one for semantic memory. The numbers refer to ‘chunks’ where a chunk represents “integrated pieces or units of information” (Eysenck & Keane, 2005, p. 191). For example, to a physicist, force, mass and acceleration constitute a clear chunk because they are associated through Newton’s second law. To a first year student, however, these three concepts are unrelated and so represent three chunks, which take up a larger portion of the student’s working memory. Note that a chunk can have considerable structure much more complex than the above example (Redish, 2004). Strongly associated chunks make up schemata or mental models (Redish, 2004), to be discussed in more detail in Section 2.3.3.2.

Practice improves performance – sometimes dramatically – by reducing the load a task places on working memory. The more automatic a task becomes, the less the load it represents for two reasons: automaticity is associated with more rapid processing, and the nature of the process may itself be changed (called restructuring) (Eysenck & Keane, 2005). Restructuring refers to going about a particular task in a different way that is more efficient. One example is counting the number of dots in a rectangular grid: one can either count the dots one by one, or one can count the number of dots along each side and then multiply the two; same outcome, different processes. Thus, automaticity refers to processes associated not only with the encoding of information, but also with how it is stored and retrieved (Eysenck & Keane, 2005).

2.3.2.1 Cognitive load theory

Cognitive load theory is developed by cognitive psychologist John Sweller and colleagues, and concerns the details of the limited working memory capacity (Sweller, van Merriënboer & Paas, 1998; van Merrienboër & Sweller, 2005).

C*ognitive load* refers to the load imposed on working memory by a given task, and it can be either intrinsic, extraneous or germane. The *intrinsic* load is a property of the subject matter itself. It refers to the number of elements (chunks) that need to be processed simultaneously to foster understanding and thus cannot be reduced by instructional design without reducing the quality of understanding. However, by initially introducing a subsection of a topic, the learner can integrate the initial elements into a coherent whole (one chunk) first, thereby freeing up space to allow for the integration of more elements. The *extraneous* load, on the other hand, refers to tasks that are not conducive to learning. An example is a poorly written problem where the solver needs to use a part of his working memory to understand the problem in the first place. Extraneous load *can* be reduced by employing good instructional design. Lastly, the *germane* load refers to the load placed on working memory in actually constructing schemata and developing automatisation.

Thus, the intrinsic load is necessary but not sufficient for learning – it simply refers to the holding of several chunks of knowledge in working memory simultaneously; it is the germane load imposed by the process of integrating this knowledge into long-term memory that is crucial to learning. The total cognitive load is the sum of the intrinsic, extraneous and germane loads. A situation in which the total load exceeds the capacity of the working memory is referred to as cognitive overload, which severly hampers learning.

2.3.3 Long-term memory

Only semantic memory is considered in this discussion of long-term memory. The definition of semantic memory provided by Tulving (1972) is in agreement with the neuroscientific definition of semantic knowledge:

> [Semantic memory] is a mental thesaurus, organised knowledge a person possesses about words and other verbal symbols, their meanings and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of these symbols, concepts, and relations. (Tulving, 1972, p. 386)

The process of transferring information from working memory to long-term memory is neither simple nor direct. *Consolidation theory* describes the process of fixing information in long-term memory, which can take hours or even days. It is assumed that memories that are still being consolidated are particularly vulnerable to forgetting or disruption (or interference) with either prior knowledge or future knowledge, as discussed previously in Section 2.2.3.3. Although this theory has been more prominent in neuroscience than cognitive psychology (Eysenck & Keane, 2005), its importance is recognized by cognitive psychologists.

Long-term memory is often referred to as having unlimited storage capacity (McInerney & McInerney, 2002). However, research in neuroscience is now suggesting that this is not the case.

Although the capacity of long-term memory is very large, Rosenzweig, Barnes and McNaughton (2002) provide evidence that memory removal may be an active process to make room for new memories.

Cognitive architecture describes the structure of *how* knowledge is stored in long-term memory. How it is stored affects how it is used and retrieved – both essential features of the learning process. The following sections outline three descriptions of cognitive architectures.

2.3.3.1 Concepts

Since antiquity, the idea that knowledge is grouped into concepts has been central to theories of knowledge storage, even though the details of such 'concepts' are more fuzzy. Eysenck and Keane (2005) offer three reasons for why humans organise knowledge in terms of concepts. First, concepts are an efficient way to represent knowledge about the world and objects within it. Second, concepts allow us to make accurate predictions. For example, upon observing a certain animal, if we can correctly categorise it as either a cat or a lion, our knowledge of the general features of each of these will quickly tell us whether the animal is dangerous. Third, concepts are essential for the accurate conveyance of ideas.

The leading theory regarding concepts is the *exemplar approach*, which has proven particularly successful when dealing with very complex concepts (Eysenck & Keane, 2005). In the exemplar approach a concept is not represented by one 'prototype' example, such as having a generic image of a chair; rather, a large number of specific instances are stored. When asked to think of a chair, we simply choose a particular image of a chair that we consider a decent exemplar (Eysenck & Keane, 2005). However, when learning about new concepts and categories, laboratory experiments have shown that individuals tend to only learn what is necessary to perform whatever task they are given to distinguish between the categories (Eysenck & Keane, 2005). A problem with exemplar theory is that experiments to validate it have not included the role played by prior or existing knowledge (Eysenck & Keane, 2005). Laboratory experiments have been deliberately far removed from participants' prior knowledge (such as inventing artificial new concepts and exemplars to learn) to avoid the problem of participants' immeasurable prior knowledge as a confounding factor. However, this leads to a relatively poor understanding of how people learn and integrate new information in a real-world setting (Eysenck & Keane, 2005).

2.3.3.2 Schema theory

Knowledge structures held in long-term memory are generally described as being organised in schemata (plural of *schema*), which are strongly associated chunks of knowledge (Redish, 2004).

At the lowest level of cognitive activity we find associations. When a certain knowledge element is activated it may lead to the activation of other knowledge elements, or make it easier to subsequently activate other elements (Redish, 2004). However, more generally there will tend to be a whole series of elements or chunks that are activated together, and these are referred to as a *pattern of association*, which Redish (2004) divides into two types: schemata and mental models. A pattern of association is a "*schema* if it is a bounded, distinct, unitary representation that is not too large to hold in working memory" (p. 13) whereas a pattern is called "a *(mental) model* if it consists of an interrelated set of elements which fit together to represent something. (…) 'Model' is the more inclusive term: a schema is a simple model" (p. 13).

Whether a specific schema is activated not only depends on whether the person has that particular structure in long-term memory, it also depends on how strongly and easily that knowledge is activated. This depends on the strength of associations as well as the *context* in which the initial elements are activated. Redish (2004) defines the context as "the activation pattern existing in the brain when the stimulus in presented" (p. 13). Consequently, the environment and thoughts of the person play a very important role in learning, as these define the context.

2.3.3.3 Sweller's cognitive architecture

The cognitive psychology so far has been descriptive, without explaining *why* the observations and proposed theories are as they are. Sweller and Sweller (2006), however, have proposed an evolutionary account of human cognition. If their model is correct, it has far reaching consequences for our understanding of human cognition from a psychological standpoint, as well as for teaching and learning.

Sweller and Sweller (2006) liken the evolution of human cognitive architecture to biological evolution, both of which are described as natural information processing systems. Learning is defined in terms of change in long-term memory: "In cognition, if there is no change in long-term memory there has been no learning" (2006, p. 437), which is in accordance with Kandel et al.'s (2000) definition. Sweller and Sweller (2006) use the terms 'knowledge', 'memory' and 'information' similarly to neuroscientists, except that ‘memory’ is only referred to in the context of the different types of memory systems (such as working memory and long-term memory) and not as pieces of knowledge. Only their discussions about learning and storage of semantic knowledge will be covered here.

Semantic information stored in a person’s long-term memory either comes from somebody else’s long-term memory or it is generated as novel information in one’s own working memory – there are no other alternatives. However, Sweller and Sweller (2006) suggest that almost all semantic information is borrowed and that only minimal information is novel. Their reasoning is outlined in the next paragraphs.

The argument relates to *how* information becomes integrated in long-term memory. Working memory is the only connection between long-term memory and the external environment, and it is also the only feature of human cognition that can alter the structure of long-term memory. Hence, learning can occur in two ways: by integrating new information from the external environment, or by restructuring the information that already exists in long-term memory.

The *borrowing and reorganising principle* refers to learning by integrating information from other individuals’ long-term memory. Sweller and Sweller (2006) emphasise, however, that borrowed information is rarely an exact copy of the original information; rather, it is reorganised (either at the time of borrowing or subsequently) to fit in with the existing information in long-term memory. Schema theory is generally used to describe how this existing information is structured. The act of integrating new information – even though it is borrowed from others – is therefore a *constructive* process.

The subsequent reorganisation opens up for a myriad ways in which the new information can be integrated into long-term memory; not all ways will result in a new schema that is in accordance with the original idea. Sweller and Sweller (2006) argue that there is a random component to the integration of new information, which has evolutionarily been married to a subsequent test of effectiveness to check whether the integration results in the desired outcome. When this is not the case, reorganisation must take place to improve the schema until the integration is satisfactory.

The random aspect of the integration process limits the number of elements that simultaneously can be combined with existing information if the learner is to have any chance of arriving at the correct combination. As the number of elements increases, the number of possible combinations increases exponentially. Due to the limited capacity of our working memory, an increase in combinations to try out results in an equivalent increase in time required by the task. Thus, for a reasonable chance at succeeding, one is limited to a very small number of elements unless one can rank the likelihood of success with the different possible combinations of elements. When borrowing information, the number of random possibilities will be low.

The second road to learning is to generate *novel* information that is not borrowed. This can only occur by the *randomness as genesis principle*. Without this option, individuals would never be able to do something that they had not learnt from others, thus preventing the advancement of collective knowledge. New information is generated though problem solving, where the beginning state and the desired goal are known, and the steps in-between are not. The problem solver primarily relies on existing information and potentially needs to reorganize this. It is only in the absence of help from current long-term memory that the randomness as genesis principle is invoked; it is a very inefficient way of arriving at new information and is therefore only used as a last resort.

Sweller and Sweller (2006) propose a third principle, namely the *narrow limits of change principle*, to explain *why* we have a limited working memory. The limited number of items that can be handled simultaneously by working memory ensures that “large, rapid, random changes to long-term memory do not occur” (Sweller & Sweller, 2006, p. 445). Such changes are likely to result in dysfunctional individuals because knowledge crucial for survival is more likely to be lost. This is similar to the argument posed by Kandel et al. (2000) in Section 2.2.3.3. The idea that the limiting factor to our learning capacity is also what enables us to be functional entities, provides an interesting new look on the role, value and purpose of working memory.

The implication of this view of human cognitive architecture is that instructional methods should focus on how to most efficiently integrate new information into the long-term memory of students.

2.4 Constructivism

That each individual constructs their own knowledge is evident from the discussions on neuroscience and cognitive psychology. There is no other alternative. Educational psychology approaches teaching and learning from yet another perspective with less focus on the physical brain. Because educational psychology strongly influences the practices within teaching and learning today, an extensive discussion of its theoretical foundation is important.

The current theoretical framework within educational psychology is *constructivism.* However, to fully understand the position of constructivism, an appreciation of its predecessor is essential.

2.4.1 The transmission myth

> Until recently, the accepted model for instruction was based on the hidden assumption that knowledge can be transferred intact from the mind of the teacher to the mind of the learner. (Bodner, 1986, p. 873)

Transmission, as used in this context, is illustrated in Figure 2.3 and is widely referred to as the predecessor to constructivism. However, this is largely based on misunderstandings and misinterpretations. The idea of transmission is as ill-fitting in educational psychology as it is in neuroscience and cognitive psychology. In fact, altogether, transmission is a non-entity.

Figure 2.3: Transmission theory (Pinniger, 2010).

At the beginning of the twentieth century *behaviourism* emerged as a scientific approach to the study of human behaviour (Skinner, 1968, 1974). Well known behaviourists were Ivan Pavlov, Edward Lee Thorndike, John B. Watson and Burrhus F. Skinner (McInerney & McInerney, 2002) – and Skinner is most commonly quoted as the foreperson for transmission teaching.

Behaviourism must also be viewed in context; it was a response to *mentalism*, which focused exclusively on the mind while ignoring the environment when explaining human behaviour: "Mentalism kept attention away from the external antecedent events which might have explained behaviour, by seeming to supply an alternative explanation" (Skinner, 1974, p. 16). Behaviourists rejected the mentalist notion of 'the mind' and focused primarily on the relationship between stimuli (inputs) and behaviour (outputs) – both observables.

> In this way we repair the major damage wrought by mentalism. When what a person does is attributed to what is going on inside him, investigation is brought to an end. Why explain the explanation? For twenty-five hundred years people have been preoccupied with feelings and mental life, but only recently has any interest been shown in a more precise analysis of the role of the environment. (Skinner, 1974, pp. 17-18)

This did not mean, however, that the behaviourists discounted mental activity; what they rejected was the dualistic notion of 'the mind' as something separate from the body. The behaviourists thought mental activity could be explained by physical processes, but as the inner workings of the brain at the time could not be directly observed, it was not considered appropriate to include it in a scientific understanding of behaviour. Skinner (1974) did, however, comment on the existence of a memory residing within the individual, and did not (contrary to some constructivist claims) believe that learning was a simple exercise in copying information into the mind of the learner.

> There was no copy of his visual appearance inside us then, as there is none now. (Skinner, 1974, pp. 109-110)

> What is said to be stored [in memory] are copies of stimuli (…) The copies cannot have the dimensions of the originals; they must be transduced and encoded – possibly as engrams, reverberating circuits, or electrical fields. (Skinner, 1974, p. 108)

This quote clearly shows Skinner's neuroscientific inclination. In fact, he would likely have been very interested in the recent advances in imaging techniques that enable direct observations of cognitive functions – however crude they may be – allowing the mind to be included into the present scientific study of human cognition and behaviour.

In the end, behaviourism was never very successful in explaining higher order cognitive processes, and it may be criticized for its simplistic view of human cognition. Still, the tenets of behaviourism formed a reasonable scientific approach at the time. The point is that the blanket statements about transmission, such as Bodner's quote at the beginning of this section, are largely incorrect. In fact, careful reading of Skinner's work may even place him, although peripherally, as a constructivist:

> It may be true that there is no structure without construction, but we must look to the constructing environment, not to a constructing mind. (Skinner, 1974, p. 117)

2.4.2 Different perspectives within constructivism

> There are different cognitive educational psychologies, each associated with a different view of knowledge construction, and members of the educational psychology research community identify in different degrees with all of these perspectives. (Derry, 1992, p. 416)

Generally, two broad areas within constructivism are outlined in educational psychology (McInerney & McInerney, 2002; Woolfolk, 2005): *personal constructivism* and *social constructivism*. The neurological and cognitive view described earlier may or may not be classified as a third type of constructivism. Geelan (1997), on the other hand, mentions six different perspectives (personal, radical, social, critical and contextual constructivism, and social constructionism), but acknowledes that these do not define any clear or absolute boundaries. Good (1993) identifies as many as 15 terms used to modify constructivism: "contextual, dialectical, humanistic, information-processing, methodological, moderate, Piagetian, postepistemological, pragmatic, radical, rational, realist, social, and sociohistorical" (p. 1015). The number and diversity of distinct subareas highlights the horizontal nature – in Bernstein's words – of the field.

> With the many versions of constructivism currently in use, we should be aware that one person's version is likely to differ from another person's version. This awareness is the first step to more productive debate on important, complex issues. (Good, 1993, p. 1015)

In this chapter I will describe personal and social constructivism – generally considered the two main areas of constructivism. I will outline some of the many subareas within this main dichotomy to clarify the internal variability within educational psychology, and discuss the main issues between them.

Geelan (1997) identifies two variables that help distinguish between the various perspectives: personal vs. social, and objectivist vs. relativist. The first variable, personal vs. social, identifies whether the perspective focuses on the individual or the social aspect of learning. The second variable, objectivist vs. relativist, reveals the perspective's epistemological view, where Geelan (1997) specifically refers to scientific knowledge. The objectivist sees scientific knowledge as a 'given', or as a "consensual, social construct" (Geelan, 1997, p. 21) that can be learnt. The relativist view differs in that it problematises scientific knowledge and questions the existence of an objective reality separate from those who observe it. In the neuroscientific and cognitive view described earlier, the individual is in focus and the reality of the external world is not problematised, so these fields belong to the personal-objectivist constructivist perspective. However, note that

> No constructivist perspectives are entirely objectivist, (…) [the ojectivists] are simply those who problematise the nature of scientific 'truth' and the existence of a knower-independent reality least. Similarly, (…) [the personal constructivists] have often explicitly recognised social learning, but their *focus* has been on individual congnition. (Geelan, 1997, pp. 20-21, author's original italics)

2.4.3 Personal constructivism

The basic broad tenet of personal constructivism can be simply and succinctly contained in one brief statement (Bodner, 1986, p. 873):

Knowledge is constructed in the mind of the learner.

Considering the understandings from neuroscience and cognitive psychology, this statement is not contentious and is indeed supported by those fields; still, within educational psychology many trees have perished for the sake of arguing for and substantiating this basic tenet. Today, however, where contentions arise are in the *interpretation* of this tenet, as well as in the *focus of the application* of it – two issues that are often confused with the concern for the validity of the original idea.

Personal constructivism focuses on the learner and his or her interaction with the world, and considers the learner's existing knowledge and motivations (McInerney & McInerney, 2002).

> Each of us builds our own view of reality by trying to find order in the chaos of signals that impinge on our senses. The only thing that matters is whether the knowledge we construct from this information functions satisfactorily in the context in which it arises. The constructivist model is an instrumentalist view of knowledge. Knowledge is good if and when it works, if and when it allows us to achieve our goals. (Bodner, 1986, p. 874)

The sentiment conveyed by Bodner is in alliance with the view proposed by neuroscience and cognitive psychology. In addition, the 'instrumentalist view of knowledge' seems to argue the same point as Sweller and Sweller (2006) do in that new knowledge that has been integrated in long-term memory is tested for effectiveness – if the test is negative, the information is reorganised or reintegrated in a different way and retested for effectiveness.

Objectivist personal constructivism can be traced back to the early years of constructivism, whereas radical personal constructivism is more recent. And outline of the two follows.

2.4.3.1 Piagetian constructivism

Jean Piaget (1896–1980) is by many thought of as the father of constructivism (Bodner, 1986; McInerney & McInerney, 2002), although the perspectives contained within constructivism have been traced back to 1710 in the writings of Giambattista Vico (von Glasersfeld, 1993). *Piagetan constructivism* belongs to the personal-objectivist perspective where knowledge is located *within* the individual and the external world is not problematised (Fosnot, 1993; Geelan, 1997).

Piaget's model of human learning arose from his studies of the development of thought in children, which he considered a natural approach to understand how children learn (Bodner, 1986). An important contribution from Piaget was his physical/organic developmental psychology perspective: different levels of children's understanding are related to stages in their development. However, in his later writing Piaget departed from the original, quite rigid view of the constrictions these stages imposed on the learner (Fosnot, 1993).

2.4.3.2 Radical constructivism

Radical constructivism, forefronted by von Glaserfeld, forms the relativist subcategory of personal constructivism (Geelan, 1997). What is 'radical' about this form of constructivism are the conclusions he draws: von Glaserfeld *uses* the ideas in personal constructivism to argue that we cannot talk about an objective, real world that is separate from the knower. Because all we can ever know is a mental construct of our experience with the world, "[w]e have no way of knowing what is or could be beyond our experiential interface" (von Glasersfeld, 1993, p. 26). In much the same way that scientists speak of theories and models that are successful in describing and predicting observations – rather than representing the truth – when describing what is known about the physical world, von Glaserfeld keeps returning to his argument of the impossibility of knowing about anything beyond the experiential interface.

> Does the fact that we can predict physical phenomena with a great deal of accuracy not mean that the picture of reality we have constructed is congruent with the "real" world outside? No. (…) If a prediction turns out to be right, a constructivist can only say that the knowledge from which the prediction was derived proved viable under the particular circumstances of the case. (von Glasersfeld, 1993, p. 26)

2.4.4 Social constructivism

Social constructivism differs from personal constructivism because it has a social focus. Social constructivism "[f]ocuses on the learner's construction of knowledge in a social context, with the individual making personal meaning from socially shared perceptions" (McInerney & McInerney, 2002). Within social constructivism the various perspectives not only differ in their epistemologies, they also differ in the role they see the 'social' playing.

2.4.4.1 Social constructivism in science

Joan Solomon, in her 1987 review of constructivist literature, describes how in science teaching, until the mid-1980s, the focus of education research was almost exclusively on the individual's construction of knowledge, ignoring social factors (Solomon, 1987). This led to inconsistent and limited results, which were improved when the social environment was considered. While recognizing the importance of the social aspect in learning and teaching, Solomon (1994) still considers ideas to be held by individuals.

Rosalind Driver, a key figure in science education research, holds a similar view. Driver was situated in the personal-objectivist category until the mid-late-1980s (Driver & Easley, 1978; Driver & Oldham, 1986) but in a seminal paper from the mid-90s (Driver, Asoko, Leach, Mortimer & Scott, 1994), she and her colleagues convey a strong social focus:

> [S]cientific knowledge is both symbolic in nature and also socially negotiated. The objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature. (p. 5)

> The challenge lies in helping learners to appropriate these models for themselves, to appreciate their domains of applicability and, within such domains, to be able to use them. (p. 7)

Consequently, the social focus of Driver and her colleagues does not come at the *expense* of the personal view, but rather *in addition* to it. They acknowledge that "learning science involves both personal and social processes" (Driver et al., 1994, p. 8).

2.4.4.2 Sociocultural constructivism

Another prominent area within social constructivism is *sociocultural constructivism* (McInerney & McInerney, 2002; Woolfolk, 2005). This focuses on the "larger social, cultural and historical environments in which learning is embedded" (McInerney & McInerney, 2002, p. 4). The founding father of sociocultural constructivism is Lev Vygotsky (1896–1934) – born in the same year as Piaget. Although Vygotsky's theories developed in parallel with Piaget nearly a century ago, they were not translated from Russian until the second half of the 20th century, long after his death (Luria, 1978).

The translation of much of Vygotsky's work was compiled in the seminal book *Mind in Society* (1978). Still frequently referenced and used, it is of relevance that the book editors themselves found Vygotsky's writing to be of a "cryptic nature" (John-Steiner & Souberman, 1978, p. 122) and admit that "we who worked as his editors found many possible, sometimes contradictory, interpretations of his work" (John-Steiner & Souberman, 1978, p. 133). A few different interpretations will be pointed out later, after a discussion of Vygotsky's writing itself.

In the introduction to *Mind in Society*, Cole and Scribner (1978) introduce Vygotsky and the social and cultural environment in which he worked. They explain that

> What Vygotsky sought was a comprehensive approach that would make possible description *and* explanation of higher psychological functions in terms acceptable to natural science. To Vygotsky, explanation meant a great deal. It included identification of the brain mechanisms underlying a particular function; it included a detailed explication of their developmental history to establish the relation between simple and complex forms of what appeared to be the same behavior; and, importantly, it included specification of the societal context in which the behavior developed. (Cole & Scribner, 1978, p. 6)

This description of Vygotsky's goals is of particular interest because references to Vygotsky's work (in particular from sociocultural constructivists) often do not mention or acknowledge his interest in explaining higher psychological functions in terms of *both* brain mechanisms (today the realm of neuroscience and cognitive psychology) and the societal context. Vygotsky's (1978) interest in both the individual and the society may place him on the 'social' end of Geelan's (1997) scale, but, I would argue, with a strong personal focus, similar to Solomon and Driver. In addition, Vygotsky (1978) does not problematise knowledge in his writing, which places him on the 'objectivist' end of the second dimension.

Of central importance to sociocultural constructivism, both to Vygotsky and those in the field today, are *semiotics*, *internalization* and *the Zone of Proximal Development*.

Semiotics are tools and signs that mediate human action (Palinscar, 1998), where *semiotic means* include "language; various systems of counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps, and mechanical drawings; all sorts of conventional signs; etc." (Vygotsky, 1981, p. 137). The social, cultural and historical nature of the development of these human constructs is considered particularly important. Vygotsky (1978) saw these tools and signs as uniquely human (i.e., they do not appear in the animal kingdom) and uniquely social, forefronting his argument for considering the social aspect of learning and development. Palinscar (1998, p. 351) elaborates: "mental functioning of the individual is not simply derived from social interaction; rather, the specific structures and processes revealed by individuals can be traced to their interactions with others". In light of the behaviourist psychology at the time these ideas were developed, this was indeed an important point made by Vygotsky.

Vygotsky's student Leontiev describes the important role played by society in learning semiotic means:

> [Children] cannot and need not reinvent artifacts that have taken millennia to evolve in order to appropriate such objects into their own system of activity. The child has only to come to an understanding that it is adequate for using the culturally elaborated object in the novel life circumstances he encounters. (Newman, Griffin & Cole, 1989, p. 63)

It is interesting to note the parallels between Leontiev's quote and Sweller and Sweller's (2006) borrowing and reorganisation principle: they all argue for the value of learning or borrowing knowledge from others rather than reinventing it themselves.

Internalization highlights Vygotsky's dual focus on both the social *and* the personal. Internalization is the "internal reconstruction of an external operation", and the process "consists of a series of transformations" (Vygotsky, 1978, p. 56). He refers to activities that initially occur externally or interpersonally, but which, after "a long series of developmental events" (Vygotsky, 1978, p. 57), are transformed to become intrapersonal activities occurring internally. An example is how the internalization of semiotic means allows for independent problem solving. John-Steiner and Mahn (1996) point out that at the beginning of learning something, individuals depend on others with more experience; however, with time, individuals can take more responsibility for their own learning once knowledge has become internalized.

Vygotsky (1978) did not go into details about *how* the internalization takes place; in fact, he acknowledged that not much was known about the process.

> The internalization of socially rooted and historically developed activities is the distinguishing feature of human psychology, the basis of the qualitative leap from animal to human psychology. As yet, the barest outline of this process is known. (Vygotsky, 1978, p. 57)

Considering Vygotsky's interest in the *explanations* for higher psychological processes in terms of brain mechanisms, it is likely that he would have wanted to integrate today's neuroscience and cognitive psychology in his theories.

The third and last of Vygotsky's central concepts is *the Zone of Proximal Development (ZPD)*, which is defined as

> the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1978, p. 86)

The ZPD is frequently used in literature, but from Vygotsky's metaphorical elaborations it becomes evident why there are many different interpretations of his ideas.

> The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state. These functions could be termed the "buds" or "flowers" of

> development rather than the “fruits” of development. The actual developmental level characterizes mental development retrospectively, while the zone of proximal development characterizes mental development prospectively. (Vygotsky, 1978, pp. 86-87)

If we try to reconcile the ZPD with Sweller and Sweller’s (2006) cognitive architecture, the current structure of the long-term memory (LTM[current]) is the ‘actual developmental level as determined by independent problem solving’. The structure of long-term memory required to successfully solve the problem (the ‘potential development’) can be called LTM[required]. The difference between these two architectures (∆LTM) represents the amount of learning necessary for the student to independently solve the problem. To get from LTM[current] to LTM[required] the student must learn by a) reorganising existing information, b) borrow information from others, and/or c) trial and error. If reorganising is sufficient, external help is not required; and, as discussed earlier, borrowing information is preferable to trial and error. Therefore, Vygotsky’s definition of the ZPD applies to situation b) where information is borrowed from adults or more capable peers. A student with guidance can only solve a problem if ∆LTM is relatively small (e.g., even with guidance a 10-year-old cannot solve a university physics problem), because altering long-term memory is incremental and time consuming. Viewed this way, the ZPD refers to the ‘distance’ or ‘area’ between LTM[current] and LTM[required], which is spanned by ∆LTM.

From Vygotsky’s ideas, the concepts of *communities of practice* and *enculturation* have arisen and become commonplace in sociocultural constructivism.

> A community of practice is a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice. A community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage. (Lave & Wenger, 1991, p. 98)

Communities of practice – such as physics – share specific language, knowledge and practices; there is a difference between those who are *within* the community and those who are *outside* it. *Enculturation* is the process of becoming part of a community of practice (Woolfolk, 2005), and refers to the journey from novice to ‘full participant’ who can train new novices (Lave & Wenger, 1991).

Since 1978, however, sociocultural constructivism has developed a considerable internal spread of views (John-Steiner & Mahn, 1996). Some sociocultural constructivists build on Vygotsky's ideas by selectively choosing certain aspects of his writings; this is particularly evident in the lack of references to Vygotsky's interest in brain mechanisms or individual psychology. The following section outlines some of these relatively recent perspectives.

2.4.4.3 Postmodern constructivism

> What unifies postmodern constructivist perspectives is rejection of the view that the locus of knowledge is in the individual; learning and understanding are regarded as inherently social; and cultural activities and tools (ranging from symbol systems to artifacts to language) are regarded as integral to conceptual development. (Palinscar, 1998, p. 348)

The idea that knowledge is *not* held by individuals represents an extreme social focus. One perspective within postmodern constructivism is Gergen's (1995) *social constructionism*.

> Social constructionism places the human relationship in the foreground, that is, the patterns of interdependent action at the microsocial level. There is little attempt to explain these patterns by recourse to psychological processes within persons. Such an attempt would be psychologically reductive, placing the social interchange in a secondary role, as "action to be understood," through a focus on the truly significant driving force in human affairs, namely mental process. Thus, the constructionist (…) avoids psychological explanations of microsocial process. (Gergen, 1995, pp. 24-25)

One other prominent view, which is of particular interest to science education, is the rejection of rational thought (Cole, 1996; Lave, 1988; O'Loughlin, 1992, 1993). Michael Cole comments that in his experience of reviewing work by sociocultural researchers, a general trait is that they reject

> the cause-effect, stimulus-response, explanatory science in favor of a science that emphasizes the emergent nature of mind in activity and that acknowledges a central role for interpretation in its explanatory framework. (Cole, 1996)

This is the sentiment conveyed by Lave (1988), who argues that the culture of the Western world has such a scientific focus that we cannot see beyond it.

> If rationality is a key *cultural* conception of meaning and value, (…) we must finally realize that the concept of rationality has no general scientific power (being ideological) to account for more and less powerful forms of cognition, the efficacy of schooling, or anything else. (Lave, 1988, pp. 173-174)

The sociocultural researcher Michael O'Loughlin has similar ideas.

> My claim is that the universalist, rational, disembedded thought valued by Piagetian constructivists is similarly ideologically bound and must be rejected in favor of a more suitable ideology that acknowledges the highly contextualized nature of the kind of learning that leads to genuine ownership of ideas and possibilities for transformation. (O'Loughlin, 1992, p. 809)

O'Loughlin (1992) argues that the consequence of advocating a rational method of thinking is that

> If the school privileges certain form of technical-rational discourse and if the socioculturally situated speech forms that students bring to school are silenced or negated, then students will receive the message that their ability to come to know and act for themselves is unimportant, and that their purpose in school is to come to terms with the discourse of school and society on its terms rather than on their own. (O'Loughlin, 1992, p. 812)

However, in the social constructivism in science education, the goal of education is just that: to learn the socially developed and shared semiotic means so that one may become an integrated part of society and one or more communities of practice. Considering the success and advances of science over the last few hundred years, such arguments against knowledge being held by individuals and rational thought are unlikely to penetrate into science education.

2.4.5 Compare and align: Do they really disagree?

> Where we once had behavioural objectives, we now have cognitive objectives, although it is sometimes a challenge to find the differences. (Brown, 1994, p. 4)

From the above discussion of the different perspectives within constructivism, I propose that most of these do not disagree notably about the fundamental ideas of learning; they primarily differ in their focus. The neuroscientists and cognitive psychologists certainly agree and exchange knowledge. Of the objectivist constructivists, the personal and the social constructivists generally acknowledge each other and agree that both personal and social aspects of learning are important. In addition, they can draw on neuroscience and cognitive science for details about the individual.

But there are those who don't agree. The relativists are primarily concerned with the philosophical questions about reality. Most scientists would not dispute this, and, as discussed in Section 2.1.1, it is indeed a valid argument. However, as far as practical usefulness of educational theories goes, this perspective is not particularly productive. Even Gergen (1995), the social constructionist, acknowledges that "there is no means by which practical derivatives can simply be squeezed from a theory of knowledge" (p. 29).

What we need are theories of learning that can explain observed phenomena, which – like physical theories and models – lay no claim on 'the truth' but rather represent the current models that best explain observations. Because of the practical focus of this project, and of physics education in general, an objectivist perspective is adopted here. The relativist ideas will be punctuated by Fosnot's (1993) comment to O'Loughlin's proposal of rejection of rational thought:

> Ironically, it was just this form of reasoning, rational inquiry, that O'Loughlin chose to use in his critique of constructivism. He categorized constructivists into two discrete groups, defined each, then used if/then reasoning to probe assumptions and applications, eventually leading the reader to conclude in accepting a sociocultural model as a viable alternative. Although within the article he was refuting rational inquiry as a goal of science education, he found its use necessary to argue his point! (Fosnot, 1993, p. 1197)

2.5 *Theory into practice*

Having covered a considerable theoretical foundation regarding human learning, this last section relates the theory to the actual practice of teaching and learning.

2.5.1 Direct instruction vs. discovery learning – the great debate

Constructivism is claimed – probably rightly so – to have brought about a paradigm shift in teaching and learning from a teacher-centred focus to a student-centred focus.

> [T]he view of the learner changed from that of a recipient of knowledge to that of a constructor of knowledge, an autonomous learner with metacognitive skills for controlling his or her cognitive processes during learning. Learning involves selecting

> relevant information and interpreting it through one's existing knowledge. (Mayer, 1992, p. 407)

This is often discussed in parallel with the paradigm shift from transmission teaching to constructivist learning. However, as discussed earlier, whether transmission teaching as portrayed in constructivist literature ever really existed is contentious; rather, it is more probable that the old teacher-centred focus was a consequence of the power structures and other societal influences common until the early twentieth century. Today, however, there is still a debate involving teacher-centred versus student-centred learning.

> The constructivist description of learning is accurate, but the instructional consequences suggested by constructivists do not necessarily follow. (Kirschner, Sweller & Clark, 2006, p. 78)

The real contentions in teaching and learning arise from the *interpretations* of constructivism, which is acknowledged by the practitioners within the field (John-Steiner & Mahn, 1996, p. 191).

Two key names in the current debate between teacher-centred and student-centred learning are Jerome S. Bruner (1960, 1966, 2006) and David P. Ausubel (1978, 2000). Both published their central work in the 1960s. Bruner advocated discovery learning (although not completely unguided) in which students were presented with incomplete information so that they would discover relationships, solutions and patterns themselves (McInerney & McInerney, 2002). Ausubel, however, considered such learning to be inefficient and generally not necessary (Ausubel, 2000). He was strongly rooted in cognitive psychology, emphasizing the importance of integrating new material – which is explicitly presented to the student – into the existing knowledge structure. However, rather than discussing the 1960s debate between Bruner and Ausubel's theories, I will present a more recent dialogue. A series of four articles from 2006 and 2007 highlight the heart of the current educational debate of discovery learning versus direct instruction and is therefore covered here in some detail.

In 2006 Kirschner, Sweller and Clark (2006) published the article *Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching*. Of the responses to the article, two are relevant to this discussion; they were addressed by Sweller, Kirschner and Clark in 2007.

The definitions of discovery learning and direct instruction were given by Kirschner et al. (2006) in the original article:

> [A]n unguided or minimally guided environment [is] generally defined as one in which learners, rather than being presented with essential information, must discover or construct essential information for themselves. (…) Direct instructional guidance is defined as providing information that fully explains the concepts and procedures that students are required to learn as well as learning strategy support that is compatible with human cognitive architecture. Learning, in turn, is defined as a change in long-term memory. (p. 75)

The contentious issue was that

> Although unguided or minimally guided instructional approaches are very popular and intuitively appealing, the point is made that these approaches ignore both the structures that constitute human cognitive architecture and evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide "internal" guidance. (Kirschner et al., 2006, p. 75)

Kirschner et al. (2006) outline how discovery learning arose from the idea that the teaching of a discipline should be based on the practice of it. However, there are no good theoretical reasons why the way an expert works in a domain should be equivalent to how a novice learns in that domain (Kirschner, 1992). In fact, one of Sweller and his colleagues' key criticisms of the constructivist instructional methods, such as 'discovery learning' and 'inquiry learning', is that there is no attempt to analyse the cognitive mechanisms of discovery and thus provide a rationale for why, psychologically, discovery learning should be superior to more structured instruction where students are told and shown the necessary semantic knowledge (Kirschner et al., 2006; Sweller & Sweller, 2006). Considering the differences in long-term memory structures between experts and novices, Kirschner et al. (2006) argue that consideration of students' cognition is essential: "Minimally guided instruction appears to proceed with no reference to the characteristics of working memory, long-term memory, or the intricate relations between them" (Kirschner et al., 2006, p. 76). This view is strengthened by the results of "[c]ontrolled experiments [that] almost uniformly indicate that when dealing with novel information, learners should be explicitly shown what to do and how to do it" (Kirschner et al., 2006, p. 79). Still, discovery learning has persisted for half a century, periodically returning under new names such as discovery learning, problem-based learning, inquiry learning, experiential learning and constructivist learning (Kirschner et al., 2006). In summary, "[t]he debate about discovery has been replayed many times in education, but each time, the research evidence has favored a guided approach to learning" (Mayer, 2004, p. 18). So why do, at least some, researchers still consider there to be a case for discovery learning?

Much of the debate seems to boil down to semantics. Kirschner et al. (2006) received two responses relevant to this discussion, which focused, in particular, on problem-based learning (PBL). Schmidt, Loyens, van Gog and Paas (2007, p. 91) state that they "concur with the authors about the failure of minimally guided instruction for novices learning in structured domains", before they proceed to argue for why PBL is *not* a form of minimally guided instruction. A very similar argument is brought forth by Hmelo-Silver, Duncan and Chinn (2007, p. 100):

> We agree with Kirschner et al. (2006) that there is little evidence to suggest that unguided and experientially-based approaches foster learning. However, IL [inquiry learning] and PBL are not discovery approaches and are not instances of minimally guided instructions, contrary to the claims of Kirschner et al. Rather, PBL and IL provide considerable guidance to students.

PBL is an approach to learning particularly popular in medical education. Students work in groups on a specific problem, which they are expected to spend a considerable amount of time on (i.e., more than one session) (Schmidt et al., 2007). A tutor is present during the PBL sessions to guide the students, and he is also allowed to provide just-in-time teaching if considered necessary. However, students should primarily consult resources themselves (a restricted set may be provided by the tutor) and are expected to study relevant sources independently outside of the PBL sessions. Schmidt et al.'s (2007) conclusion is that "PBL involves many of the principles relevant to CLT [cognitive load theory] and is *not* an example of minimally guided instruction when it is implemented with the proper degree of scaffolding" (p. 96). In fact, different understanding of words may exaggerate the real size of the schism, as pointed out by Hmelo-Silver et al. (2007, p. 104):

> What Kirschner et al. view as effective instruction is often fully compatible with IL and other constructivist instruction. Most proponents of IL are in favor of structured guidance

> in an environment that affords choice, hands-on and minds-on experiences, and rich student collaborations.

Still, there is *not* complete agreement between the camps, although the divide is not as severe as initially suggested. Sweller et al. (2007), in their reply to the comments, suggest that the arguments put forth regarding PBL *being* compatible with cognitive load theory “results in a series of logical contradictions” (p. 115). Their major issue is that

> [a]t no point (…) is there any mention of the effect of working memory and its limitations. (…) What would be the consequences of simply outlining a clear and effective solution, to the problem rather than having learners spend unnecessary time and effort on extraneous search activities? (p. 116) [*sic*]

Ultimately, the major disagreements are not primarily about the theoretical foundations but rather are focused on the *implications*.

> Both papers stress that modern PBL/IL are very structured with strong scaffolding and as we understand their argument, that the more structured they are, the better they work. If there is a disagreement, it is that both commentaries stop short of what we see as the ultimate conclusion, namely, a need for the major instructional emphasis to be on direct, explicit instruction such as worked examples, case studies as modeling examples, or just tuition. (Sweller et al., 2007, p. 119)

To close the ‘cultural gap’ between the different camps, it is therefore important that methods of instruction have clear references to how they address the various features of human cognitive architecture and fuction to provide an effective learning situation. In addition, Kirschner et al.’s (2006) comment that “[t]he advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide ‘internal’ guidance” (p. 75) does not provide any clear indication as to *when* less guidance is preferable. The remainder of this chapter discusses elements of this debate – the individual, the social and an aspect of motivation – and some specific findings that are relevant for this work.

2.5.2 The individual

Neuroscience and cognitive psychology provide the majority of the relevant knowledge about the individual in teaching and learning. Students’ prior knowledge can be described in terms of their cognitive architecture, whereas the alteration of this knowledge – the learning – requires the consideration of working memory.

2.5.2.1 Novices vs. experts

The difference between novices and experts lies in their long-term memories. Unlike novices, experts have sophisticated schemata that contain an enormous amount of principled knowledge and specific problem states. Principled knowledge refers to ”a cohesive and well-integrated body of domain knowledge” (Alexander, 2003, p. 11); specific problem states refer to specific cause-effect cases that the expert has memorised, which allows him to circumvent the logical reasoning between cause and effect (Feldon, 2007). For example, an expert chess player immediately knows what move to make upon seeing a certain chess board configuration. Having analysed the configuration several times before, he has simply stored the knowledge of which response is most advantageous.

When solving problems, novices generally focus on surface features whereas experts have a comprehensive overview of the field that enables them to see the underlying principles of a problem (Sutherland, 2002). According to Elstein (1994), the development of expertise is more strongly associated with extensive and well organised knowledge in schemata and pattern recognition than the use of particular problem solving methods. The schemata help the expert separate relevant from irrelevant information and allow for meaningful and efficient interpretation of information and problem structures (Kirschner et al., 2006). Other characteristics of experts include a high level of automaticity and a well-developed set of both cognitive and metacognitive strategies (Feldon, 2007).

2.5.2.2 The journey from novice to expert

At the tertiary level, educators are practitioners within their own field and often have minimal knowledge about educational theories. Such experts can lack awareness of how their enculturation has affected their knowledge structures – which processes have become automated and which patterns of association may be characteristic of their field – and therefore what must be explicitly taught. Considering the large difference between the knowledge structures of experts and novices, the expert should have a certain level of metacognitive self-knowledge regarding his own knowledge structure. This can help him avoid cognitively overloading the students and present new knowledge in a way that maximizes the likelihood that students successfully integrate it into their long-term memory structures.

To help learners efficiently progess on the road to expertise, identifying the learners' current knowldge becomes the starting point for teaching. Equipped with this information, the appropriate teaching tool to extend the learner's knowledge can be identified – the one that targets the learner's ZPD. The success of this method was verified by Kalyuga and Sweller (2005) in an adaptive eLearning experiment where students solved a series of problems. Using a computer, students' expertise was assessed after each problem they solved, and the next problem was dynamically chosen accordingly. In comparison with a control group, who solved a fixed set of problems, the dynamic group showed superior performance on a post-test.

Students are rarely at exactly the same level of expertise, which is why differentiation of teaching tools is essential to optimise individual learning situations. Expertise is traditionally assessed by measuring performance, but van Merriënboer and Sweller (2005) suggest that it should include ”measures that reflect the quality of available cognitive schemata” (pp. 166-167) as well. This is an area in need of further research, but, as it stands, the teacher has to use whatever means are available to assess the student's expertise to provide problems or other forms of teaching that will facilitate learning.

Four different aspects of prior knowledge are important to consider for evaluation of prior knowledge. The sheer *quantity* of prior knowledge (both declarative and procedural) is obviously of importance, as is the *organization* of this knowledge (de Jong & Ferguson-Hessler, 1986; Delclos & Harrington, 1991). These two components make up the schemata of the problem solver. The larger and better organized the schemata, the more accessible knowledge is to the problem solver. Also of importance is the level of *automaticity* the problem solver displays, which refers to "the execution of effortless cognitive procedures that are acquired through the consistent, repeated mapping of stimuli to responses" (Feldon, 2007, p. 95). This frees up space in working memory, which can then be devoted to processing other information. Whereas quantity, organization and automaticity are all features of the domain specific schemata, the *strategy* employed by the problem solver belongs to a separate strategy schema (de Jong & Ferguson-Hessler, 1986). Problem solving strategies involve both procedural strategies (how to approach and deal with the problem) and metacognitive strategies (self-monitoring and self-reflection during problem solving).

2.5.2.3 The Model of Domain Learning

Whereas a learning theory attempts to explain a certain aspect of learning, a learning model aims to be applicable and thus is required to select appropriate and incorporate several (or preferably all) factors that influence learning. The Model of Domain Learning (MDL), developed by Alexander, attempts to explain the journey from novice to expert in academic domains by considering the interplay of prior knowledge, interest and strategic processing (Alexander, 2003).

The nature of each of these three factors changes markedly as the learner develops from novice, via competent learner, to expert, as do the requirements to teaching methods. All physics lecturers are experts within their domain, characterized by both breadth and depth of knowledge; to reach the stage of expertise, the expert has displayed high motivation to persist with the subject. One of the most important fuels for motivation is interest, and individuals are generally more interested in domains in which they have extensive knowledge, and have more knowledge of domains in which they are interested (Alexander, Kulikowich & Schulze, 1994; Alexander, Murphy, Woods, Duhon & Parker, 1997). As a consequence, students in their final year of university education, who are nearing the stage of expertise, have in most cases such a high individual interest that the lecturer does not need to focus on the motivational aspect of teaching in lectures. For complete novices, on the other hand, the students' prior knowledge is severely limited and fragmented at best. The lecturer can thus not expect these students to be motivated by the same factors as he is. An important aspect of teaching novices is therefore to encourage them to stay motivated throughout the course by teaching in a way that makes it possible for students to take good lecture notes (e.g., through adequate pacing of the lecture and reducing assumption on prior knowledge), by explicitly flagging important concepts, connections or results, by teaching the students relevant learning strategies they need to develop, and by teaching how to attack problems and direct students to resources relevant for exam study (Pressley, Yokoi, van Meter, Van Etten & Freebern, 1997).

The third factor of MDL is strategic processing: *how* do the students learn the new material. Again, the situation is very different from novice to expert. There has been substantial research into the ways in which experts learn, and most of the expert strategies rely heavily on prior knowledge. Generating an initial overview of a text before reading it with a selective eye towards important information, requires substantial prior knowledge, as does critical interpretation and evaluation of the content (Pressley et al., 1997). The limited knowledge of novices prevents them from applying these strategies, and because different domains require different learning strategies, novices need to be taught which strategies to apply for effective learning.

Thus, novices are required to be led by the hand by experts not only to discern the central from the peripheral knowledge, but also to learn how to become effective domain learners and to inspire motivation. Consequently, the special attention novices require is not a reflection of lower intelligence or ability, but a characteristic of their developmental stage.

2.5.2.4 Instructional design

In physics, lecturing and problem solving (including laboratory work) are the two most common instructional tools. The usefulness of these tools crucially depend on their design, how and when they are used, and the way the learner interacts with them. The key to a good instructional design is to stay within the limits of working memory; this is done by minimising the extraneous cognitive load.

There are three well-documented ways to reduce extraneous cognitive load (Kalyuga, Chandler & Sweller, 1998, 2000). The *split-attention effect* refers to the negative consequences of presenting the same information in two ways that both target the same sense (e.g., diagram and text both target the visual sense). This requires the reader to mentally integrate the information into a coherent whole, which unecessarily increases the extraneous load – text and diagram should therefore be physically integrated. However, if information is presented through two different senses (generally auditory and visual channels), referred to as the *modality effect*, learning has been shown to enhance in novices. Lastly, the *redundancy effect* describes how an excessive amount of unnecessary information (either because it is already known or because it is irrelevant) hampers a person's learning. However, for different levels of expertise, information that has been integrated to avoid the split-attention effect for a novice will result in the redundancy effect for an expert. Thus, ”instructional methods that work well for nocive learners have no effects or even adverse effects when learners acquire more expertise” (van Merrienboër & Sweller, 2005, p. 163). This is referred to as the *expertise reversal effect*.

2.5.2.5 Learning by problem solving

Focusing on problem design, apart from reducing extraneous load, another way to manage cognitive load is to divide a problem into sub-problems. This reduces the intrinsic load by requiring the solver to only consider a subset of the problem at the time (Atkinson, Derry, Renkl & Wortham, 2000). Alternatively, worked example problems can be used to foster learning. This can be seen as an instructional tool that has features of both lecture-type direct instruction and problem solving. To illustrate a new principle, using two different examples is far superior to using just one and sufficient to achieve transfer (Atkinson et al., 2000). The first worked example should be relatively simple to illustrate the principle, whereas the second should be more complex. Problem variability is effective for learning, with certain restrictions: high variability increases cognitive load and should thus be used with instruction that has low cognitive load (such as worked examples rather than practice problems) (Atkinson et al., 2000); also, the surface features of the examples should differ so that students can identify the underlying principles. Exposure to different problems with the same underlying principle enables students to divorce the relevant from the irrelevant information (Atkinson et al., 2000), a defining step in the development towards expertise.

2.5.2.6 Concept maps and knowledge maps

A less common but very useful teaching aid is visual overviews such as concept maps and knowledge maps.

Concept maps is only one, but probably the best known, term used to describe a *visual* overview of several individual concepts and their relationships. Such maps are used both as teaching aids and diagnostic tools for knowledge evaluation. The concept maps developed by Novak follow certain rules of construction, such as being read from top to bottom, and moving from general to more specific concepts as one descends down the map (Novak, 1998).

Knowledge maps do not have this requirement of direction, but rather consist of nodes with verbal information interconnected with differentially nameable links (Patterson, Dansereau & Newbern, 1992). Research has shown that knowledge maps used as learning tools enhance retention of main ideas within a domain (Rewey, Dansereau, Skaggs, Hall & Pitre, 1989), and are useful reference tools in problem solving (O'Donnell & Dansererau, 1990; cited in Patterson et al., 1992). Students taught using knowledge maps as communication aids have been shown to outperform conventionally taught students, a result believed to be due to the clear overview such a map provides, as well as the reduced verbal content (Patterson et al., 1992).

According to Kilic (2003), the research on visual maps is more widespread in less mathematical science subjects such as biology (Buntting, Coll & Campbell, 2006; Heinze-Fry & Novak, 1990; Keraro, Wachanga & Orora, 2007) and chemistry (Brandt et al., 2001; Markow & Lonning, 1998) than in physics. In physics, the majority of research into concept or knowledge maps uses these as assessment rather than teaching tools (see for example Ingec, 2009; Pankratius, 1990; Roth & Roychoudhury, 1993). This is relevant because the structure of knowledge is different in different fields. Physics, in particular, has a very strong hierarchical knowledge structure, and so the knowledge map structure used for less mathematical subjects may not be ideally suited for physics, which could benefit from a visual map designed based on its own knowledge structure.

2.5.3 The social

Although learning occurs within individuals, education is a social enterprise and activity. Learning most often occurs in social contexts, and it is important to understand how these affect learners. In a group situation, for example, the learner needs to consider the needs of the others; this introduces cognitive load that may not lead to learning because “the coordination and execution of communication and interaction in groups is, in itself, often a cognitively taxing experience” (Sweller et al., 2007, p. 117). However, the social aspect may also be beneficial for learning because “[i]n a vacuum, learners are sometimes able to provide collaborative guidance but the cognitive cost of collaboration is high” (Sweller et al., 2007, p. 117). The following discusses some relevant aspects of the social side of learning.

2.5.3.1 Collaborative learning

Collaborative learning refers to mutual engagement of group members in a challenging task where all members jointly work on the same problem (Damon & Phelps, 1989).

A study by Sutherland (2002) compared novice chemistry students who analysed information in problems collaboratively in mixed ability groups, same ability groups and students who worked individually. The subsequent performance of the mixed ability group was better than that of the same ability group (in accordance with general findings, see for example Linchevski & Kutscher, 1998; Webb, 1992) but, perhaps surprisingly, was not statistically significantly different to those students who had practiced individually. For effective collaboration

> research suggests that students need the opportunity to explain to others, to receive adequate information when they ask a question, and the ability and motivation to self-elaborate on explanations they receive. (Sutherland, 2002, p. 161)

The efficacy of two of these learning methods – explaining to others (or to oneself) and receiving adequate responses to questions – will be discussed in turn.

In their review article *Learning from examples: Instructional principles from the worked examples research*, Atkinson et al. (2000) summarise findings of a set of German studies by Renkl in the late 1990s. Renkl had found that most learners were passive or superficial self-explainers and believed that by forcing learners to self-explain worked examples, their understanding of the material would improve, as had been shown by Chi and colleagues (Chi, Bassok, Lewis, Reimann & Glaser, 1989; Chi, de Leeuw, Chiu & LaVancher, 1994). Several studies were conducted to test this hypothesis in different situations; of particular interest to the discussion of cooperative learning are the three studies summarised by Atkinson et al. (2000) in which Renkl paired learners together. After studying the worked examples individually, one partner would explain the solution rationale to the other. The participants' learning was subsequently assessed. The results were not what Renkl had expected.

> The demand to explain for a co-learner actually increased explanation activities, but did not lead to better learning results. Instead, the listeners tended to outperform the explainers. Post-hoc analyses indicated that learners with little prior experience with tutoring tended to perform poorly when cast in the role of teacher, while participants with some tutoring experience learned as much as the listeners. (Atkinson et al., 2000, p. 200)

These studies provide an excellent illustration of cognitive load theory, as the extraneous load of the teaching situation reduced the germane load that leads to learning. Although Atkinson et al. (2000) do not use the concept of cognitive load explicitly in their explanations, this theory offers simple theoretical explanations for the observations that

> [l]earners who are not familiar with the role of an explainer (tutor) and for whom the learning materials are difficult (those with low prior knowledge) are overwhelmed and stressed by the dual task of teaching and learning. (Atkinson et al., 2000, p. 201)

Studies have shown that providing explanations when they are needed is much more beneficial for learning than presenting the same explanation before students have attempted to explain or understand the material themselves first (e.g., Minstrell & Stimpson, 1996; Schwartz & Bransford, 1998; Webb, 1991). When students have already engaged with the material and tried to make sense of it, the subsequent explanation provides the necessary scaffolding to understand the material and also appears more meaningful for the students (Hmelo-Silver et al., 2007). An important aspect of this is that if students have not realized certain differentiating features within the material – such as the difference between mass and weight in physics, which are used synonymously in everyday language – they will not pick up on subtleties regarding these features in a lecture (Schwartz & Bransford, 1998). This ties in with the exemplar approach discussed in Section 2.3.3.1: if students consider as one concept (e.g., mass/weight) what a physicists thinks of as two different concepts (e.g., mass vs. weight/force), any information about either of the two concepts will be lumped together into information about the combined concept in the students' minds – the two concepts will not be represented by two distinguishable schemata. Therefore, unless the distinction is made explicitly clear and the students are made aware that their current 'combined' concept is not sufficient, why would they change their way of thinking of it?

Cognitive psychology offers a framework that allows us to understand the positive effects of collaboration. The knowledge structures of two peers are likely to be relatively similar – compared to an expert's – although far from identical. Because of this, it is less likely that one student will convey information in such a way that the listening student suffers cognitive overload. The collaborating students are therefore expected to be able to discuss a problem and follow each other's arguments – they operate within each others' ZPDs – because of their similar cognitive architectures; they have no other alternative. Because the two students aim to learn the same material, they may also have greater understanding for each others' difficulties in learning certain concepts and may be able to provide better explanations on certain issues.

However, collaborative learning also carries the drawbacks of digressions and interruptions. The lack of difference between collaborative and individual learning in Sutherland's (2002) study indicates that collaboration and independent learning both have their strengths and limitations, and a complete theoretical understanding of the interactions of all the aspects of these is still far from well understood.

2.5.3.2 Language in learning

Knowledge is communicated through language. Some understanding of the role language plays in education is therefore important.

One should not underestimate the role of authority figures in learning (Bruner, 1966). An unapproachable lecturer or tutor may be very good at explaining things, but if the student feels intimidated to talk to this person, he may end up learning more by talking to a peer instead. Power structures are established and perpetuated through language (O'Halloran, 2007). The move from teacher-centred to student-centred learning was an important event in weakening the teacher power over students, but surely the goal is not to render the teacher powerless?

Vygotsky emphasised the importance of language (semiotics) and the social in education.

> the internalization of the external requires semiotic mediation, and in this semiotic mediation [Vygotsky] was right to draw attention to the abstract tool of language as the most pervasive one for manipulating the internalization of the external. (Hasan, 1999, p. 22)

This opens up for fields that focus on language and social interaction, namely linguistics and sociology. Followers of Basil Bernstein integrate these fields and thus provide a slightly different perspective on education. Danzig (1995) writes about the importance of language based on Bernstein’s theory.

> Language then gives the individual a way to organize and control phenomena; at the same time, language controls the individual. (Danzig, 1995, p. 161)

Some work has been done on mathematics by the followers of Bernstein (O'Halloran, 2007; Veel, 1999), but none in physics. Therefore, the following discussion about mathematics will be used to illustrate pedagogy derived from Bernstein’s work because of the two fields’ similar knowledge structures. Mathematics has a hierarchical knowledge structure and is *strongly classified*, which means that it has “its unique identity, its unique voice, its own specialized rules of internal relations” (Bernstein, 1996, p. 21). With this in mind, Veel argues that

> In examining mathematics syllabuses it becomes clear that the strongly classified nature of the knowledge necessitates a high degree of control over the selection and sequencing

> of content. Only with careful control of selection and sequencing can the knowledge be rendered teachable. (Veel, 1999, p. 210)

Novices in mathematics have not yet developed the necessary control over the *language* of mathematics to be "competent at independently construing mathematical meanings" (Veel, 1999, p. 204). Veel (1999) therefore proposes that a more responsible approach to the teaching of mathematics to novices "would be the careful scaffolding of knowledge through a process of guided interaction" (p. 213).

Considering the similar knowledge structures of physics and mathematics – both have hierarchical knowledge structures and are strongly classified – the above argument also applies to the teaching of physics to novices. In this way the knowledge structure of a subject affects pedagogy and the role the teacher plays in student learning.

2.5.4 Self-efficacy

The area within the motivation literature considered in this work is self-efficacy. Self-efficacy is defined as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives" (Bandura, 1994, p. 71). It has consistently been found to be a good predictor of academic achievement, study strategies and persistence in the face of difficulty (Cavallo, Rozman & Potter, 2004; Pajares, 2002), and of choice of academic major and career (Hackett, 1995).

There are different levels of self-efficacy ranging from global life skills ("When I make plans, I am certain I can make them work"), through general academic self-efficacy, domain specific self-efficacy (e.g., a specific university course), down to task-specific self-efficacy (e.g. personal belief in ability to perform uncertainty calculations within a physics course) (Choi, 2005; Lent, Brown & Gore, 1997). Of importance is that the correlation between a self-efficacy measure and the achievement measure is greatest when the two measures are matched in their level of specificity (Choi, 2005; Lent et al., 1997).

2.5.4.1 Self-efficacy and academic tasks

Self-efficacy is a dynamic construct that can be influenced and changed by feedback on academic tasks. The two main categories of such feedback are mastery experiences and social persuasion.

Mastery experiences are situations in which students master a task, in turn influencing their belief in their capability to achieve their potential (Cervone, 2000; McInerney & McInerney, 2002; Palmer, 2006). In physics those tasks could be solving problems, leading to solving more challenging problems, or understanding new concepts or how concepts are linked. Social persuasion, on the other hand, occurs via two different situations. The first case is when one observes a peer of similar ability mastering a task, thus reinforcing the belief that one can also perform the same task. The second case is when positive appraisal based on actual performance is provided, emphasizing that the students are making progress (McInerney & McInerney, 2002; Palmer, 2006), boosting their self-belief in personal achievement potential.

In subjects with which students are familiar, firm beliefs about performance capabilities are developed, and students show fairly stable self-efficacy (Cervone & Palmer, 1990). A certain internal resistance to change is necessary to avoid being greatly affected by temporary anomalies in performance, but there is a fine line between healthy and unhealthy resistance. It has been found that it is not uncommon for students to keep an unrealistic self-efficacy in the face of repeated counter-evidence (Cantor & Kilhstrom, 1987). In such cases of poor performances the correlation between self-efficacy and performance is reduced. Furthermore, students who do not respond to feedback increase their risk of failure.

Unlike students who are familiar with the subject, novices are not expected to have formed stable self-efficacy beliefs related to that subject. Their belief in their potential to achieve *should* be tentative only and easily changed in response to feedback (Cervone & Palmer, 1990). However, evidence exists that initial self-efficacy can be surprisingly resistant to change, even in the face of clear counter-evidence (Lepper, Ross & Lau, 1986). Cervone and Palmer (1990) showed that people require several rounds of feedback before a stable and well-calibrated self-efficacy is established. These findings were in agreement with Tversky and Kahneman’s (1974) description of the ‘anchoring and adjustment’ strategy where, upon receiving feedback, people adjust their self-efficacy to yield a final value that is *biased in the direction* of the original self-efficacy (anchor), rather than adjusted *to* the performance value.

Measures of self-efficacy depend on when they are made. One construct used to explain temporal variations in an individual's self-efficacy is "test anxiety" about assessments such as assignments, quizzes, group presentations and the final examination. By far students get most anxious over higher stake tests, such as end of semester examinations (Zoller & Ben-Chaim, 1989). In a large meta-analysis of 562 studies, Hembree (1988) concluded that test anxiety is inversely related to self-efficacy, a finding more recently confirmed by Ruthig, Perry, Hall and Hladkyj (2004). In addition, in another meta-analysis of 151 studies, Hembree (1990) found that with respect to causality, it is test anxiety that causes poor performance rather than previous poor performance causing test anxiety. Short and long time scale changes are also evident in test anxiety (Hembree, 1988). Spielberger, Gorsuch, Lushene, Vagg and Jacobs (1983) found that students studying to become science teachers experienced a decrease in overall test anxiety from their first to second year at university, but still had increased levels of test anxiety before tests.

2.5.4.2 Self-efficacy and gender

Generally females report lower academic science self-efficacy than males (Pajares, 2002), and the same result applies with physics (Cavallo et al., 2004). The general difference emerges in middle to late primary school (Andre, Whigham, Hendrickson & Chambers, 1999; Pajares, 2002), but there is no consensus in the literature on what causes such gender differences (Dalgety & Coll, 2006). Some studies have found that many gender differences in self-efficacy disappear when previous academic achievement is controlled for (Pajares, 2002). However, Cervone and Palmer (1990) observed that in the absence of prior knowledge, males reported a statistically significantly higher self-efficacy than females. As experience was gained, this difference declined but was not eliminated by the end of the study. An interesting point to note is that Arch (1987) found that females tended to devalue their performance, and in general were more self-critical, which may provide some insight into the *reason* for the lower academic self-efficacy of females.

The gender difference seen in self-efficacy translates to test anxiety: females self-report higher test anxiety levels in mathematics and science than males, observed from year 3 of primary school (Hembree, 1988). In addition, the ‘harder’ the subject, the higher the associated test anxiety (i.e., in order of increasing anxiety: biology < physics ≈ chemistry < mathematics) (Zoller & Ben-Chaim, 1989). In a meta-analysis of 30 studies Becker (Becker, 1989) found that males consistently outperformed females in academic achievement tests in the ‘harder’ sciences (biology, general science and physics), but not in the softer sciences (geology and earth sciences). However, she also found that this effect was on average greater for studies that focussed on gender and science, suggesting experimenter effects or publication bias. It should be emphasised, however, that the gender difference occurs both for test anxiety (Hembree, 1988, 1990) and for self-efficacy (Anderman & Young, 1994; Andre et al., 1999; Cervone & Palmer, 1990) even when there is no difference in academic achievement. When interpreting such data it is useful to be aware of Hembree's (1990) meta-analysis in which he found that high school males with high test anxiety were less likely to take more maths courses than females with high test anxiety, thus skewing the gender differences even further.

Pajares (2002) discusses the gender difference in terms of males and females operating with different 'metrics' when self-reporting both test anxiety and self-efficacy, whereas Wigfield, Eccles and Pintrich (1996) suggest that males and females have different self-reporting standards. If males and females indeed use different metrics, then analyses of self-efficacy and test anxiety need to consider gender in order to provide meaningful interpretation.

2.5.5 Work within tertiary physics

As this study examines physics novices, I take a brief look at studies focusing on introductory physics teaching. As in most other subjects, the traditional lecture style has proven ineffective (Hestenes & Wells, 1992; Hestenes, Wells & Swackhamer, 1992; Wells, Hestenes & Swackhamer, 1995). Alternative teaching methods, such as Overview, Case Study Physics, the Modeling Method and Studio Physics have shown significantly higher gains in student learning (e.g., Sorensen, Churukian, Maleki & Zollman, 2006; Van Heuvelen, 1991; Wells et al., 1995). In particular, interactive methods have provided significant gains in conceptual understanding (Hake, 1998), but these are generally not easily implemented (see for example Cummings, Marx, Thornton & Kuhl, 1999; Sorensen et al., 2006).

Work done in introductory physics (McDermott, 2001) has found that tutorials in which students work in small groups of three or four on problems related to material covered in lectures are very successful at developing student conceptual understanding and abilities to solve qualitative problems in particular, but also quantitative problems. A similar type of tutorial, called Workshop Tutorials, has successfully been used in first year physics at the University of Sydney since 1995. These tutorials are described in the next section and serve as the comparison for the newly developed Map Meetings.

2.5.5.1 Workshop Tutorials

Workshops Tutorials are non-compulsory 50-minute student-centred tutorials with 50-60 students assigned to each tutorial class. In 2007 a 2% mark was given for attending a minimum of 10 out of 12 tutorials. Students are encouraged to work collaboratively in groups of four on problems provided in the tutorial. Such cooperation in which “relative novices work together to solve challenging learning tasks that neither could do on their own prior to the collaborative engagement” is known as *peer collaboration* (Damon & Phelps, 1989, p. 13). The problem sheet contains qualitative, quantitative and demonstration problems, where the latter is associated with simple experiments available in the tutorial room. Students answer problems on a team sheet, which is handed in at the end of the tutorial. This is not marked or returned. Tutors interact Socratically with the students and primarily respond to student questions.

Evaluations of Workshop Tutorials have found that students with high school physics who attended more than half the tutorials performed statistically significantly better in the final examination than those who attended fewer than half the tutorials, even though the backgrounds of the two groups were not statistically significantly different (Sharma, Millar & Seth, 1999). Similarly, for students without high school physics, higher attendance correlated with higher examination mark (Sharma, Mendez & O'Byrne, 2005). However, interestingly, Sharma et al. (2005) found that students who stayed with the same collaborative group throughout the semester performed significantly better than those who did not. Qualitative feedback indicated that students liked the relaxed atmosphere of the Workshop Tutorials, but some students suggested that a tutor summarise the tutorial content at the end of the tutorial (Sharma et al., 1999). Still, Workshop Tutorials are well established and the positive effects they have on student learning and the student experience have been researched and documented.

Workshop Tutorials served as the control environment to the intervention in this study. Details of Workshop Tutorials pertinent to this comparison are discussed in more depth in Chapter 4.

3 Context of the study

This chapter explains the relevant details of the Australian education system. A section is also included about me because I, as the researcher, bring my own set of experiences and biases to the project.

3.1 *Australian high school education*

Seven of Australia's 21 million people live in the state of New South Wales (NSW), and 4.3 million of these live in Sydney. Education is the responsibility of each of the six states and two territories, rather than a federal enterprise, and the high school structure discussed here is the one in NSW.

Education is compulsory until year 10 when students sit for their School Certificate; student retention at this stage is nearly 100%. After year 10, students can continue for another two years to obtain the Higher School Certificate (HSC). In 2007, 66,473 students sat the HSC examinations; 50,451 did mathematics and 9,167 did physics (Board of Studies, 2007).

The HSC subjects are all two-year programs: year 11 is referred to as the Preliminary course whereas year 12 is the HSC course. Only assessments in the HSC course count toward students' final HSC mark, although satisfactory completion of the Preliminary course is a requirement.

Each subject has a weighting, referred to as 'units', which reflects the amount of teaching time devoted to it. Each unit corresponds to approximately 60 hours of classroom study per year. Students are required to satisfactorily complete 12 units in year 11 and 10 units in year 12. In addition, students must study at least four subjects; three of the subjects must have a weighting of 2 units or more; and maximum six units may be from courses in science for both years (Board of Studies, 2008b). Students receive 50% of their final mark from internal assessments set and marked within each school and the remaining 50% from the statewide end-of-year examination.

3.1.1 HSC Physics

The HSC Physics course is weighted 2 units. The curriculum has a relatively low emphasis on mathematics. The course Objectives are (Board of Studies, 2009, p. 8):

"Students will develop knowledge and understanding of:

1. the history of physics

2. the nature and practice of physics
3. applications and the uses of physics
4. the implications of physics for society and the environment
5. current issues, research and development in physics
6. kinematics and dynamics
7. energy
8. waves
9. fields
10. matter."

Topics 6-10 are core physics topics in the traditional sense. The remaining topics reflect the emphasis of the HSC on the development, philosophy and impact on society of physics.

The specific topics are divided into four modules, each of equal relative importance with respect to both time and assessments marks.

> **Space:** Covers gravitation, kinematics, circular motion at constant velocity, potential energy and work, and special relativity.
>
> **Motors and generators:** Covers magnetism and its interaction with charges and how this is related to motors and generators, including transformers.
>
> **From ideas to implementation:** Covers electric fields, electromagnetic waves including wave-particle duality, and condensed matter physics covering the electronic energy band structure in different materials and how this gives rise to the different behaviour of insulators, metals and semiconductors. A discussion of superconductivity and BSC theory is also included.
>
> **Option:** The option allows students to choose a topic from one of the following: Geophysics, Medical Physics, Astrophysics, From Quanta to Quarks and The Age of Silicon.

Mechanical waves, the electromagnetic spectrum, geometrical optics, electricity, Newton's laws, energy and momentum, basic atomic structure and some astrophysics (the evolution of the universe, energy and mass equivalence, and stellar evolution) are covered in science and physics prior to year 12, whereas fluids and thermodynamics are covered in the first year university physics syllabus, but not in the HSC.

For the internal assessment, which contributes 50% towards the final mark, the breakdown of marks is (Board of Studies, 2009):

- Knowledge and understanding: 20%
- First-hand investigations: 15%
- Scientific thinking, problem-solving and communication: 15%

In sum, the focus of the HSC Physics course is more holistic and less mathematical than the physics courses offered at the University of Sydney.

3.1.2 HSC Mathematics

In the HSC, students are not required to study mathematics, but most do. Four different mathematics courses are offered, which range from 2 to 4 units. Of the four courses, there is considerable content overlap between three of them (see Table 3.1); the 4-unit course subsumes the 3-unit course, which subsumes the 2-unit course. Only the General Mathematics course is completely separate.

HSC Course	*Course component(s)*	*Relative weight of examination*	*Course weight*
General Mathematics	General Mathematics	2 units	2 units
2-unit Mathematics	Mathematics	2 units	2 units
3-unit Mathematics	Mathematics	2 units	3 units
	Mathematics Extension 1	1 unit	
4-unit Mathematics	Mathematics Extension 1	2 units	4 units
	Mathematics Extension 2	2 units	

Table 3.1: The four mathematics courses offered in the HSC.

3.1.2.1 General Mathematics

The General Mathematics course emphasizes application based mathematics. It is considered suitable for students who wish to pursue vocational jobs or studies, or university studies within business, the humanities, nursing and paramedical sciences (Board of Studies, 2000).

The topics covered are (the five topics are from the official syllabus; the subtopics in brackets are broad categories I see based on the syllabus):

1. Financial mathematics (investments, taxation, loans and depreciation)
2. Data analysis (basic statistics)
3. Measurement (geometry and trigonometry)
4. Probability (basic ideas and applications)
5. Algebraic modeling (skills and techniques, linear and non-linear relationships)

3.1.2.2 2-unit Mathematics

The 2-unit Mathematics course is "sufficient basis for further studies in mathematics as a *minor* discipline at tertiary level in support of courses such as the life sciences or commerce" (Board of Studies, 2008a, p. 7). It covers a broad range of abstract mathematics areas (of the 14 topics listed in the syllabus, I quote general areas of mathematics as I see them):

1. Plane geometry
2. Functions – both algebraically and geometrically (linear, quadratic, exponential and logarithmic)
3. Probability (fundamentals only)
4. Series (arithmetic and geometric)
5. Calculus – both algebraically and graphically (differentiation and integration)

3.1.2.3 3-unit Mathematics

The 3-unit course provides a sufficient mathematical foundation for students who intend to continue on to tertiary studies in which mathematics is a major discipline, such as the physical and engineering sciences (Board of Studies, 2008a).

The 3-unit syllabus subsumes the 2-unit syllabus, but goes deeper into each topic. This is done by both extending the content knowledge covered *and* expecting students to manage harder problems within each topic. In addition, 3-unit Mathematics covers an additional four topics (to the original 14) that fall within two of the areas described above: functions includes inverses and higher order polynomials, and probability is extended quite considerably by including combinatorics.

3.1.2.4 4-unit Mathematics

The 4-unit Mathematics course provides the necessary background for students who wish to undertake the study of mathematics at tertiary level, and is useful for those who pursue subjects such as science, economics and industrial arts (Board of Studies, 1997). The treatment of mathematics also focuses on the broader and deeper aspects of the subject, as is reflected in the following quote from the syllabus: "The general aim is to present mathematics as a living art which is intellectually exciting, aesthetically satisfying, and relevant to a great variety of practical situations" (Board of Studies, 1997, p. 10).

Whereas the 3-unit syllabus is mostly an extension of the 2-unit syllabus, the 4-unit Mathematics course covers a much broader field of mathematics knowledge. The whole 3-unit syllabus is contained in the 4-unit syllabus, but guidelines recommend that only about 30% of the time should be devoted to harder 3-unit topics. This makes clear how much more content knowledge the 4-unit syllabus contains, which, in terms of study time, is only one third larger than the 3-unit course.

The following 4-unit topics are outlined in the syllabus (Board of Studies, 1997):

1. Graphs
2. Complex numbers
3. Conics
4. Integration
5. Volumes
6. Mehcanics
7. Polynomials
8. Harder 3-unit topics

3.1.2.5 Dealing with HSC Mathematics in this project

It was not obvious how the four different mathematics courses would be dealt with in this project. The number of units undertaken in the HSC determines which final examination(s) students sit and how much these examinations contribute to the final mark (see Table 3.2). The maximum possible course mark reflects the number of units the course represents.

	Examination				
	General mathematics	*Mathematics*	*Mathematics extension 1*	*Mathematics extension 2*	*Maximum course mark*
General	100	-	-	-	100
2-unit	-	100	-	-	100
3-unit	-	100	50	-	150
4-unit	-	-	100	100	200

Table 3.2: Overview of the total examination marks in the HSC Mathematics courses.

A possible way to compare students' mathematics knowledge was to simply add up the examination marks to produce one composite mathematics mark that reflected both the number of units the course represented and the student's performance. However, when this was trialled and correlated with the first semester physics examination results, it yielded a trimodal distribution with a much poorer correlation than either of the mathematics courses individually. Consequently, the relative performance within each mathematics course was more relevant than the level of the course itself with respect to university physics examination performance. Therefore, students were grouped according to HSC Mathematics when mathematics was analysed.

Although I had decided to separate students by mathematics background, it was still not clear how the 3-unit and 4-unit students would be represented by one variable since they sat two examinations. The correlations between the two examination results were very high: for the 3-unit course the correlation between the Mathematics and Mathematics Extension 1 examination marks was $r(221) = 0.82$, $p = 0.000$; for the 4-unit course the correlation between the Mathematics Extension 1 and Mathematics Extension 2 examination marks was $r(154) = 0.84$, $p = 0.000$. In the social sciences, variables that correlate this strongly are considered to measure the same construct, which, in the case of two different mathematics examinations, is exactly what is happening. Correlating the individual mathematics examination results with the first semester university physics marks showed no clear differences between the two HSC mathematics examinations for either the 3-unit or 4-unit courses. This suggests that both parts of these two mathematics courses are equally important for university physics. The combined mark showed a somewhat stronger correlation with the physics examinations in all but one case, thereby strongly suggesting that the sum of the two HSC Mathematics marks is a more representative variable than any one of them individually. The

HSC Mathematics variable used will be the sum of the two HSC Mathematics marks the 3-unit and 4-unit students have. For the students with General Mathematics or 2-unit Mathematics, there is only one mark per student.

3.1.2.6 Summary

In summary, the 4-unit Mathematics students have the most exposure to mathematics. The content covered is not only much more extensive than in any of the other courses, it also covers mechanics, which takes up most of the first semester physics course, giving these students an advantage. The 3-unit course gives students a sufficient background to deal with the mathematics covered in physics at university. However, the Board of Studies does not recommend the 2-unit course to students who intend to study physics at university, and the General Mathematics course does not prepare students for university physics.

3.2 Physics at the University of Sydney

The University of Sydney is the oldest university in Australia (founded in 1850) and has a strong research focus. As per March 2008, the university had a student population of 46,000.

3.2.1 The students in first year physics

At the University of Sydney students have much freedom with respect to course choices, and students' degree choice generally does not dictate their subjects or even majors. It is common to undertake double degrees in which students complete two degrees in five years, rather than one degree in three years. A common degree enrollment for students studying first year physics is the Bachelor of Science (B.Sc.). In their first year, these students undertake four subjects per semester, only one of which can be physics. Of the remaining three subjects, students must study one mathematics subject and one other science subject, while the fourth subject may be from *any* area (including other faculties, such as Arts or Economics and Business) (The University of Sydney, 2010). Similarly, students in other faculties can study physics in their first year, even though their intended major is in a completely different field. The two degrees most commonly represented amongst the students who do not intend to pursue physics are Bachelor of Engineering (B.E.) and Bachelor of Medical Science (B.Med.Sc.). Most of these students do not study physics past first year and therefore become ambassadors of physics.

3.2.2 First year physics courses

The School of Physics offers three different courses in each semester, where course choice depends on prior formal physics instruction (generally whether the students undertook HSC Physics or not) and interest. In each semester the three courses cover largely the same material, so students can only enroll in one course per semester.

The *Advanced* courses in both first and second semester were not considered in this project. These courses are offered to the academically strongest students and require a good result in HSC Physics and a strong overall performance in the HSC. These courses cover the most content and assume strong mathematics backgrounds.

3.2.2.1 The Fundamentals course

The *Fundamentals (FND)* course runs in first semester and is designed for students with no prior formal physics instruction. The course aims to rapidly acquaint students with physics terminology so that they are able to undertake the same courses in second semester as those students with a physics background. The course consists of three modules, and it does not use calculus. **Language of physics** is a four-week module designed to introduce the language, methods and problems dealt with in physics. It does this through covering fluid statics and satellite motion. **Mechanics** is taught for six weeks and covers kinematics, Newton's laws, friction, some rotational motion, energy and work, and momentum and collisions. The **Waves** module covers, in the last three weeks, oscillations and waves, including travelling and standing waves, the Doppler effect and beats.

3.2.2.2 The Regular course

The *Regular (REG)* course is also a first semester course but is designed for students with senior high school physics. The material covered is similar to that in the Fundamentals course, but it does not contain the Language of Physics module, and it is a calculus based course. The Regular course begins with a seven-week Mechanics module covering the same topics as the Fundamentals course, although more in-depth. The following three weeks is on **Thermal physics**, covering the zeroth, first and second laws of thermodynamics. Lastly, the final three weeks is on **Waves** and covers essentially the same material as the Fundamentals course.

3.2.2.3 The Environmental course

In second semester the *Environmental and Life Sciences (ENV)* course (generally referred to as *Environmental* only) is designed for students who do not intend to continue with physics in second year. It has a strong biological focus and does not use calculus. Three modules are covered: the first four weeks focus on **Properties of matter**, covering fluid statics and dynamics, including surface tension, non-Newtonian fluids and elastic behaviour of solids; **Electricity and Magnetism** lasts for five weeks and covers electric fields and potential, capacitance, circuits, magnetism and induction; **Radiation physics** in the last four weeks focuses on electromagnetic radiation, basic quantum physics (including wave-particle duality, the uncertainty principle and the Bohr model of the hydrogen atom), nuclear physics and biological effects of radiation.

3.2.2.4 The Technological course

The *Technological (TEC)* course runs in parallel with the Environmental course in second semester – it has a stronger engineering focus and is more mathematical, using calculus. The course is appropriate for students continuing with physics in second year. The **Fluids** module runs for two weeks and covers fluid statics and dynamics. The following module, **Electricity and Magnetism**, runs for seven weeks and covers essentially the same material as the Environmental course, but each topic is covered more in-depth. The **Quantum physics** module fills the remaining four weeks and covers the basic quantum physics of the Environmental course, but with wavefunctions, the particle in a box description and quantum numbers replacing the nuclear and biological physics.

3.2.3 Course structure

At the University of Sydney, each semester lasts for 17 weeks: 13 teaching weeks, one week mid-semester break, and one non-teaching week before the final two examination weeks. Each teaching week has three one-hour lectures, one one-hour tutorial and one three-hour laboratory session. In addition, a duty-tutor is available for consultation two hours per day. Each module is taught by a different lecturer, whose power point slides are normally available on the web prior to the lecture. Lecture attendance may be up to 200 students, and the lecture format is relatively traditional; however, interactive teaching methods are embedded in lecturers, including buzz sessions (where students talk amongst themselves for a short period of time about a physics problem), interactive lecture demonstrations (Johnston, Hopkins, Varvell, Sharma & Thornton, 2007), personal response systems (Sharma, Khachan, Chan & O'Byrne, 2005) and questions from students are encouraged during lectures. Course assessment is by assignments (10%), tutorial attendance (2%), laboratory work (20%), an in-lab test (8%) and a final three-hour examination (60%).

The final examination has 12 questions in total; the first six questions (five marks each) are conceptual while the remaining six (10 marks each) are traditional questions requiring both calculations and interpretation of answers. There are no multiple choice questions. Calculators and a provided formula sheet may be used, but no other material is allowed in the examination room. The examinations are marked by members of the School of Physics. Each person marks at most two questions in one course, and to ensure marking consistency each question is marked by one person only.

3.3 I – the researcher

I was born and raised in Norway by Norwegian parents, neither of whom is tertiary educated. I attended the geographically assigned public primary and secondary schools in my home town, which has 40,000 inhabitants. Being a social democracy, private schools are extremely rare in Norway. I followed the Norwegian curriculum until year 10, after which I studied the International Baccalaureate (IB).

I have undertaken my tertiary education at the University of Sydney, Australia. From 2003-2006 (four years, as the academic year follows the calendar year in Australia) I studied a Bachelor of Science (Advanced) (Honours). Honours is a one-year program exclusively devoted to one subject (in my case physics), with 50% course work and 50% research (similar to a Masters of Science thesis). In parallel with my PhD (2007-2010) I have completed a Master of Education.

In primary and secondary school I would often tutor my peers in science and mathematics. At university I have been tutoring in Workshop Tutorials, privately and in the residential colleges since 2006.

I have always reflected on my own learning to optimize the efficiency with which I can learn. I believe that this constant evaluation of learning strategies has been an invaluable part of my educational experience. My teaching experience has given me an insight into how other students think and learn and which teaching methods work better than others. However, it has been the combination of my experiences with and reflections upon both teaching *and* learning that has formed the foundations of this project.

4 The Intervention: Link Maps and Map Meetings

The heart of this project is Link Maps: visual maps presenting the essential features of the physics knowledge students are expected to learn. In this chapter I discuss the development and structure of the Link Maps and how this process has thrown more light on the knowledge structure in physics itself. I also discuss Map Meetings – the environment in which Link Maps were implemented.

4.1 Link Maps

Link Maps appear similar to concept maps owing to their colourful non-linear representation of subsets of domain knowledge. However, this is a superficial comparison and does not reflect the ideas underlying their invention nor their theoretical foundation. Concept maps and knowledge maps generally focus on a myriad concepts and associations and have specific sets of rules for creation (cf. Section 2.5.2.6). Link Maps, on the other hand, were specifically developed for physics in which there are relatively few central concepts – the challenge in learning this unique discipline is not the number of concepts to be learnt but the number of associations (links) to be formed. All Link Maps produced for this project can be found in Appendix D.

4.1.1 Design of Link Maps

Link Maps were originally developed in my Honours project for the Fundamentals course, which focuses exclusively on Mechanics and Waves. In my PhD project, the original maps were improved and Link Maps were developed for a further three courses.

For both the Fundamentals and Regular courses, Mechanics is the largest module (see Table 4.1). All Link Maps within this module were based on the most common concepts in course material: displacement, velocity, acceleration, force, energy, mass and momentum. These concepts were identified from the Mechanics module outline, which clearly specified the terms and concepts students were expected to learn. Initially, about 70 concepts were identified. Inspection of these concepts in conjunction with my own physics knowledge isolated the seven fundamental concepts stated above.

	Fundamentals		Regular	
Week	*Module*	*Topic*	*Module*	*Topic*
2	Mechanics	Buoyancy	Mechanics	Kinematics
3		Pressure		Newton's laws
4		Kinematics		Energy
5		Kinematics		Momentum & Collisions
6		Newton's laws		Rotational motion
7		Friction		Rotational motion
8		Rotational motion	Thermal physics	0^{th} law of thermodynamics
9		Energy		1^{st} law of thermodynamics
10		Momentum & Collisions		2^{nd} law of thermodynamics
11	Waves	Oscillations	Waves	Oscillations
12		Waves I		Waves I
13		Waves II		Waves II

Table 4.1: Topics covered in tutorials, which start in week 2, in the first semester Fundamentals and Regular courses. Note that in week 2 the Fundamentals students were also given a Symbols and Units map, and both courses were given a Vectors and Scalars map in the week covering Newton's laws. In the Fundamentals course, the Kinematics map was used for two weeks, whereas the Rotational motion map was used for two weeks in the Regular course. Note that in the Fundamentals course, the first two modules (Language of physics and Mechanics) are jointly referred to as Mechanics.

The fundamental concepts were strategically placed in three columns on a white A4 sheet, called the *fundament* sheet (see Fig. 4.1). The central column contained the two concepts considered the most central in physics – energy and force. On the left hand side were placed displacement and its first and second time derivative – velocity and acceleration. On the right hand side were placed mass and momentum. The only change in the fundament sheet from the Mechanics module to the Waves module was to exchange the right hand side concepts with time and phase.

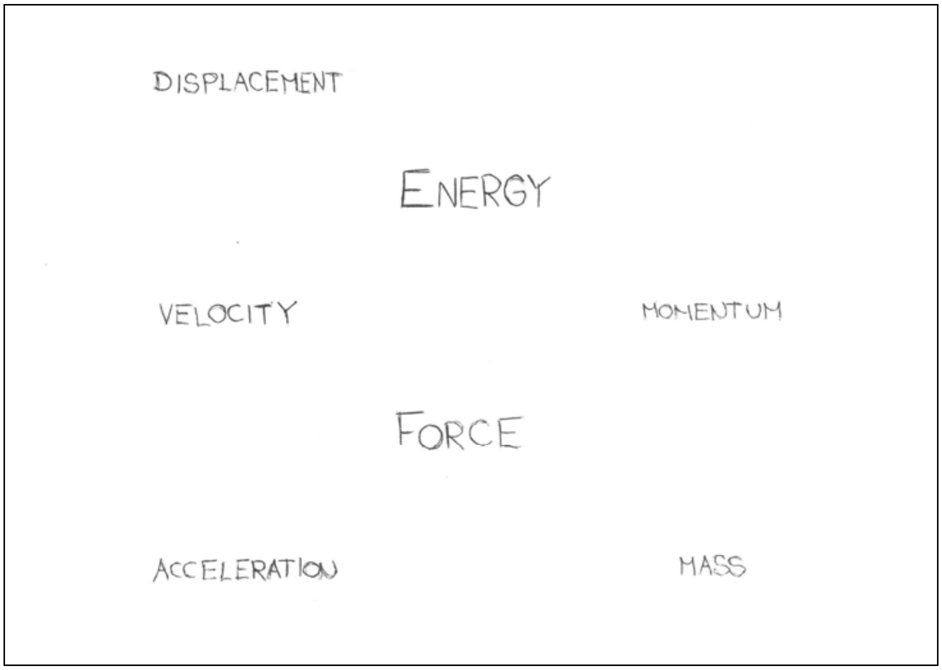


Figure 4.1: The fundament sheet for the Mechanics module.

Generally, only the relevant concepts from the fundament sheet were included on a particular Link Map. In the Momentum and Collisions map (Fig. 4.2) all concepts were retained as they did not clutter the map, whereas in the Energy map (Fig. 4.3) only energy and force were kept, while work and power were added.

Link Maps have several characteristic features. Concepts were written using words rather than symbols because many first year students have not yet automatised the link between concepts and their symbolic representation. Whenever a new concept was introduced, its symbol was written in red and the unit in green superimposed on the concept (see work and power in Fig. 4.3). If considered to aid understanding or consolidation, diagrams, boxes or bubbles were also used (see Figs. 4.2, 4.3 and 4.4). Another consistent feature was the colours used for the headings, links between concepts, equations and definitions.

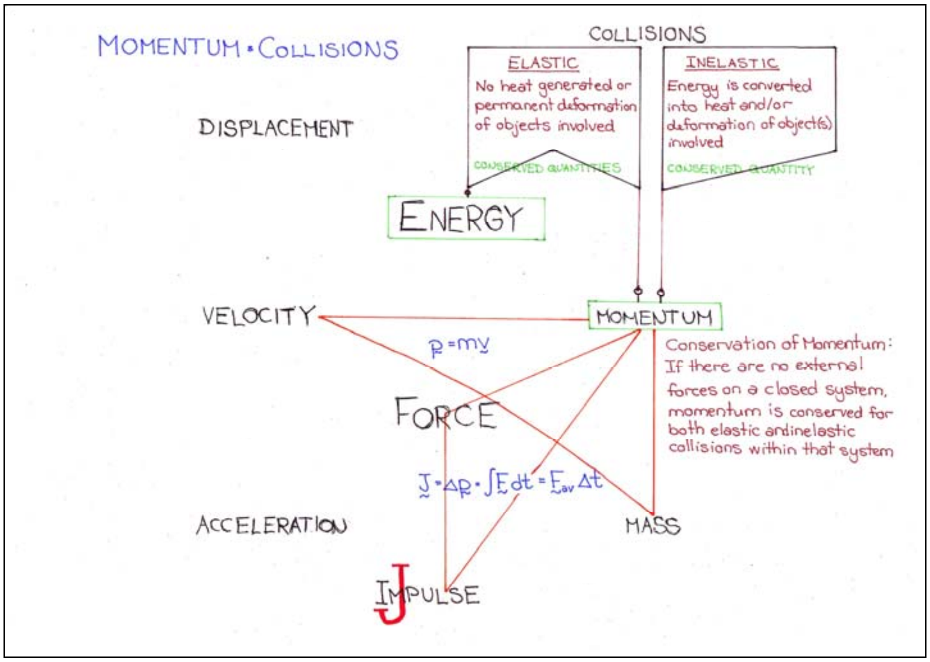


Figure 4.2: The Momentum and Collisions Link Map for the Regular course.

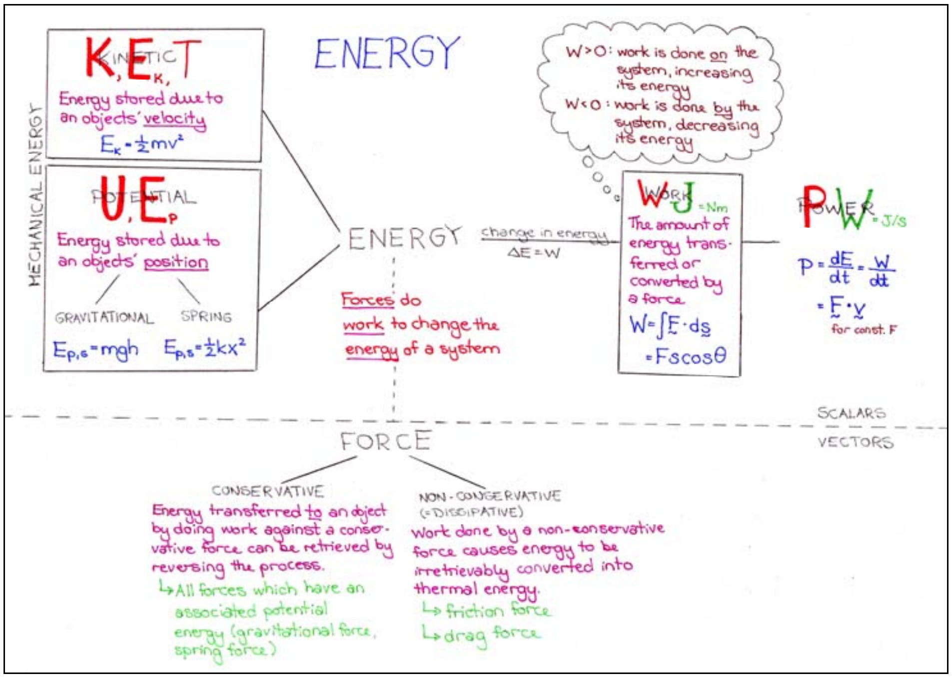


Figure 4.3: The Energy Link Map for the Regular course.

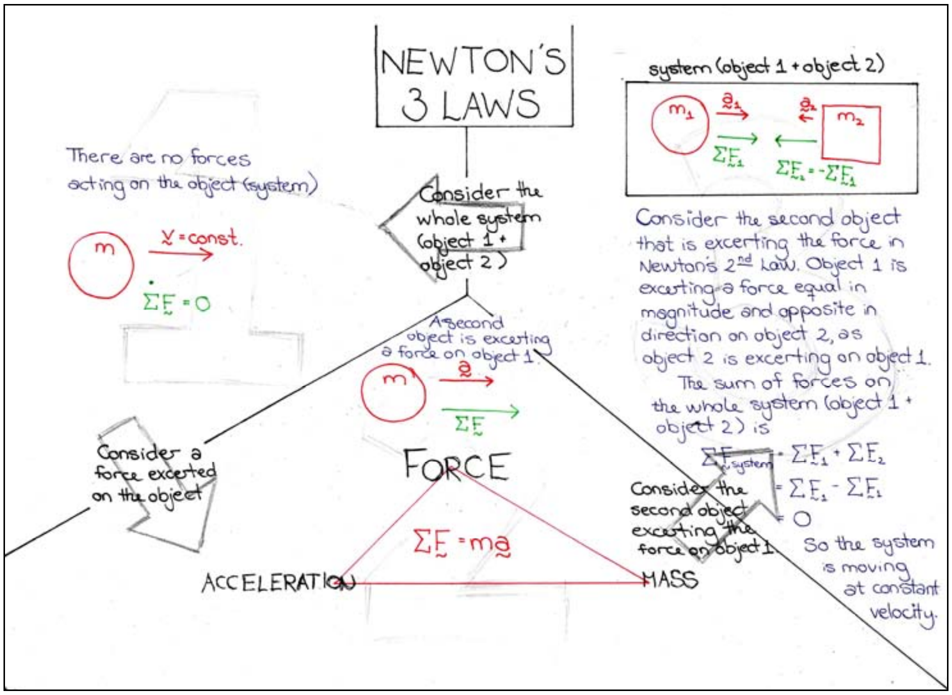


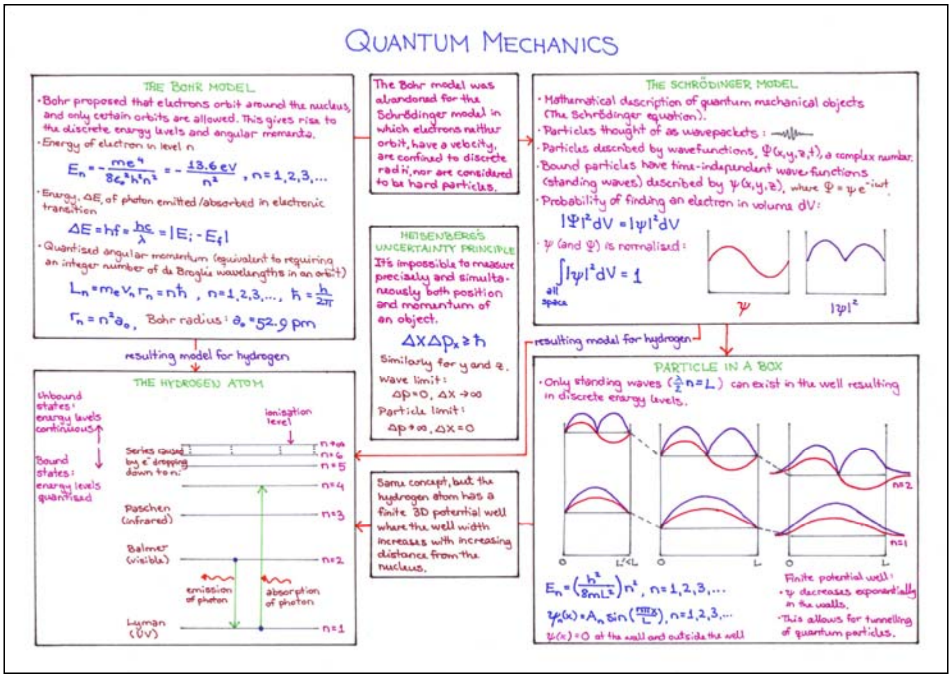
Figure 4.4: The Link Map of Newton's three laws. The map was used for both the Fundamentals and Regular courses.

Although the consistent features provided a framework for structuring the maps, the final layout of each map was a product of these general rules together with what was perceived to be the best representation of the given topic. Figure 4.4 shows the map covering Newton's three Laws. The map is divided into three sections, one for each law; this was considered the most logical presentation – the physics knowledge itself guided the construction of the map. The map clarifies the essence of each law, including the bare minimum of information that correctly describes it for this level, and the large arrows with text make clear the intimate relationship between them. Simple diagrams illustrate each law, so students are provided with both visual and verbal information to increase the likelihood of learning the topic.

In addition to Mechanics and Waves, the other modules covered were Thermal physics, Fluids, Properties of matter, Electricity and Magnetism, Quantum physics and Radiation physics (see Tables 4.1 and 4.2), each of which has a different set of core concepts, although some overlap. In Thermodynamics and Fluids the fundament sheets were not similar to Mechanics. In Electricity and Magnetism, however, the structure was quite similar to the Mechanics fundament sheet: energy and force were retained in the center, whereas the left hand side concepts were replaced with charge, electric field and magnetic field, and the right hand side concepts with electric potential, current, resistance, capacitance and self-inductance. Radiation physics and Quantum physics did not have fundament sheets at all. These modules were very different to Mechanics and Electricity and Magnetism: the focus was on the connection between extended concepts (such as the Bohr model or Heisenberg's uncertainty principle) that themselves required explanation. Thus, the Radiation physics and Quantum physics Link Maps (e.g., Fig. 4.5) are different to the other Link Maps because, again, the material itself guided their design.

	Environmental		**Technological**	
Week	*Module*	*Topic*	*Module*	*Topic*
2	Properties of matter	Fluid statics	Fluids	Fluid statics
3		Fluid dynamics		Fluid dynamics
4		Stress vs. strain	Electricity & Magnetism	Charges & E-fields
5		Curious fluids		Electric potential
6	Electricity & Magnetism	Charges & E-fields		Capacitance & Dielectrics
7		Electric potential & Capacitance		Circuits
8		Circuits & Magnetism [2 maps]		Magnetism
9		Induction		Induction
10	Radiation physics	Electromagnetic radiation		Electromagnetism [no map]
11		Quantum physics	Quantum physics	Wave-particle duality
12		Nuclear physics		Quantum mechanics
13		Biological effects of radiation		Quantum numbers

Table 4.2: Topics covered in tutorials in the second semester Environmental and Technological courses. Both the Environmental and Technological students were given a Symbols and Units map in their first week on Electricity and Magnetism (with the Charges and E-fields map). In week 8 there were two separate maps (one on Circuits and one on Magnetism) in the Environmental course; in the Technological course there was no map in week 10 because the topic (Electromagnetism) represented a summary of all the previous topics covered in the Electricity and Magnetism module.



- Bohr proposed that electrons orbit around the nucleus, and only certain orbits are allowed. This gives rise to the discrete energy levels and angular momenta.
- Energy of electron in level n

$$E_n = -\frac{me^4}{8\epsilon_0^2 h^2 n^2} = -\frac{13.6\,\text{eV}}{n^2}, \quad n = 1,2,3,\ldots$$

- Energy, ΔE, of photon emitted/absorbed in electronic transition

$$\Delta E = hf = \frac{hc}{\lambda} = |E_i - E_f|$$

- Quantised angular momentum (equivalent to requiring an integer number of de Broglie wavelengths in an orbit)

$$L_n = m_e v_n r_n = n\hbar, \quad n = 1,2,3,\ldots, \quad \hbar = \frac{h}{2\pi}$$

$$r_n = n^2 a_0, \quad \text{Bohr radius: } a_0 = 52.9\ \text{pm}$$

Unbound states: energy levels continuous

Bound states: energy levels quantised

Series caused by e^- dropping down to n:

The Bohr model was abandoned for the Schrödinger model in which electrons neither orbit, have a velocity, are confined to discrete radii, nor are considered to be hard particles.

It's impossible to measure precisely and simultaneously both position and momentum of an object.

$$\Delta x \Delta p_x \geq \hbar$$

Similarly for y and z.

Wave limit:
$\Delta p = 0,\ \Delta x \to \infty$
Particle limit:
$\Delta p \to \infty,\ \Delta x = 0$

Same concept, but the hydrogen atom has a finite 3D potential well where the well width increases with increasing distance from the nucleus.

- Mathematical description of quantum mechanical objects (The Schrödinger equation).
- Particles thought of as wavepackets :
- Particles described by wavefunctions, $\Psi(x,y,z,t)$, a complex number.
- Bound particles have time-independent wave functions (standing waves) described by $\psi(x,y,z)$, where $\Psi = \psi e^{-i\omega t}$
- Probability of finding an electron in volume dV:

$$|\Psi|^2 dV = |\psi|^2 dV$$

- ψ (and Ψ) is normalised:

$$\int_{\text{all space}} |\psi|^2 dV = 1$$

- Only standing waves ($\frac{\lambda}{2} n = L$) can exist in the well resulting in discrete energy levels.

$$E_n = \left(\frac{h^2}{8mL^2}\right) n^2, \quad n = 1,2,3,\ldots$$

$$\psi_n(x) = A_n \sin\left(\frac{n\pi x}{L}\right), \quad n = 1,2,3,\ldots$$

$\psi(x) = 0$ at the wall and outside the well

Finite potential well:
- ψ decreases exponentially in the walls.
- This allows for tunnelling of quantum particles.

Figure 4.5: The Quantum Mechanics Link Map for the Technological course.

Twelve to fourteen Link Maps were developed for each physics course, resulting in 50 Link Maps in total. However, these were not all completely different as there were many overlapping topics between the parallel courses in each semester (see Tables 4.1 and 4.2). Because the Regular and Technological courses treated the topics in more depth, equations were presented in the calculus form rather than the algebraic form and the Link Maps generally contained more information.

4.1.2 Link Maps and knowledge

Classification, characterisation and description of physics knowledge are largely unchartered territory. Most work on knowledge structures has been carried out on horizontal knowledge structures (Maton & Moore, 2010), primarily because those concerned with studying knowledge structures are situated in horizontal fields and therefore generally do not have sufficient knowledge of a hierarchical field to characterize it in depth.

The design of Link Maps was informed and guided by the structure of physics knowledge. However, the Link Maps themselves further illuminate the physics knowledge structure. This work has therefore, quite unintentionally, emerged as one of the most extensive studies of the knowledge structure of physics.

The following discusses some important findings and ideas. Newtonian mechanics (referred to as mechanics) is in focus for two reasons: it was the module on which the idea of Link Maps was developed, and mechanics is a representative sub-field of physics (for reasons that will be explained later).

4.1.2.1 The seven fundamental Mechanics concepts

Earlier in this chapter I only briefly outlined how the seven concepts on the Mechanics fundament sheet were selected. Had another physicist been asked to perform the same task, he may have chosen slightly differently, but I have yet to encounter a physicist who strongly disagrees with my seven concepts. In physics we take this for granted – that my physics knowledge is similar to your physics knowledge. However, this is not the case in all academic fields; in fact, it appears to be a characteristic of hierarchically structured fields.

Very little has been written about the hierarchical knowledge structure, so the following description of *how* I selected the seven fundamental concepts is necessary. To physicists it may seem obvious and superfluous, but it will hopefully clarify *how* we think by making implicit knowledge explicit; to practitioners of horizontal knowledge fields, the following gives a detailed insight into physics thinking.

I begin with force. Among the 70-odd concepts from the Mechanics module outline were weight force, tensile force, contact force, normal force and buoyant force, to mention a few. The modifying adjectives preceding the noun 'force' only inform of the context in which the force appears; they do not describe types of forces that follow different rules. The following medical analogy clarifies this. Take ibuprofen, a common pain killer: Wikipedia (2010) lists 76 different brand names for this drug, including Advil, Nurofen and Ibux. Regardless of name, the drug is the same. 'Ibuprofen' can be thought of as the fundamental concept because it is the non-contextual name of the drug (i.e., it does not reflect manufacturer or country). Similarly, 'force' is the fundamental non-contextual concept, whereas modifying adjectives are context referents.

Displacement and mass are generally not associated with modifying adjectives. These concepts were chosen because they are fundamental in their own right – they cannot be explained in terms of any other *more* fundamental concepts. Displacement is the fundamental measure of space. Being a vector quantity (i.e., it has both magnitude and direction), it is also more general than distance, which is a scalar (it only has magnitude). Mass was chosen for similar reasons – it is the fundamental measure of 'stuff'.

Having decided on displacement and mass as fundamental, density, for example, was not a fundamental concept because it is defined by mass and volume. Volume, measuring three-dimensional space, can be expressed in terms of three orthogonal space measures and is therefore not 'fundamental'. Some may argue that density, rather than mass, should be chosen as the fundamental concept. This I would not necessarily oppose – in fact, when dealing with fluids, density is a more convenient measure than mass – but in Mechanics mass was chosen for two reasons. First, Newton's three laws lie at the heart of Mechanics, and these refer to masses not densities. Second, students are more familiar with mass than density, so mass provides a solid anchor in students' long-term memory to which new knowledge can be associated. Recall from Section 2.2.3.2 that the encoding of new information is more successful if it is meaningfully associated with knowledge already stored in long-term memory.

Although this section focuses on the structure of physics knowledge itself, this cannot be completely separated from the knowers. My understanding of the hierarchical knowledge structure of physics is only as good as the knowledge stored in my long-term memory, because this is the knowledge I can actively process. I will refer to *domain knowledge structures* as the collective knowledge structure of a domain – what can potentially be learnt by talking with people and reading books and articles. *Knower knowledge structures*, on the other hand, refer to the knowledge structure of individual knowers as stored in their long-term memory.

The distinction between domain and knower knowledge structures is necessary to explain why velocity, acceleration and momentum are on the Mechanics fundament sheet. Velocity and acceleration are both defined by displacement and time only. Time is another fundamental concept (like displacement and mass), but one that students know so well that explicit instruction is not needed. After careful consideration I decided that including time on the fundament sheet would unnecessarily clutter the map, and so it was omitted. When students begin first year university physics – in particular those students without prior physics knowledge – their knowledge of velocity and acceleration is related to, but not completely the same as, a physicist's knowledge of these concepts. Learning Mechanics means to adapt a physicist's knowledge (which should mirror the domain knowledge structure) of these concepts so that when a teacher and a student (or two students) communicate, they take the words to mean the same. If they do not speak the same language, accurate communication is not possible. Because comprehension of velocity and acceleration are so fundamental to the enculturation into physics, they were included on the fundament sheet. Momentum was chosen for the same reason.

Energy was chosen as a fundamental concept. However, the elusiveness of what energy really is and its intimate relationship with force and mass may suggest that it is less fundamental than displacement, mass and time – or, perhaps it is even more fundamental; that, however, is a different discussion.

In summary, not all concepts on the Mechanics fundament sheet are fundamental to the domain knowledge structure of physics; some are only fundamental to the knower knowledge structures of novices – the students we are teaching.

4.1.2.2 How Link Maps present a hierarchical knowledge structure

All the Mechanics Link Maps are based on the same fundament sheet. This provides a common basis that allows the maps to be connected together. Imagine that the Mechanics maps were semi-transparent and stacked on top of each other. Viewing the collection of maps from the top so that they are superimposed on each other, a three-dimensional *network* of interconnected knowledge would emerge. For example, from the central part of the map, information about force would radiate – the different types of force, its link with energy, its role in defining pressure and its relationship with mass and acceleration, to mention a few. The fundament sheet allows the knowledge on the different maps to be *integrated*, which is the defining trait of a hierarchical knowledge structure. Link Maps are therefore unique in the way they enable an integrated multi-dimensional knowledge structure to be represented on two-dimensional A4 sheets of paper.

However, not all modules have a fundament sheet. If the key to presenting a hierarchical knowledge structure lies in a shared fundament sheet, what does the lack of a fundament sheet say about a module? To answer this question, we first need to understand knowledge structures better.

4.1.2.3 What constitutes the hierarchy?

Neuroscience explains how different sensory aspects of memories are stored in different locations in the brain. For example, a memory of a box has many different sensory components: tactile (weight and texture), visual (both the look of the box and the visual appearance of the word 'box'), olfactory and auditory (both sounds associated with the box and the sound of the word 'box' itself). When we think of an exemplar of a box, all these memories are recalled and seamlessly integrated into a coherent memory.

This suggests that what can be called the 'ground level of the hierarchy' is perceptual information or knowledge that we have received through our five senses due to our interaction with the world. From our sensory knowledge we derive concepts such as box, man and tree. As discussed in Section 2.3.3.1, such generic concepts are not stored as prototypes, but rather as a collection of exemplars that we have encountered. Further, it is our knowledge of boxes, people and trees that has allowed us to develop the general concept of mass, and our experience of sequences of events has allowed us to understand time.

When students start university physics they already have conceptual understanding of mass and time. Recall that a characteristic of experts is their extensive knowledge base, and so students are already tentative experts on these concepts. This allows students to build on them to learn Mechanics – which guides the way we teach the module.

In other physics modules the basic concepts are not as everyday, such as electric fields and wave functions. In these cases students need to be explicitly taught the concepts. However, it is often impossible to teach them by sensory experiences; electric fields, for example, cannot be seen or touched. In such cases, one must teach the new concepts via other concepts students already understand. Electric fields are often taught from many different angles, including as paths taken by test charges, field lines, vectors and as $\boldsymbol{E} = \boldsymbol{F}/q$. This allows students to build a collection of different types of exemplars of electric fields. However, much of what the students learn is not specific to electric fields, but rather develops an understanding of the more fundamental concept of a field. Therefore, it is easier for students to subsequently learn about other types of fields due to the characteristics these all share.

The better integrated and well consolidated such new abstract concepts are in long-term memory, the more able these are to be used as 'solid anchors' on which new relationships and concepts can be built. However, students are rarely given much time to integrate new concepts before they are expected to relate them to new information. Therefore, anchoring of new concepts takes place in parallel with the establishment of links to other concepts. The speed with which new concepts and links can be established is limited by the capacities of our working memory and the memory consolidation process. Moreover, according to cognitive load theory, knowledge that is not strongly anchored and still requires effort to recall will represent a greater load on working memory.

What emerges from this discussion is that consideration of *time* is essential; time represents the limiting factor on the quantity of knowledge that can be covered in the first year physics syllabus.

4.1.2.4 Why is knowledge within certain modules less hierarchical?

Most modules contain only a very small subset of all the domain knowledge that belongs to that particular area of physics. Because physics has a hierarchical knowledge structure, the order in which knowledge is taught is not random; concepts are generally introduced before relationships involving these concepts. As discussed earlier, knowledge of the basic concepts can be seen to represent the first level of the hierarchy (of the module, not necessarily of the entire knower knowledge structure), and so forms an important foundation. Building the foundation, however, takes time. For certain modules, covering the basic concepts and certain relationships between them may be all there is time for in first year. In these cases students learn the definitions of words and relationships *within* topics, not across them.

4.1.2.5 How is the module knowledge structure reflected in the Link Maps?

Bloom's revised taxonomy allows for a structured and informative analysis of the information on the maps. Note that Link Maps only contain Factual and Conceptual (i.e., declarative) knowledge, not Procedural or Metacognitive knowledge, so only the first two categories will be discussed.

The two subcategories of Factual knowledge are 'Knowledge of terminology' and 'Knowledge of specific details and elements' (cf. Section 2.1.2.1). Terminology refers to technical vocabulary – symbols, units and numbers in this case. Symbols and units are presented in a very specific way in Link Maps, as discussed earlier; only occasionally are numbers included – and then only as constants. Consequently, the information on the Link Maps that belongs to 'Knowledge of terminology' is clearly coded and easily separated from the remaining information. Information belonging to 'Knowledge of specific details and elements' is absent from the Link Maps. Such knowledge is of relevance to understand physics in society and is generally covered in lectures (as anecdotes, interesting asides or historically relevant information), but since it is not important to the understanding of physics content itself, it was not included on Link Maps.

The only exception, some may argue, is potentially some information on the Quantum Mechanics Link Map (Fig. 4.5), which describes the Bohr and Schrödinger models of the atom. That “the Bohr model was abandoned for the Schrödinger model” is not necessary to know to understand physics. However, although knowledge of the Bohr model itself is not necessary (the Schrödinger model is more successful), it provides a link between mechanics and quantum mechanics and hence a simpler introduction to a model of the atom – although some research has indicated that quantum mechanics is better taught by omitting the Bohr model altogether (Fischler & Lichtfeldt, 1992). Because knowledge of the Bohr model is useful and most certainly requires understanding, I conclude that not even the Quantum Mechanics map contains ‘Knowledge of specific details and elements’. Hence, the only types of Factual knowledge in Link Maps are symbols and units (and the occasional constant). All other information requires a certain degree of understanding – it is Conceptual knowledge.

Conceptual knowledge has three subcategories: ‘Knowledge of classifications and categories’, ‘Knowledge of principles and generalizations’ and ‘Knowledge of theories, models, and structures’ (cf. Section 2.1.2.2). The first category is generally associated with definitions of words and represents the most concrete of understanding, the second category refers to fundamental ideas, and the last category contains the understanding of entire theories and models – the most abstract form of Conceptual knowledge. Within each Link Map information belongs to one of the first two subcategories. The Energy Link Map (Fig. 4.3), for example, clearly shows categories of energy (kinetic and potential) and force (conservative and non-conservative), whereas the Momentum and Collisions map (Fig. 4.2) clearly states the law of conservation of momentum, which belongs to ‘Knowledge of principles and generalizations’.

Because each Link Map only covers one topic within a module, no map contains knowledge that belongs to the subcategory ‘Knowledge of theories, models, and structures’. However, it can be argued that the *collection* of Link Maps within some modules belongs to this subcategory, as related to the previous discussion of how it is the collection of Link Maps with a shared fundament sheet that allow these to present the hierarchical knowledge structure.

After the earlier discussion of what comprises the hierarchy, we see Bloom’s revised taxonomy in a new light. Focusing on Conceptual knowledge, the first level, ‘Knowledge of classifications and categories’, corresponds to the concepts that form the basis of the hierarchy. Next, ‘Knowledge of principles and generalizations’ refers to relationships between these concepts. And finally, ‘Knowledge of theories, models, and structures’ refers to several relationships that are tied together into a comprehensive hierarchy. One may therefore perhaps say that the categories in Bloom’s revised taxonomy refer to different ‘sizes’ or chunks of a knowledge structure: the first category comprises a very small section of a knowledge structure – i.e., the definition or categorisation of a concept; the next category relates at least two bits from the first category; the third category refers to the schema or mental model that comprises several concepts and relationships to form a model or theory.

Building on Basil Bernstein’s (Bernstein, 1996) work, the sociologist of education Karl Maton has in recent years begun developing Legitimation Code Theory (LCT) to provide a framework with which to analyse knowledge, both in discourse and within disciplines. *Semantics*, one of the five areas within LCT, introduces *semantic gravity* and *semantic density*.

> *Semantic gravity* (SG) refers to the degree to which meaning relates to its context. Semantic gravity may be relatively stronger (+) or weaker (-). Where semantic gravity is stronger (SG+), meaning is more closely related to its context; where weaker, meaning is less dependent on its context.
>
> *Semantic density* (SD) refers to the degree to which meaning is condensed within symbols (a term, concept, phrase, expression, gesture, etc). Semantic density may be relatively stronger (+) or weaker (-). Where semantic density is stronger (SD+), symbols have more meaning condensed within them; where semantic density is weaker (SD-), symbols condense less meaning. (Maton, in press, p. 5)

Theoretically, semantic gravity and semantic density are independent constructs. However, in academic fields they are often inversely related – knowledge that has strong semantic gravity generally has weak semantic density and vice versa. In physics, abstract constructs and equations are abstract *because* they are generalized, and by virtue of being generalized they are necessarily context-independent. Semantic gravity and semantic density can therefore be seen as inversely related measures of the ‘distance’ a concept is away from the ‘ground level of the hierarchy’.

4.1.2.6 The structure of the tertiary physics curriculum

Teaching physics is not just about teaching physics knowledge itself; it is also about teaching how that knowledge is organised. This clarifies *why* Mechanics is often the first module taught in physics. It is the area of physics that builds most strongly on students’ interaction with their everyday world, so the ‘ground level of the hierarchy’ is quite well established. Because students already have a relatively solid understanding of these concepts, the curriculum can focus on the relationships between these concepts (a feature of hierarchical structures), together with teaching the definitions of concepts (a feature of horizontal structures with stronger focus on language). Thus, in only a few weeks, a comprehensive coverage of mechanics is possible, even for students with no prior knowledge of physics. In fact, mechanics is not formally taught again in the Australian context, unlike most other modules in physics. Mechanics is therefore the area within physics where students can reach a hierarchical knower knowledge structure the most rapidly. From then on knowledge of mechanics becomes assumed knowledge that is incorporated into other areas of physics, such as electromagnetism, quantum mechanics and statistical thermodynamics – even though many students know less mechanics than their teachers assume.

In light of the characterisation of the knowledge within the modules, it becomes clear why physics exhibits a ‘spiral’ curriculum where students return to the same topics year after year. Each year the curriculum goes more in-depth – or higher up the hierarchy – because it builds on the material covered the year before.

Quantum mechanics provides an excellent example of the spiral curriculum. Quite far removed from people’s everyday interaction with the world, the length scales at which quantum mechanics (as opposed to Newtonian mechanics) operates is so small that humans do not perceive them directly. This means that the ‘ground level’ of the quantum mechanics hierarchy must be formally taught. In addition, the concepts are more abstract – often they are models. The basic ‘stuff’ dealt with in quantum mechanics is represented by a *wave function*, not mass. Whereas students easily conceptualise mass, they have very little concept of what a wave function is and, even less so, how it is reconciled with mass. A wave function is highly mathematical and immaterial and it takes a long time to construct a knowledge base that is sufficient to use this concept to understand ideas within the hierarchy. Because some of the fundamental concepts in quantum mechanics are models rather than empirical objects, one may say that in terms of Bloom’s revised taxonomy the highest level of Conceptual knowledge (which includes ‘model’) also forms the *basis* of the theory of quantum mechanics. This may suggest that to fully analyse the knowledge structures of some of the most abstract physics knowledge the subcategory ‘Knowledge of theories, models, and structures’ should be extended. Or perhaps one can identify a cyclical nature of hierarchical knowledge structures where models can be redefined as basic concepts for new models and theories.

4.1.2.7 Implications for teaching physics

Learning physics refers to the process of internalising the domain knowledge structure to develop one's own knower knowledge structure. Teaching should aid students in this process and help make it as efficient as possible. Given the lack of awareness of knowledge structures among knowers, it appears logical that the teaching of a domain should be associated with some explicit instruction of the knowledge structure of that domain – a form of Metacognitive knowledge. This can help students by giving them a framework for how to organise their knowledge. If students do not understand the hierarchy, other topics will be harder to understand because they don't know how to think about or learn the material.

Previously I discussed how different types of information on the Link Maps (representing the domain knowledge structure) belong to different subcategories in Bloom's taxonomy. However, it important that students *realize* at which level of the taxonomy information belongs and learns it *at this level*. To explain, I will use Einstein's famous equation $E = mc^2$ as an example.

Many people who have never studied physics will know this equation. However, what does 'know' mean in this case? To a physicist this equation not only reads 'energy is equal to mass times the speed of light squared', the equation tells a profound story of the very nature of mass as inextricably linked to energy, as observed in nuclear reactions. To further comment on the earlier discussion of fundamental physics concepts, $E = mc^2$ tells us that mass may not be as fundamental as we thought – it is simply an alternative expression of energy. This, however, is not how a non-physicist sees $E = mc^2$. To this person, 'e equals m c squared' may represent nothing but a string of symbols, which does *not* represent Conceptual knowledge, but rather Factual knowledge without understanding.

It is interesting that the difference between the knowledge of $E = mc^2$ between the physicist and the non-physicist has nothing to do with the knowledge element itself; rather, it is defined by how this knowledge element is *integrated* into the knower's knowledge structure. When students learn, therefore, it is important to focus on *how* new knowledge is integrated; the way knowledge is stored is just as important as it being stored at all. This emphasises the importance of appropriate encoding of new information – if it is integrated into the existing knowledge structure as conceptual knowledge, it is more solidly stored; but if it is simply stored as a knowledge element that is only integrated with the verbal utterance of the sequence of symbols ('e equals m c squared'), this represents a much weaker integration that is more easily lost.

That non-physicists may have some physics knowledge stored as Factual rather than Conceptual knowledge is not necessarily a cause for concern. When it is a concern, however, is when physics students store Conceptual physics knowledge as Factual knowledge. Why might this happen? Some may believe that it is the fastest way to learn enough physics to pass the exam; however, in most cases it is likely to be because they are not aware of their own techniques for storing knowledge or the difference between hierarchical and horizontal knowledge structures. Unless students are told to reflect on this, it remains implicit Metacognitive knowledge – or a lack thereof. If students are not aware of their own learning methods, how and why will they change them? Whether this can explain why some students leave mathematics and physics as soon as they can, saying that they 'just never got the hang of it' and whether explicitly teaching them about the hierarchical knowledge structure could help, would be a very interesting line of research.

In physics, the domain knowledge structure is undoubtedly hierarchical. However, *knower* knowledge structures are *not* necessarily hierarchical. To many students, the different areas covered in physics represent relatively separate entities that are only loosely connected – a reflection of students' physics knowledge structures being more horizontal than those of their teachers. In empirical disciplines, such as science, knowers are introduced to the field through knowledge associated with the empirical world before they are taught about the more general and abstract ideas, which is the level at which contextual knowledge becomes integrated. Educators need to be aware of the horizontal knowledge structure of novices and understand how this affects students' interaction with the material. The consequences of this situation have not been addressed explicitly in literature and pose an interesting theoretical question with relevant applications.

4.1.2.8 How Link Maps reflect module knowledge structures

The Mechanics and Electromagnetism Link Maps represent the archetypical Link Maps with a clear hierarchical structure – they are very condensed and most of the information requires understanding. Perusal of maps within the other modules reveals that some of these appear less Link Map-like. Although these maps most certainly express links and relationships within the map, the lack of a common fundament sheet prevents the maps from being viewed together to represent a higher level knowledge structure.

As mentioned earlier, individual Link Maps only contain information from three of the five subcategories within Factual and Conceptual knowledge, and most belong to the latter category.

Link Maps with a stronger focus on defining concepts – i.e., stronger emphasis on knowledge belonging to 'Knowledge of classifications and categories' have more words (usually in boxes and bubbles). Link Maps with a linking focus – i.e., more 'Knowledge of principles and generalizations' – have more equations and links. This suggests that written language in physics is important for establishing concepts, whereas mathematics is the preferred language for communicating relationships between concepts. A more detailed study of this would be of interest.

4.2 Map Meetings

Link Maps were implemented on a weekly basis in 50-minute *Map Meeting* tutorials. In the first 10-15 minutes the tutorial supervisor discussed the Link Map in a 'summary lecture', after which students were given a colour copy of the map and a problem sheet. The next 25-30 minutes were devoted to collaborative small group work with the supervisor and a tutor available. In the final 5-10 minutes the supervisor discussed a difficult question or other issues on the board with the whole class. The following sections describe these three parts in more detail.

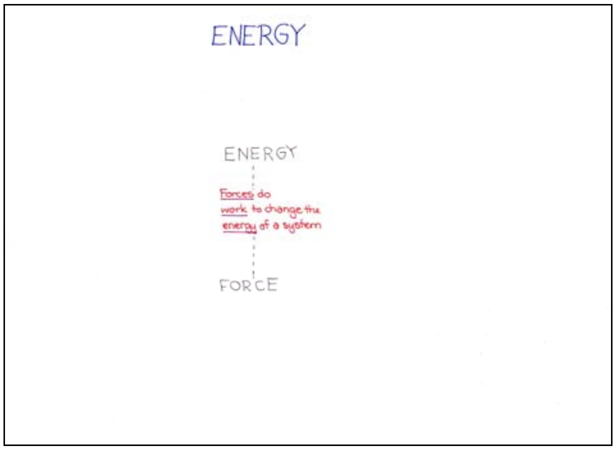
4.2.1 The summary lecture

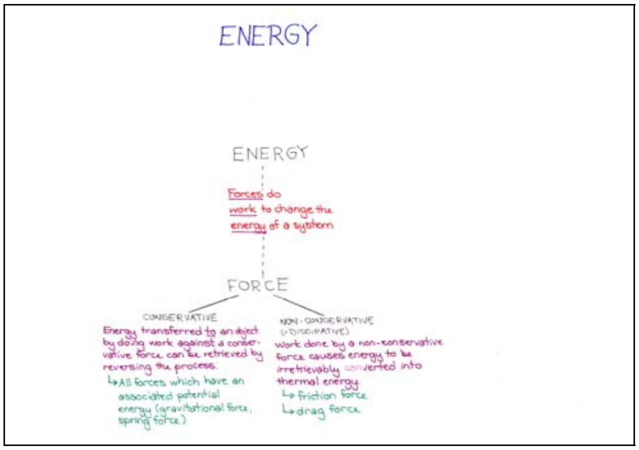
Within one week of initial exposure to a new topic, most students have not committed the knowledge to long-term memory. In Map Meetings, the weekly topic was therefore covered coherently so that comprehension of (or even attendance at) the relevant lectures was not assumed. Revisiting material in tutorials increased the probability of memory consolidation.

Map Meetings revolved around the weekly Link Map, which was expected to be a beneficial learning tool for several reasons. The visual element was important because "[m]ost people (at least in western cultures) and presumably most students in science classes are visual learners" (Felder, 1993, p. 287); the visual consistency in the presentation style was designed to reduce cognitive load once students had learnt how to 'read' the maps. By both visually and mathematically showing the relationships between concepts, extrinsic load was reduced because students would not need to search for these important connections themselves.

Constructing the concepts and links in one's own knower knowledge structure or schema is a lengthy and complex process limited by the capacity of working memory. In a study of pre-service physics teachers, Ingec (2009) found that although the participants had knowledge about impulse and momentum, they had difficulty establishing relationships among the concepts in a self-constructed concept map. Many other studies support this finding: low-achieving students, in particular, are often unable to understand material at a deeper level without explicit instruction (Abrahams & Millar, 2008; Cook, Carter & Wiebe, 2008; Sturm & Bogner, 2008). This is why the Link Maps were produced by me rather than by the students to capture an expert's interconnected view of the knowledge.

For each Link Map three to six separate and self-contained sub-sections were identified and transferred onto transparencies. During the summary lecture, the supervisor constructed the Link Map in front of the students using the method of *layering*. The first transparency was placed on an overhead projector and the contents discussed (see Fig. 4.6). The second transparency was subsequently overlaid on the first one. The newly added information was discussed, and any links to the previous information were highlighted. This process was repeated until the Link Map was complete.





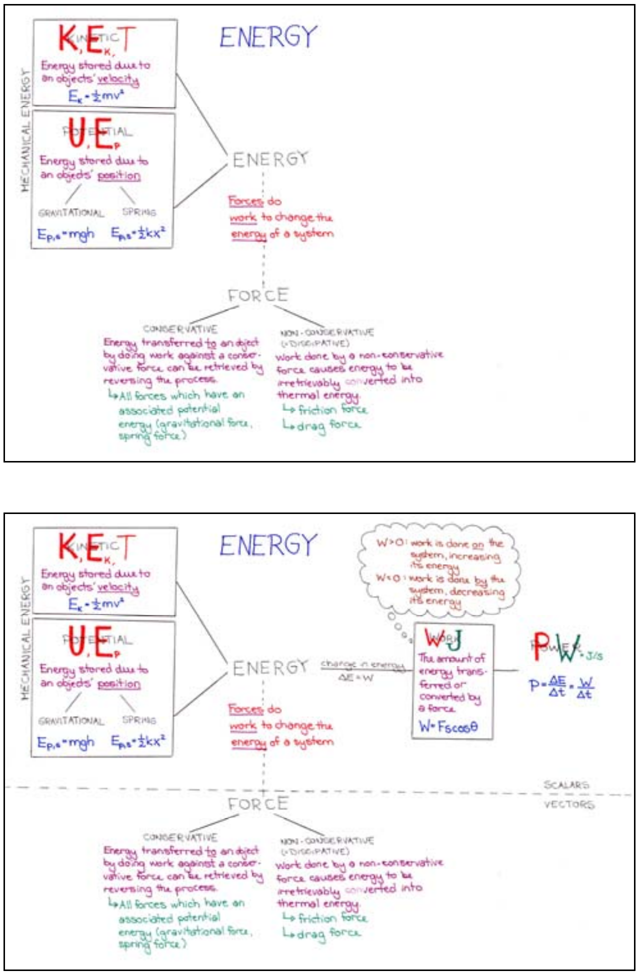


Figure 4.6: Illustration of the layering procedure where parts of the Link Map are introduced sequentially.

Layering explicitly directed students' attention to the information being discussed, in line with Eriksen and St. James' (1986) 'zoom-lens' model. The final map, in some cases, contained a considerable amount of information, so layering also aimed to manage cognitive load. By considering parts of the map separately, the intrinsic load was reduced, whereas the extraneous load was reduced by avoiding any irrelevant information. This maximised the potential germane load, which leads to learning. When later using the map, students were expected to mentally see the layering and thus isolate relevant parts of the map.

Although the summary talk and the Link Map cover essentially the same knowledge, they play quite different roles in cumulative knowledge-building. The summary talk discusses generalized information on the Link Map using examples and explanations. In terms of LCT, whereas information on the map has weak semantic gravity, the talk has elements of relatively strong semantic gravity.

The verbal discourse helps link the abstract information with specific concrete examples, and reflects the strong relationship between the concrete, empirical world and the generalised, abstract representation of this world that is used in physics. The following excerpt from the Momentum and Collisions summary talk script illustrates this:

> Momentum is defined as **p** = m**v**. This construct may seem a bit artificial to you, but you actually use intuitive calculations of momentum every day. To evaluate the severity of a potential collision, you consider the combination of mass and velocity of the object you may collide with. A mosquito crashing into you at 100 km/h is unlikely to do much damage, whereas a car hitting you at only 15 km/h will be quite unpleasant. Similarly, there's a reason why cricket batsmen wear helmets whereas table tennis players do not.

This introduces a largely undeveloped aspect of LCT: *Temporality* (Maton, 2005).

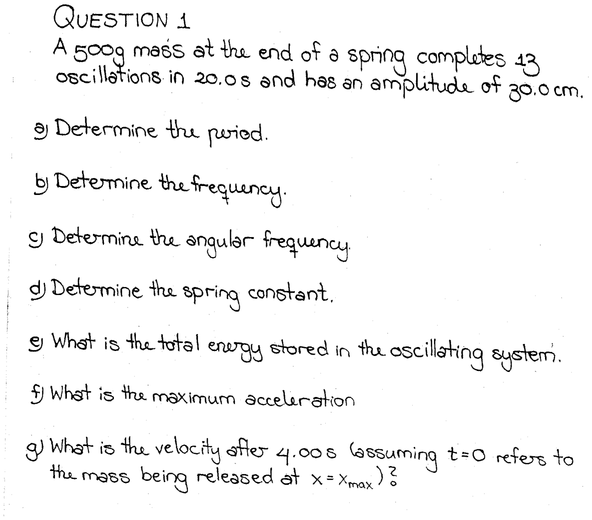
> [I]t is not just the states of 'stronger' and 'weaker' [semantic gravity and density] but also these movements up and down the continua that are the key for enabling cumulative knowledge building. (Maton, 2008, p. 8)

The process occurs primarily *within* each layer when information is discussed.

In addition to presenting the knowledge covered in the course, the Link Maps and the summary talks therefore explicitly model the hierarchical knowledge structure in physics.

4.2.2 Problem solving session

The problem solving session resembled Workshop Tutorials, and Map Meetings were also conducted in the same room as Workshop Tutorials. Students were encouraged to work in collaborative groups of four, and the supervisor and tutor helped students and encouraged those off task to work. Students were not forced into group work to not discourage attendance among those who preferred independent work. Sutherland's (2002) finding that there was no difference in measured learning between mixed ability groups and individual work supported this choice, and individual work was expected to be more beneficial than dysfunctional groups where students felt uncomfortable or spent most of their time off task.



QUESTION 1

A 500g mass at the end of a spring completes 13 oscillations in 20.0 s and has an amplitude of 30.0 cm.

a) Determine the period.

b) Determine the frequency.

c) Determine the angular frequency.

d) Determine the spring constant.

e) What is the total energy stored in the oscillating system.

f) What is the maximum acceleration

g) What is the velocity after 4.00 s (assuming $t=0$ refers to the mass being released at $x=x_{max}$)?

Figure 4.7: Example of a simple many-part tutorial problem. The problem was given to both Fundamentals and Regular students in the tutorial on Oscillations in week 11 of first semester.

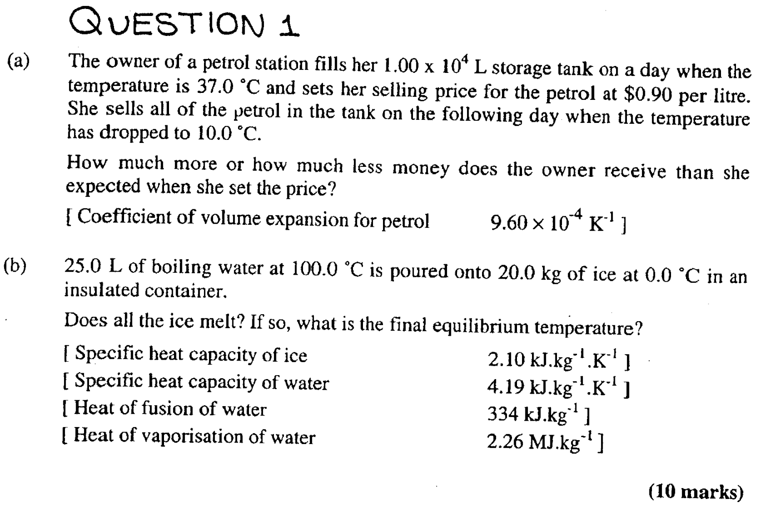
The problem sheet usually had three or four many-part problems, and each problem generally had several questions embedded in it (see Fig. 4.7) (note the distinction between problems and questions). Students were not expected to complete the entire sheet during the tutorial. Most problems (except past examination problems) were designed by me, whereas some were copied or adapted from the Workshop Tutorial sheets. For the four different courses, there were on average 11.6–15.7 individual questions per problem sheet (see Table 4.3). The mean number of questions was higher in second semester than in first semester and higher for the Regular and Technological courses than the Fundamentals and Environmental courses. However, this number is not necessarily proportional to the time required to answer the questions.

	Problem complexity			Mean number per week		
	Simple	*Medium*	*Complex*	*Individual questions*	*Past exam questions*	*Demonstration questions*
FND	41%	43%	16%	11.6	0.9	0.75
REG	29%	49%	23%	12.5	1.3	0.50
ENV	33%	55%	12%	14.6	1.3	0.67
TEC	20%	59%	20%	15.7	1.1	0.83

Table 4.3: Details of Map Meeting problem sheets separated by course.

Both qualitative and quantitative questions were used, reflecting the style of the final examination. The problem set required the use of *all* the important information on the Link Map at least once. Revisiting this information would further aid student understanding and consolidation of the material, especially because problem solving required the students to actively use the material. In addition, problem solving was designed to develop students' Procedural knowledge – in particular their 'Knowledge of subject-specific skills and algorithms'.

The problem sheets had, on average, one past examination problem each week (see Table 4.3 and Fig. 4.8 for an example). Pedagogically this allowed students to become familiar with the style of the examination problems. Many examination problems are quite simple, thereby providing students with mastery experiences; familiarity and mastery were expected to reduce unrealistic fears of the examination.



QUESTION 1

(a) The owner of a petrol station fills her 1.00×10^4 L storage tank on a day when the temperature is 37.0 °C and sets her selling price for the petrol at \$0.90 per litre. She sells all of the petrol in the tank on the following day when the temperature has dropped to 10.0 °C.

How much more or how much less money does the owner receive than she expected when she set the price?

[Coefficient of volume expansion for petrol 9.60×10^{-4} K^{-1}]

(b) 25.0 L of boiling water at 100.0 °C is poured onto 20.0 kg of ice at 0.0 °C in an insulated container.

Does all the ice melt? If so, what is the final equilibrium temperature?

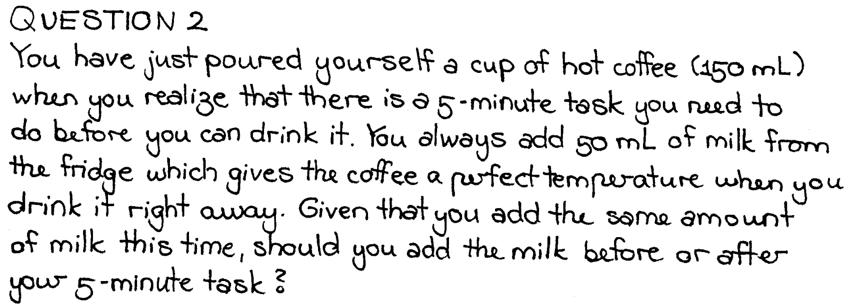
[Specific heat capacity of ice 2.10 $kJ.kg^{-1}.K^{-1}$]
[Specific heat capacity of water 4.19 $kJ.kg^{-1}.K^{-1}$]
[Heat of fusion of water 334 $kJ.kg^{-1}$]
[Heat of vaporisation of water 2.26 $MJ.kg^{-1}$]

(10 marks)

Figure 4.8: Example of a past examination problem included on the tutorial problem sheet. The problem was given to Regular students on the zeroth law of thermodynamics in week 8 of first semester.

In at least half of the tutorials for each course (see Table 4.3) there was a demonstration question associated with an experiment provided in the tutorial room. In most cases the same demonstration was used in the Workshop Tutorials. The main motivation for including demonstrations was to increase the similarity of the problem solving session with Workshop Tutorials, which generally have three to five demonstrations.

The problems contained a mixture of simple and complex questions. Simple questions generally only required one or two pieces of information from the map (such as in Fig. 4.7), thus strongly scaffolding the students. More complex questions required integration of several pieces of information (as in Fig. 4.9), and often relied on material covered in previous weeks. These questions were more challenging, which was also considered to be important examination practice. The alternation of problem complexity was designed to scaffold knowledge and understanding for all students as task difficulty must be neither too hard nor too easy for each individual to promote learning (Reigosa & Jiminez-Aleixandre, 2007). Since most of the information on each Link Map was relatively new to students, each piece of information would likely comprise individual chunks of intrinsic cognitive load. The extraneous load was reduced through clear questions without any unnecessary information, thereby maximising the potential germane load.



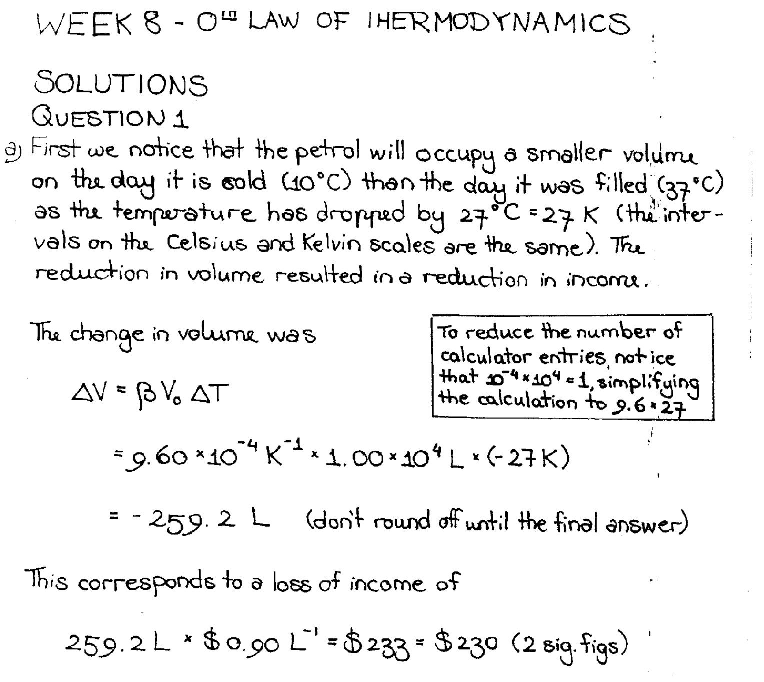
QUESTION 2

You have just poured yourself a cup of hot coffee (150 mL) when you realize that there is a 5-minute task you need to do before you can drink it. You always add 50 mL of milk from the fridge which gives the coffee a perfect temperature when you drink it right away. Given that you add the same amount of milk this time, should you add the milk before or after your 5-minute task?

Figure 4.9: Example of a complex tutorial problem. The problem was given to Regular students on the zeroth law of thermodynamics in week 8 of first semester.

Quantitatively evaluating each problem was a very difficult task, carrying large uncertainties. However, an attempt to categorise each problem as ‘simple’, ‘medium’ or ‘complex’ yielded the overview given in Table 4.3. There were more simple problems in first semester than second semester, and the Fundamentals and Environmental courses had more simple problems and fewer complex problems than the Regular and Technological courses. This is not surprising given the lower levels of prior knowledge of the Fundamentals and Environmental students.

The solution sheet given at the end of the tutorial *explained* the solution to the problems, rather than just providing a satisfactory answer. This meant that sometimes the solutions contained more material than necessary to satisfactorily answer a problem. This was done to help students understand the problem had they not done so while working on it themselves. The solutions also contained useful hints and tips (see Fig. 4.10).



WEEK 8 - 0th LAW OF THERMODYNAMICS

SOLUTIONS

QUESTION 1

a) First we notice that the petrol will occupy a smaller volume on the day it is sold (10°C) than the day it was filled (37°C) as the temperature has dropped by 27°C = 27 K (the intervals on the Celsius and Kelvin scales are the same). The reduction in volume resulted in a reduction in income.

The change in volume was

To reduce the number of calculator entries, notice that $10^{-4} \times 10^{4} = 1$, simplifying the calculation to 9.6×27

$$\Delta V = \beta V_0 \Delta T$$

$$= 9.60 \times 10^{-4}\,K^{-1} \times 1.00 \times 10^{4}\,L \times (-27\,K)$$

$= -259.2$ L (don't round off until the final answer)

This corresponds to a loss of income of

259.2 L × \$0.90 L^{-1} = \$233 = \$230 (2 sig. figs)

Figure 4.10: Solutions to the first part of the problem in Figure 4.8. Note the helpful details provided for the students in brackets and boxes throughout the solution.

Handwriting rather than typewriting the sheets had both practical and motivational reasons; it allowed greater flexibility with the layout, and a neatly handwritten sheet looked more informal than a typewritten sheet, in line with the aim of making Map Meetings a friendly tutorial environment.

4.2.2.1 Collaborative work and theory

Peer collaboration has been shown to be highly effective, with its greatest strength being "fostering the acquisition of basic conceptual insight" (Damon & Phelps, 1989, p. 14), one of the main aims of Map Meetings. Piaget also argued that peer collaboration was an important causal factor in the development of logical thinking (Forman, 1989). The small group collaboration can be seen to rest on Vygotsky's social constructivism, in particular on his theory of the Zone of Proximal Development, which states that learning is optimized when students at roughly the same knowledge level collaborate and learn from each other (John-Steiner & Mahn, 1996).

However, from a cognitive psychology perspective, students, once they encounter a problem for which they lack a certain piece of information or understanding to solve it, can obtain this information relatively easily from peers, thereby saving time searching for the information. This reduces the extraneous load, but the danger is that the peers may simply provide the whole answer, leaving the student not understanding how it was obtained.

Motivation is another benefit of peer collaboration. Students are generally quite social, and positive experiences with peer collaboration may increase students' motivation to attend tutorials. In addition, by seeing peers solving problems the students are provided with vicarious learning experiences, which is one of the four sources of self-efficacy (Bandura, 1997). There may also be some verbal and social persuasion from peers positively influencing students' self-efficacy. Vicarious experience, together with verbal and social persuasion, has been found to be the most important factors affecting self-efficacy for females in science, technology, engineering and mathematics careers (Zeldin, Britner & Pajares, 2008; Zeldin & Pajares, 2000).

4.2.2.2 Tutors and theory

The tutors' role was to be both teachers and motivators. As teachers they provided just-in-time teaching of material relevant to problems or the summary lecture. The tutors were instructed to use the Socratic Method when by providing the least information necessary to help the students reach the answer to their problem. Once they were helped to the answer, because their attention was already on the issue, they were more likely to retain the information. As motivators, the tutors always tried to be positive, friendly and approachable. A positive attitude towards physics sends an important signal to students that those in the field enjoy what they do, whereas being friendly and approachable aimed to make students feel comfortable and not discourage them from asking questions.

4.2.3 The plenary

In the final five to ten minutes the supervisor discussed a problem on the board. Typically, a problem students had found particularly challenging was carefully explained – taking students on the journey of logic of how to reason through the problem from beginning to end. Such explicit teaching of metacognitive strategies have been particularly beneficial for low-achieving students in secondary school (see, e.g., Ben-David & Zohar, 2009). Teaching structured problem-solving strategies has also been found to support the development of conceptual understanding and foster a conceptual approach to problem solving among physics novices (Gaigher, Rogan & Braun, 2007).

It was essential that the students had already attempted the problem as students are more likely to learn if they have worked on the material themselves first. Studies have shown that learning is most effective when explanations given are direct answers to student questions (Webb, 1991), or after students have worked on a difficult task and realised some of its differentiating features without necessarily having successfully completed it (Schwartz & Bransford, 1998).

4.3 Comparison of Map Meetings and Workshop Tutorials

Table 4.4 outlines the differences between Map Meetings and Workshop Tutorials. Whereas Workshop Tutorials devote the entire 50-minute session to problem solving, Map Meetings are more varied and have a summary lecture, problem solving and a plenary session at the end to conclude the tutorial. With this structure, Map Meetings focus on developing Conceptual (and some Factual) knowledge during the summary lecture, Procedural knowledge during the problem solving session and Metacognitive knowledge in the plenary. This is a simplified summary, but it clarifies the individual roles played by the different parts of Map Meetings.

	Workshop Tutorials	**Map Meetings**
Material available	Problem sheet. Solution sheet provided at the end.	Link Map (in colour). Problem sheet. Solution sheet provided at the end.
Structure	Students work in groups of four on problems for 50 min. Tutors available to help.	10-15 min summary lecture. 25-30 min group work in groups of four on problems. 5-10 min plenary.
Level of scaffolding	Low.	Relatively high.
Demonstrations (small experiments)	2-5 different demonstrations available in the room, which students can work with when they choose.	One demonstration *if* considered suitable (most tutorials, but not all), which students can work with when they choose during the problem solving session.
Topic content	The same topic is covered in both tutorials.	
Staff level	Three tutors per class.	Two tutors per class.
Class size	50-60 students are assigned to each tutorial class.	

Table 4.4: Comparing the two different tutorial environments.

5 Methods and analysis

5.1 Methodology

An experiment has three essential components: the sample, the intervention and the instrument with which the effect of the intervention is measured. In addition, both external and internal validity must be verified to ensure a reliable experiment.

5.1.1 The experiment

In *true experiments* participants for the treatment and control groups are selected by true random assignment. All groups are treated equally, except with respect to the independent variable, which is controlled by the researcher. The independent variable generally refers to the treatment or intervention. This method allows for control and removal of threats to the internal validity of the experiment, appropriately determining cause and effect.

Quasi-experiments are similar to true experiments, but differ in that the selection process for participants is not truly random. This type of experiment allows research to be conducted when random assignment of participants is impossible, impractical or unethical. However, the internal validity of the experiment is not ensured because the parameter responsible for the self-selection of participants into different groups may affect the dependent variable. When individuals' behaviour, not the researcher's methods, determines who will constitute the sample, a third confounding variable is introduced that depends on certain intrinsic characteristics of the participants. Although such non-probability sampling may affect the internal validity, it can still "under the right conditions (…) give useful results" (Cochran, 1977, p. 10).

The experiment in this project is a naturalistic quasi-experiment; it is naturalistic because it was carried out in a real learning environment – and because of this, it is a quasi-experiment. The different types of instruments used in this project were chosen to allow for triangulation of results, thereby increasing the validity of the findings.

5.1.2 The sample

The *population* refers to all individuals the researcher wants to describe – in this case the Fundamentals and Regular students at the University of Sydney. Although these will share many characteristics with first year university students elsewhere, the validity of such a comparison cannot be guaranteed. The part of the population that is used either as treatment or control group is called the *sample*. In this case, the sample is therefore the same as the population.

Students were centrally allocated to tutorial classes – a process outside my control. Of 12 tutorial classes in total, I randomly chose two to be Map Meetings and the remaining three to be Workshop Tutorials in the Fundamentals course and four Map Meetings and three Workshop Tutorials in the Regular course. I was the tutorial supervisor in the two Fundamentals Map Meetings and two Regular Map Meetings, whereas the remaining Regular Map Meetings and all Workshop Tutorials had different supervisors. For ethical reasons, students were discouraged from, but not disallowed to, swap tutorials during the semester. All such swaps, however, were recorded.

Senior high school and enrollment information were obtained from the university database and university physics examination results from the School of Physics with informed consent (Appendix C.2). This study has approval from the Human Research Ethics Committee at the University of Sydney (see Appendix C.1).

5.1.3 Tutorial attendance

Attendance at tutorials was not compulsory, but a 2% attendance mark was awarded if students attended at least 80% of the tutorials (corresponding to missing two tutorials per semester). Students received a 1% attendance mark for attending at least 40% of the tutorials (5 tutorials). Attendance was recorded via a sheet on each tutorial table where students wrote their name and student ID number (SID). To avoid students recording other students who were not present, tutors checked the sheets during each tutorial.

5.1.4 The instruments

5.1.4.1 Validity and reliability

Tests used to assess the effect of the intervention must be *valid,* meaning that they measures skills, knowledge or information directly relevant to the expected experimental outcome. The validity can only be assessed by human experts, such as the researcher or an expert panel.

The internal validity refers to whether one can conclude that the independent variable caused the change in the dependent variable. Any extraneous or uncontrolled condition related to the independent variable – called a confounding variable – is a threat to the internal validity; examples are changes related to time in long duration projects, treatment and control groups that are not equivalent and measurement errors. The ambiguity of cause and effect are related to two problems: 1) the temporal order problem: when two variables are measured simultaneously one cannot draw any conclusions upon which variable caused a change in the other, and 2) the third variable problem: the dependent variable is affected by some other variable in addition to the independent variable.

External validity refers to the type of generalizations that can be drawn from the data, and is generally divided into two categories. The generality of findings refers to the inferences that can be made on the population based on the sample, whereas the generality of conclusion describes whether the findings can be generalized to other populations. The major threat to the external validity lies in whether the sample is representative of the population. However, it is also important to consider the environment in which the experiment was conducted to avoid this behaving as a third variable affecting the outcome.

The instruments should be checked for *reliability*, which has two aspects: consistency and discriminatory power. The consistency reflects whether a person would obtain the same result if the test were repeated, whereas the discriminatory power is a measure of how well the test separates varying levels of the dependent variable in question. Unlike the validity, reliability can be assessed statistically (Ding, Chabay, Sherwood & Beichner, 2006).

When comparing true experiments with quasi-experiments, the former is better able to meet the discussed criteria because all the variables are controlled by the researcher. With quasi-experiments, it is not so. However, quasi-experiments mimic or are performed in naturalistic settings and, if they are done well, can provide more generalisable and useful findings – although they are often not as clean and clear as for true experiments. In addition, due to the environment in which they were carried out, research findings are authentic and transferrable, and the intervention can be made ready for implementation without major alterations.

5.1.4.2 The questionnaires

Questionnaires are a cheap and quick way of collecting large amounts of data. As long as the response rate is large enough (50-60% is generally acceptable, 80% is excellent) (see for example Cummings, Savitz & Konrad, 2001; DIIA, 2006), one can assume that the sample is representative of the population, allowing the researcher to adequately estimate relevant population parameters. An important limitation of questionnaires is that self-reporting is not necessarily accurate, e.g., people report an idealized rather than a realistic view of themselves. Furthermore, attention needs to be paid to the design of the survey and how closely the items in the questionnaire represent the variable to be measured.

Questionnaires were administered four times in 2007: in weeks 3 and 13 of first semester and again in week 3 and 13 of second semester (see Appendix E.2). For logistic reasons, the week 3 administrations were in lectures while those in week 13 were in tutorials. For each questionnaire the students were given a short three-minute presentation about the purpose of the research and privacy protocols. Return rates were between 78% and 91% for students attending the lecture or tutorial and between 53% and 61% for all enrolled students.

1. I generally manage to solve difficult physics problems if I try hard enough
2. I know I can stick to my aims and accomplish my goals in physics
3. I will remain calm in my physics exam because I know I will have the knowledge to solve the problems
4. I know I can pass the physics exam if I put in enough work during the semester
5. The motto ‘If other people can, I can too’ applies to me when it comes to physics

Table 5.1: The physics self-efficacy statements.

The first five items in the questionnaire measured students’ self-efficacy (see Appendix G.3 for validation of the self-efficacy items). The five statements (see Table 5.1) were based on the General Self-Efficacy Scale (Schwarzer, 1993). Students were asked to indicate on a 5-point Likert scale whether they strongly disagreed (1), disagreed (2), were neutral (3), agreed (4) or strongly agreed

(5) with the statements. The statements were situated in a physics education context since I was specifically interested in physics self-efficacy.

The next five items on the questionnaire were about students' attitudes towards physics in general – these were not used due to lack of relevant findings.

The remaining items (about 20 each time) aimed to measure students' physics goal orientations. This instrument was not completely developed by the end of 2007, however, and could therefore not be used for analyses in this project. The articles reporting on the development of this questionnaire are attached in Appendices G.1 and G.2.

The second questionnaire, at the end of first semester, contained two short answer questions asking which tutorial type students preferred and what they liked and disliked about the tutorial they were attending when completing the questionnaire.

5.1.4.3 Focus groups and interviews

Midway through second semester, students were invited – first by email (Appendix E.1), followed by an in-class announcement – to participate in focus groups to discuss their tutorial experience. Eleven students with experience from both the Fundamentals and Regular courses in first semester and the Environmental and Technological courses in second semester volunteered.

The questions asked in the focus group were divided into topics. The topics discussed were tutorial general – why students attended tutorials or not, whether they worked or not during the tutorial and whether the tutors were helpful – and tutorial specific – how motivating and useful for learning were the following four parts of the Map Meetings (and Workshop tutorials where relevant): summary lecture, Link Map, problem solving session, and board session. See Appendix E.1 for the complete interview schedule.

A video camera was used to record the sessions to make it easier to identify who said what, as well as to record body language. The camera was placed so that the students could be seen at least in profile. All students agreed to being filmed, subject to institutional privacy protocols. The focus groups were transcribed and the transcripts coded according to the different topics discussed – a process that was completed after two revisions of the original coding. The transcripts were analysed by thematic analysis.

5.1.4.4 Tutorial observations

Observations of both types of tutorials were undertaken in week 9 of first semester by two physics education research experts not associated with the project (one for the Fundamentals course, one for the Regular course). The observers were asked to comment on the level of involvement of tutors and students and provide an overall impression of each tutorial type.

5.1.4.5 Other qualitative feedback

Other qualitative feedback included minutes from the Student-Staff Liaison Meetings and emails from students and staff.

5.1.4.6 The end of semester examinations

Academic achievement was measured using the raw mark from the end of semester examinations. Initial analyses revealed that neither individual question marks nor the collective marks from the conceptual or traditional questions produced any findings of interest, so only the total examination mark is used in the following analyses.

5.1.5 Analyses and interpretation

A description of common statistical analyses can be found in Appendix B and a detailed explanation of factor analysis in Appendix G.1; here I will discuss the ambiguities of statistical analyses and interpretations.

5.1.5.1 Normality

In all education research, prior to performing any statistical analyses, sample normality – or the lack thereof – must be evaluated to determine which statistical analyses can be carried out. This may seem simple, but the fact that an expert on normality devotes 36 pages to discussing numerous ways of testing for normality (D'Agostino, 1986) reveals that it is not. Although "[a]ttempting to make final recommendations is an unwelcome and near impossible task involving the imposition of personal judgments" (p. 405), D'Agostino provides some insightful – and quite surprising – advice on how to best evaluate normality.

The most commonly used test for normality in education research receives little sympathy: "For testing for normality, the Kolmogorov-Smirnov test is only a historical curiosity. It should never be used" (p. 406). Rather, “[t]he Shapiro-Wilk type tests are probably overall most powerful" (p. 406). These tests better estimate normality, but still have problems when several values in the data set are the same, which is often the case with questionnaire data. Consequently, "[a] detailed graphical analysis involving normal probability plotting should always accompany a formal test of normality" (p. 405).

Therefore, in analyzing my results I used a combination of the Shapiro-Wilk test in SPSS and perusal of the associated sample histograms before determining whether to employ parametric or non-parametric tests. In ambiguous cases, I carried out both types of analyses to investigate whether they produced results that were in agreement – when they were, the normality classification was less relevant.

5.1.5.2 Statistical significance

Another issue that is less clear-cut than often portrayed in the education literature is the use and interpretation of statistical tests. In the social sciences, significance testing has reached the status of the Holy Grail. However, interestingly, the value and philosophy of such testing is rarely discussed, although a debate of significance testing has been ongoing for a century. Already in 1919, the experimental psychologist Edwin G. Boring warned that the mathematical measure of statistical significance “may need to be discounted in arriving at a scientific conclusion. The case is one of many where statistical ability, divorced from a scientific intimacy with the fundamental observations, leads nowhere” (p. 338). Nearly one hundred years later, his idea resonates in a similar argument by the forecasting expert J. Scott Armstrong: “Despite repeated calls for evidence, no one has shown that the applications of tests of statistical significance improve decision-making or advance scientific knowledge” (2007, p. 335).

With this I do not aim to enter into an extensive debate about the use of significance testing in education research; I merely wish to draw attention to the dogmatic allegiance often observed. Inherently, statistics aims to describe what cannot be simply summarised – which demands considerable knowledge and skill from the researcher to be accurately and appropriately handled. Therefore, *understanding* is paramount.

The calculated statistical significance, or *p-value*, is an incredibly influential measure. It represents the probability that a result is detected as real when in fact it is not. Because of the probabilistic nature of samples, there is always a possibility that a result is falsely reported as real, or that a real result fails to be detected. The former is referred to as a *type I error* or a *false positive* whereas the latter is a *type II error* or *false negative*. The two types of error are inversely related. The probability of a type I error is referred to as α. When statistical tests are performed, if $p < \alpha$, the result is said to be *statistically significant*. If we require $\alpha = 0.01$ rather than the more common $\alpha = 0.05$, the type I error will decrease (there is only 1% chance that what is detected as a real result occurred by chance), but the type II error will increase (there is a greater chance that a real result fails to be detected). In medicine where the potential consequences of a type I error can be dire – both medically and financially – α is usually set quite low (to 0.01 or 0.001). However, in education research the consequences are rarely that severe. Rather, one would presumably aim to maximize the likelihood of identifying real effects, as opposed to valiantly guard against type I errors. Therefore, $\alpha = 0.05$ is generally used. However, given that α marks an arbitrary point on a continuum rather than a strict demarcation of a dichotomy, where does this value come from?

In 1925, R. A. Fisher published the first edition of *Statistical Methods for Research Workers* (1925). The book contained six tables, one of which was very extensive – the one associated with the introduction of the ANOVA test. For each value of α, a table was required, and so Fisher chose to publish only one table – the one associated with $\alpha = 0.05$. “5% is arbitrary (as Fisher knew well), but fulfils a general social purpose. People can accept 5% and achieve it in reasonable size samples, as well as have reasonable power to detect effect-sizes that are of interest” (Stigler, 2008, p. 12). According to Stiegler (Stigler, 2008), Fisher’s book played a central role in establishing $\alpha = 0.05$ in the social sciences. Consequently, the significance level social researchers follow so slavishly today was coined because “[o]dds of about 20 to 1, then, seem to have been found a useful social compromise” (Stigler, 2008, p. 12). Had computers existed at the dawn of statistical significance – thereby circumventing the necessity for large and cumbersome tables – our current treatment of statistical significance would likely look quite different.

In this thesis I have chosen to adhere to the traditional $\alpha = 0.05$ – simply because it makes analyses more accessible to our well established ‘statistics schemata’. The enormous amount of data that were analysed was most easily handled by allowing statistically insignificant results to not be further pursued; statistical significance was a way for me to find the gems in the mud. However, given the arbitrary – albeit sensible – value of α, I did not treat is as an absolute cut-off. Hence, I will refer to results where $p < 0.10$ as 'nearing statistical significance'.

5.1.5.3 Effect sizes

More useful statistical evaluations, in addition to descriptive statistics, are "effect sizes, and use [of] confidence intervals and replications to assess confidence" (Armstrong, 2007, p. 336). The fact that Link Maps and Map Meetings were developed and trialled with four separate courses allows for increased power of comparison of results (even though there were certain differences between the courses, so they were not complete replications). Where appropriate, confidence intervals were included in figures and effect sizes were used in analyses. For correlations, *Pearson's r* is an effect size that measures the correlation between two variables, whereas to evaluate the relevance of a comparison of means, the *Cohen's d* effect size (Cohen, 1988) was used. Cohen's *d* expresses the difference in means in terms of standard deviations:

$$d = \frac{\overline{x_2} - \overline{x_1}}{\sqrt{0.5({s_1}^2 + {s_2}^2)}}$$

Values of d = 0.2, 0.5 and 0.8 are referred to as small, medium and large. Consequently, a statistically significant difference between two means does not necessarily reflect whether this difference is large enough to be of interest: very large sample sizes can reach statistical significance with a small effect size, in which case the result may not be of relevance, whereas very small sample sizes may not reach significance even though the effect size is large.

5.1.5.4 The role of statistics

Statistics is a tool that helps researchers understand large data sets. Depending on the characteristics of the data, different types of statistics are more or less useful. In this project, I have used traditional statistics; I have not used more sophisticated techniques, such as structural equation modeling. The reason for this is two-fold: first, with an incomplete data set (i.e., all variables were not known for all subjects), investigating the interrelationships between several variables would exclude a large number of subjects; second, with advanced statistical methods it is easy to lose touch with the data and treat the analysis uncritically as a black box. My approach to the analysis was to perform whichever tests allowed me to become acquainted with the data. This meant employing primarily simple descriptive statistics, tests of difference and association, and evaluating both significances and effect sizes. Ultimately, this marriage of statistical ability and scientific intimacy with the fundamental observations was what enabled a story to be told.

6 Results

6.1 Description of sample

Before I analyse the findings of the study, the sample is described here to get an insight into who the students that participated in this study were.

6.1.1 HSC background

High school results were available for 74% of the Fundamentals students (*N* = 272) and 82% of the Regular students (*N* = 380); international and interstate students, mature age students and students who did not sit the state-wide set of examinations – the New South Wales High School Certificate (HSC) – do not have their results automatically entered into the university data base, and these were therefore not available. Even if they were available, these results are based on different courses and instruments (examinations and internal assessments) and could not have been used because they could not easily be compared to the 2006 HSC results. However, the university selection criteria for entry into the various degree courses are based on carefully developed conversion scales to ensure fair entry regardless of high school background. Since the students of known background constitute a significant majority in each course, they had a strong influence on the overall group parameters.

The course guidelines recommend that students with no background in senior high school physics enroll in the Fundamentals course, whereas those *with* senior high school physics enroll in the Regular course. Of the students with known backgrounds, 9% of the Fundamentals and 8% of the Regular students had a background *not* recommended by the course guidelines (see Table 6.1). With respect to mathematics, the Fundamentals students had a lower level of prior knowledge than the Regular students: 82% of the Regular students had either 3- or 4-unit HSC Mathematics, whereas only 53% of the Fundamentals students did so. Similar fractions of students had studied chemistry in high school, whereas more Fundamentals students (67%) than Regular students (26%) had studied HSC Biology. Students' high school backgrounds therefore identified the Fundamentals course as having a stronger 'life sciences' orientation than the Regular course.

HSC course	*FND (N = 195)*	*REG (N = 300)*
Physics	9%	92%
Chemistry	70%	76%
Biology	67%	26%
No recorded mathematics	4%	1%
General Mathematics	8%	1%
2-unit Mathematics	35%	17%
3-unit Mathematics	37%	45%
4-unit Mathematics	16%	37%

Table 6.1: Fraction of students having studied various courses in the Higher School Certificate. Note that the percentages are of the number of students for which high school background was known. If only those students who sat the final exam (N = 234 for FND; N = 351 for REG) were used, the percentages deviated by a maximum of one.

Detailed data exploration, including the senior high school subjects listed in Table 6.1 and HSC English, was carried out. Only HSC Physics and Mathematics proved relevant to the ensuing analyses, so HSC Chemistry, Biology and English will not be discussed further.

6.1.2 Degree

The first year physics cohort was dominated by three degrees: Bachelor of Medical Science, Bachelor of Science and Bachelor of Engineering. Their distribution in the two courses, however, was different.

The Fundamentals course had 50% Medical Science students and 24% Science students, with the remaining 26% scattered across another 19 different degrees (see Appendix F). The Regular course, on the other hand, had 30% Medical Science students, 25% Science students and 16% Engineering students. The remaining 29% were enrolled in 22 different degrees, of which 23% of the whole course were enrolled in double degrees including either a B.Sc. or a B.E. or both. This supports the stronger ‘life sciences’ orientation of the Fundamentals course.

6.1.3 Gender differences in HSC backgrounds

The Fundamentals course had 58% females; the Regular course had 33% females. Comparing the academic backgrounds between females and males, there was a borderline statistically significant difference in favour of males for HSC Physics in the Regular course (females: *M* = 81.12, *SD* = 4.96, *N* = 91; males: *M* = 82.49, *SD* = 5.86, *N* = 184; *t*(273) = 1.92, *p* = 0.056). When the Regular course was separated by HSC Mathematics level, there was a statistically significant difference between the mean HSC Physics marks for females and males for 2-unit and 3-unit Mathematics students in favour of males (see Table 6.2) but not for 4-unit students.

HSC Mathematics level	*Gender*	*N*	*Mean HSC Physics mark*	*SD*	*Sig.*	*Cohen's d*
2-unit	F	15	78.87	5.46	0.028	0.62
	M	31	82.61	6.55		
3-unit	F	43	80.95	4.27	0.040	0.40
	M	85	82.75	4.80		
4-unit	F	32	82.47	5.71	0.71	0.08
	M	63	82.94	5.65		

Table 6.2: Descriptive statistics with associated t-test comparing mean HSC Physics marks between genders in the Regular course, grouped by HSC Mathematics level.

Performing the analyses for the Fundamentals and Regular courses separately, there were no differences between genders when comparing their performances in the four different HSC Mathematics courses.

To investigate whether students' level of HSC Mathematics affected their performance in the HSC Physics course, the mean HSC Physics marks were compared between the 2-, 3- and 4-unit Mathematics students. ANOVAs were performed separately for females and males, and only for Regular students since these had HSC Physics. Neither analysis reached statistical significance, although females neared significance (females: *F*(2, 87) = 2.84, *p* = 0.064; males: *F*(2, 176) = 0.05, *p* = 0.96). A Tukey post-hoc test showed that it was the difference between 2- and 4-unit females that neared significance (*p* = 0.054). This suggests that the level of mathematics undertaken in the HSC is *not* an important predictor variable for performance in HSC Physics, except, possibly, for 2-unit female students.

6.1.4 Student migration from first to second semester

Whereas course choice in first semester generally depends on high school physics background, course choice in second semester depends largely on student interest. Students can also choose to undertake one semester only in physics, which need not be in first semester.

Not all students sit the final examination – some discontinue for whatever reason. In most cases, however, at the time of attending tutorials or completing a questionnaire, students are not aware that they will not sit the final examination. Hence, their participation is genuine, and these students were included in relevant analyses. Table 6.3a shows all students who at some point were associated with any given course as measured by tutorial attendance, questionnaire response or the examination. Table 6.3b comprises only those students who sat the final examination. Comparing the two tables, 43 students did not sit any examinations. Each of the four courses saw a decrease in student number between 5% and 11%, with the Fundamentals course having the largest drop.

Focusing on those students who did sit the end of semester examinations (Table 6.3b), there are a few things to note. First semester had the most students, with 585 compared to 462 students in second semester. The Regular course was the largest course in first semester; the Environmental course was the largest in second semester. In terms of student migration, 90% of those Fundamentals students who continued on to second semester enrolled in the Environmental course. The Regular students, however, split roughly equally into the Environmental and Technological courses. The Environmental course, therefore, had an approximately half-half split of students with different backgrounds from first semester, whereas most of the Technological students came from the Regular course. Also note that 193 (33%) first semester students did not continue on to second semester, and 70 students (15%) entered second semester without having completed any first semester physics examinations in 2007.

Exploratory analyses of the vast amount of data collected in this project revealed that students' high school physics background is of particular interest in this study. I therefore decided to focus on the Environmental course only in second semester because this course had Fundamentals and Regular students in approximately equal numbers. The Environmental cohort naturally divides into four sub-groups according to first semester course (Fundamentals or Regular), which reflects prior physics knowledge, and second semester tutorial type (Map Meetings or Workshop Tutorials).

a)		*First semester course*			
		FND	*REG*	*None*	*Total*
Second semester course	ENV	144	132	29	305
	TEC	14	137	39	190
	None	104	99	0	203
	Total	262	368	68	698

b)		*First semester examination*			
		FND	*REG*	*None*	*Total*
Second semester examination	ENV	130	126	31	287
	TEC	13	123	39	175
	None	91	102	43	236
	Total	234	351	113	698

Table 6.3: Overview of student migration from the Fundamentals and Regular courses in first semester to the Environmental and Technological courses in second semester in terms of all students (a) and only those students who sat the end of semester examinations (b). Note that 43 students were at some point part of first year physics, but did not sit any examinations.

6.1.5 Summary

In summary, the Fundamentals course had a stronger life science orientation than the Regular course. The Fundamentals students also had a poorer academic high school background with respect to physics related subjects – the majority had no high school physics and the students had lower levels of mathematics on average. In the ensuing analyses, the Fundamentals and Regular students will be the focus in first semester and the Environmental students in second semester – the latter approximately equally populated by the two first semester courses.

6.2 Tutorial attendance

6.2.1 First semester

6.2.1.1 Attendance

Figure 6.1 shows weekly tutorial attendance throughout first semester.

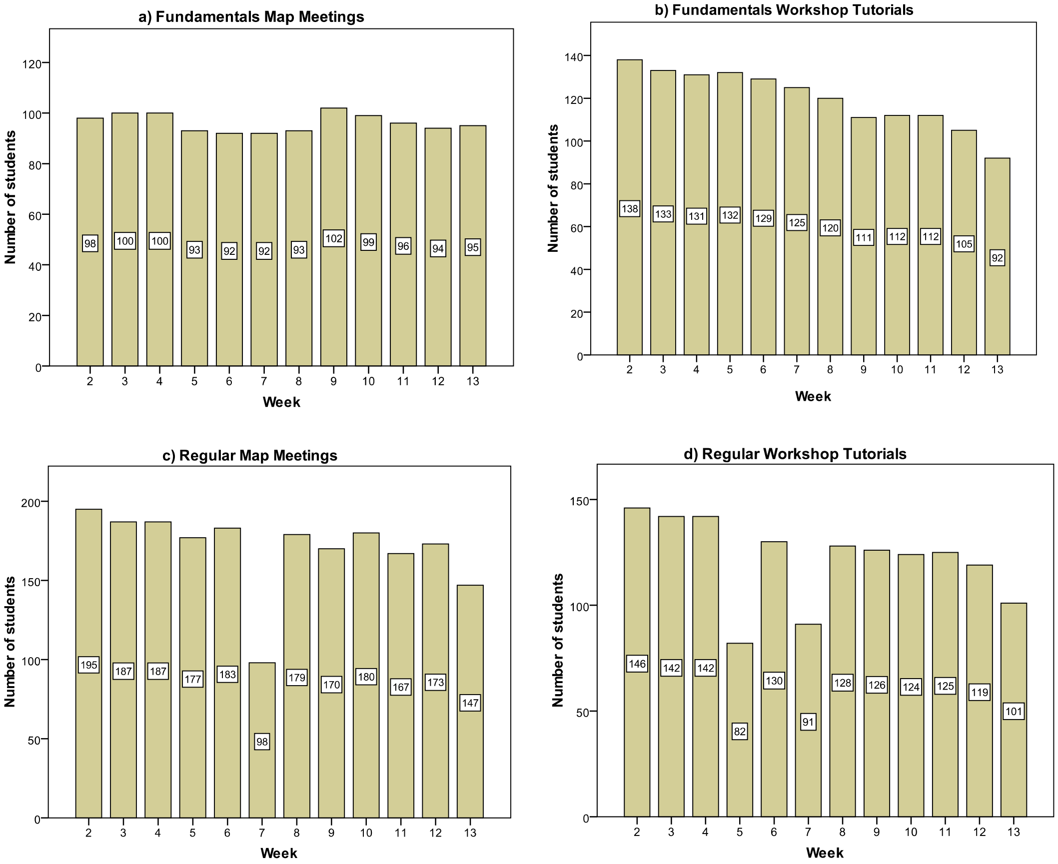


Fig. 6.1: Weekly attendance for the four different groups of tutorials in first semester: a) Fundamentals Map Meetings, b) Fundamentals Workshop Tutorials, c) Regular Map Meetings and d) Regular Workshop Tutorials.

Two public holidays were the cause of the instances of lower attendance in the Regular course; these were not on the same day of the week and therefore did not affect the same students. Students were encouraged to attend another tutorial if a public holiday was on their scheduled tutorial day, but for many students this was impossible, impractical or inconvenient.

In the Fundamentals course, the attendance in the Map Meeting tutorials remained essentially constant throughout the semester. The Workshop Tutorials, on the other hand, experienced a steady decline; in the last week of semester, attendance was only 67% of initial attendance.

For the Regular course the situation was not as clear cut. Workshop Tutorials show a somewhat steeper decline than Map Meetings – the total drop in attendance from beginning to end of semester is 31% for Workshop Tutorials and 25% for Map Meetings.

These findings indicate that Fundamentals students found it more worthwhile attending Map Meetings than Workshop Tutorials; a similar but less marked trend favouring Map Meetings is seen in the Regular course.

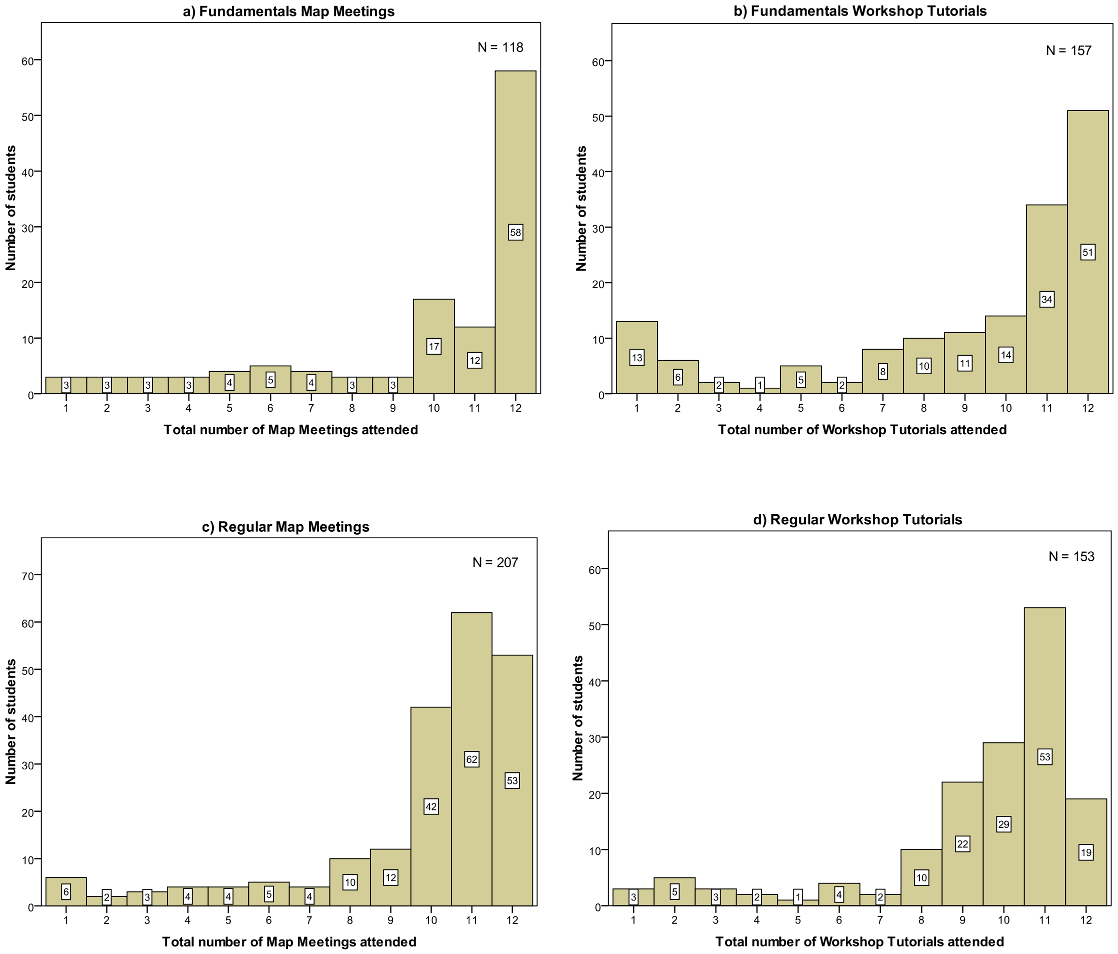


Fig. 6.2: Histograms of total number of tutorials attended by students in first semester: a) Fundamentals Map Meetings, b) Fundamentals Workshop Tutorials, c) Regular Map Meetings and d) Regular Workshop Tutorials.

Figure 6.2 shows how many students attended any given total number of tutorials. Most students attended almost all tutorials, regardless of course or tutorial type. Eyeballing the histograms, there is a significant change in attendance at ten tutorials – this division was also seen in the pilot study in 2006 (see Lindstrøm & Sharma, 2009). Students who attended at least ten out of the 12 tutorials were considered to have been committed to attending tutorials and 'fully exposed' to their effect; they were therefore called 'persistent' Map Meeting students or 'persistent' Workshop Tutorial students. Those attending one to nine tutorials were given the prefix 'non-persistent'. Among the persistent students, only one student had attended more than one of the other tutorial type; this was not considered to be an issue. In general, however, if students attended more than one of each tutorial type, the effect of tutorial types on them was considered to be ambiguous. Hence, only those non-persistent students who had attended at most one tutorial of the alternative type were included in further analyses.

Course	*Map Meetings*	*Workshop Tutorials*	*None*	*Both*
FND	118 (74%)	157 (63%)	4	17
REG	207 (76%)	153 (66%)	15	7

Table 6.4: Overview of the total number of students involved in any given tutorial at any time during first semester (regardless of whether they sat the end of semester examination). The number in brackets is the percentage of those students who were persistent.

Table 6.4 provides an overview of tutorial attendance. In brackets are the fractions of persistent students. This is remarkably consistent for each tutorial type, with (75±1)% of students attending Map Meetings being persistent Map Meeting students and (65±2)% of those attending Workshop Tutorials being persistent Workshop Tutorial students. Recall that students only received a token 2% participation mark if they missed at most two tutorials. Very few students never attended a tutorial; these students will not be analysed any further as they are not relevant to this research.

As indicated earlier, students could swap tutorials. Seventeen Fundamentals students and seven Regular students attended at least one tutorial of each type during the semester (last column in Table 6.4). These 'double' students attended between eight and 13 tutorials in total, and were therefore dedicated students. Of the 24 students, seven attended one single tutorial that was not their normal tutorial, two were allocated a different tutorial type when they changed course from

Regular to Fundamentals early in the year, and three attended a mixture of the two tutorial types. The remaining 12 students (nine Fundamentals, three Regular) all changed from Workshop Tutorials to Map Meetings between weeks 4 and 9. There are no clear trends in backgrounds among these students, except that mathematically they were not the strongest students in the course (none had 4-unit Mathematics). No students swapped the other way, strongly suggesting that Map Meetings were considered a more valuable learning environment by students who had tried both tutorial types *and* had the opportunity to change their tutorial time.

6.2.1.2 Persistent versus non-persistent students

Among the Fundamentals students who sat the final examination, a greater proportion of the non-persistent students compared to the persistent students had an unknown high school background (known background: 158 persistent, 24 non-persistent; unknown background: 36 persistent, 16 non-persistent; $\chi^2(1, N = 234) = 7.57$, $p = 0.003$). A similar trend was seen in the Regular course, but the result was not significant. This suggests that those students who enrolled in university immediately after completing their HSC were more likely to become persistent tutorial students.

	Map Meetings		*Workshop Tutorials*		
Course	*Persistent*	*Non-persistent*	*Persistent*	*Non-persistent*	*Sig.*
FND	87	18	99	43	0.018
REG	157	44	101	47	0.038

Table 6.5: Number of students who became persistent and non-persistent tutorial students in the two different courses. Only those non-persistent students who attended at most one tutorial of the opposite type are included. The significances refers to chi squared tests checking whether a greater fraction of Map Meeting students became persistent than Workshop Tutorial students.

Table 6.5 shows how many students became persistent and non-persistent students in Workshop Tutorials and Map Meetings respectively. To ensure that no students were counted twice, only those Workshop Tutorial students who attended at most one Map Meeting were included as non-persistent Workshop Tutorial students, whereas the non-persistent Map Meeting students comprised those who attended at most one Workshop Tutorial. For both courses there was a clear statistically significant difference between the two tutorial types (see Table 6.5). This shows that students who attended Map Meetings were statistically significantly more likely to attend at least 10 tutorials than students who attended Workshop Tutorials. No other variables exhibited a statistically significant difference between persistent and non-persistent students. This supports that it was the tutorial type itself that gave rise to the difference in persistence.

6.2.2 Second semester

Tutorial attendances in Environmental tutorials in second semester showed the same trends as those in first semester (Fig. 6.3), thereby strengthening these findings: attendance in Map Meetings stayed relatively constant, whereas Workshop Tutorials experienced a steady decline throughout the semester.

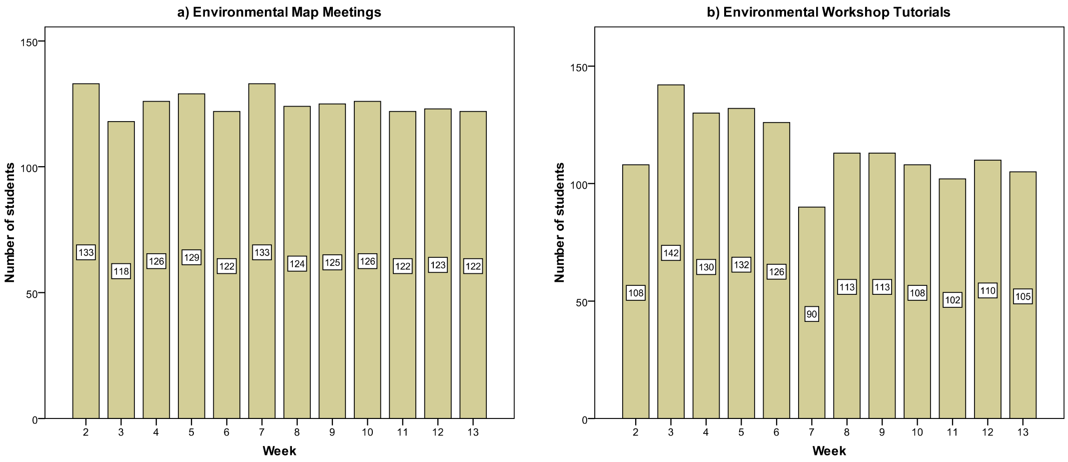


Fig. 6.3: Weekly tutorial attendance in second semester (ENV) for a) Map Meetings and b) Workshop Tutorials. Note that there was a public holiday in week 7 affecting Workshop Tutorials. In week 2 there was a scheduling error that resulted in students being relocated to different tutorials in week 3.

Seventy four percent of all the Environmental students who attended at least one tutorial attended at least ten tutorials when not distinguishing between tutorial types. Fig. 6.4 shows that 64% of students who attended at least one Map Meeting became persistent Map Meeting students, whereas the corresponding number for Workshop Tutorial students was 50%. This is the same trend as that seen in first semester. Among the Map Meeting students the number of students *increases* from 10 to 12 tutorials, whereas in Workshop Tutorials the number of students decreases. This may suggest that in Map Meetings students came because the tutorials were useful, whereas in Workshop Tutorials students had a stronger focus on getting their 2% attendance mark. The following quote from three Technological students (formerly Regular students) supports this:

Interviewer: Why do you come to tutorials?

Ida: Because we have to.

Interviewer: What do you mean by ‘have to’?

Ida: It’s two percent.

Interviewer: Exactly. Does that mean you have to?

Ida: Two percent’s the difference between a credit and a pass.

Interviewer: Depending on how well you do in the exam, yes.

Julie: It also depends on the tutors as well. The mind map ones, like [mentions name of two tutors], are really friendly.

Ida: The other ones [in Workshop Tutorials] are scary.

Hank: Oh, yes!

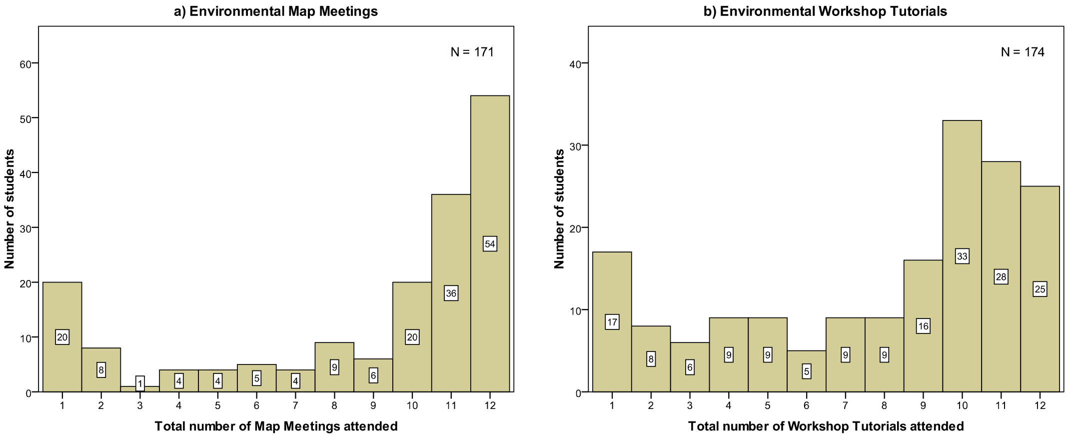


Fig. 6.4: Histograms of total number of tutorials attended by students in second semester in a) Environmental Map Meetings and b) Environmental Workshop Tutorials.

Fifty seven students attended at least one of each type of tutorial, whereas 22 attended at least two of each. Of these 22, 17 were persistent students. A problem with tutorials in the second week of semester forced several students to change their initially allocated tutorial time, so I only investigated students who attended at least two of each type of tutorial. Eleven of the 22 students swapped from Workshop Tutorials to Map Meetings, whereas the remaining 11 attended a mixture of tutorials with no clear pattern. No students swapped from Map Meetings to Workshop Tutorials, just like in first semester.

Investigating how students moved from tutorials in first to second semester (Table 6.6) – not separated by first semester course – there was an approximately equal split between the four groups (Map Meeting or Workshop Tutorial in first semester to Map Meeting or Workshop Tutorial in second semester; each group had between 21% and 29% of the cohort). The smallest group was that of students going from Map Meetings in first semester to Workshop Tutorials in second semester. Of the persistent Map Meeting students in first semester who did Workshop Tutorials in second semester, only 55% became persistent in second semester; of those who did Map Meetings in the second semester, 79% became persistent students. This difference is statistically significant ($\chi^2(1, N = 129) = 8.57, p = 0.003$). A similar result is not seen among those who were persistent Workshop Tutorial students in first semester. This suggests that many persistent Map Meeting students who were initially allocated to Workshop Tutorials in second semester swapped early in the semester so that they appear as Map Meeting students in second semester. In a group of five Technological students, four had been allocated to Workshop Tutorials but changed to Map Meetings (the last one was already allocated to Map Meetings).

> Interviewer: You guys actually changed over…
> Hank: Yeah, we were timetabled for the workshop ones this semester…
> Ida: I changed my timetable so I could fit a mind map one in because there were only two mind map ones and I was busy for both, so I changed my maths tute. (…) [Other students] did want to change across, but they just can't fit it into their timetable.

		Semester 2, MM		*Semester 2, WT*		
		Persistent	*Non-persistent*	*Persistent*	*Non-persistent*	*Sig.*
Semester 1, persistent students	MM	60	16	29	24	0.003
	WT	34	19	44	19	0.52

Table 6.6: Overview of what persistent students from first semester (either Fundamentals or Regular) who enrolled in the Environmental course did in second semester with respect to persistency in tutorials. Numbers refer to number of students.

6.2.3 Summary

In summary, Map Meetings were somewhat more popular than Workshop Tutorials: twelve students swapped from Workshop Tutorials to Map Meetings during first semester, but no students swapped the other way; and about 10% more of the students in both the Fundamentals and Regular courses became persistent Map Meeting students than persistent Workshop Tutorial students. Persistent students were those who attended at least 10 out of 12 of one type of tutorials. Second semester attendance patterns mirrored those in first semester, with more students preferring Map Meetings. In addition, several students who had attended Map Meetings in first semester but were allocated to Workshop Tutorials in second semester swapped into Map Meetings.

6.3 Self-efficacy

Data collection for students' self-efficacy occurred in lectures in week 3 and in tutorials in week 13 in both semesters. Information on students' self-efficacy is therefore strongly associated with their attendance in lectures and tutorials – the latter being more relevant here. We can assume that there is no sampling bias with respect to the persistent students, who attended nearly all tutorials. However, the non-persistent students, by definition, attended fewer tutorials and were therefore less likely to respond to questionnaires. Because the non-persistent students who responded to the questionnaires are not representative of the non-persistent students on the whole, the non-persistent students were omitted from the self-efficacy analyses.

Table 6.7 shows how many persistent students responded to each questionnaire.

		First semester			*Second semester*		
Course	*Tutorial*	*Week 3*	*Week 13*	*Weeks 3 and 13*	*Week 3*	*Week 13*	*Weeks 3 and 13*
FND	MM	49	71	45	41	41	34
	WT	49	66	36	21	28	18
REG	MM	117	125	94	41	45	33
	WT	79	43	38	13	25	12

Table 6.7: Overview of the number of persistent students who responded to the questionnaires. The tutorial distinctions refer to the first semester tutorials in first semester and second semester tutorials in second semester.

6.3.1 Initial self-efficacy

By week 3 students had attended only one tutorial. As one single tutorial was not expected to have markedly affected students' initial self-efficacy, students were not separated by tutorial group in these analyses. There was a small correlation between HSC Physics mark and initial self-efficacy for the Regular students (*r*(151) = 0.17, *p* = 0.032), which indicated that 3% (R^2 = 0.029) of students' initial self-efficacy could be explained by their HSC Physics mark. When separating the group by gender, the statistical significance disappeared. Only one statistically significant correlation was found between HSC Mathematics and initial self-efficacy: 2-unit Regular females exhibited a large statistically significant correlation (*r*(7) = 0.83, *p* = 0.005). However, the numbers are very small (*N* = 9). Therefore, there were no clear trends in correlations between students' initial self-efficacy with their HSC Physics (Regular students only) and HSC Mathematics (Fundamentals and Regular students).

Because no clear trends were identified, HSC Physics and HSC Mathematics were not considered in the following analyses of self-efficacies in first semester: *all* persistent students are included, not just those persistent students for whom high school background is known.

Gender has been identified as an important variable in self-efficacy (see Appendix F) with females consistently reporting a lower self-efficacy than males. Gender is covered separately later in this section; in the following analyses the ratio between females and males does not change significantly between administrations within each course (for the three columns in Table 6.7, keeping the tutorial types separate, 57-61% were female in the Fundamentals course and 32-42% were female in the Regular course), so the differences in reported results cannot be attributed to differing fractions of females contributing to any given subgroup.

6.3.2 Self-efficacy in first semester

Separating by course, there were no significant differences (and only small effect sizes) in mean self-efficacy between the persistent Workshop Tutorial students and the persistent Map Meeting students. At the end of the semester, again there were no statistically significant differences between the two tutorial groups, although it neared significance for the Regular course in favour of Map Meeting students (MM: *M* = 18.32, *SD* = 2.60, *N* = 125; WT: *M* = 17.33, *SD* = 3.37, *N* = 43; *t*(60.07) = 1.76, *p* = 0.083, equal variances not assumed, Cohen's *d* = 0.33). This suggests that Map Meetings had a more positive effect on students' self-efficacy than did Workshop Tutorials. The rest of this section investigates this proposition in more detail. To analyse students' *change* in self-efficacy, I used the subset of students who responded to both questionnaires and viewed it in four different ways.

6.3.2.1 T-tests

Table 6.8 shows that all four groups experienced a decrease in self-efficacy from the beginning to end of the semester.

			Mean self-efficacy				
Course	*Tutorial*	*N*	*Week 3 (SD)*	*Week 13 (SD)*	*ΔM*	*Sig.*	*Cohen's d*
FND	MM	45	18.80 (3.36)	17.98 (2.56)	-0.82	*0.044*	0.28
	WT	36	18.33 (3.03)	16.86 (2.94)	-1.47	*0.001*	0.49
REG	MM	94	18.81 (2.73)	18.40 (2.67)	-0.40	0.11	0.15
	WT	38	17.79 (2.67)	17.24 (3.48)	-0.55	0.14	0.18

Table 6.8: Mean self-efficacy for persistent students at the beginning and the end of first semester. Only students for whom self-efficacy is known at both times are included. *ΔM* refers to the change in mean self-efficacy from week 3 to week 13.

The most severe decreases in self-efficacy occurred in the Fundamentals course. The decrease was statistically significant for both Workshop Tutorials and Map Meetings, but was much more severe for the former as reflected by the effect size. For the Regular course, the decreases were not statistically significant and smaller than for the Fundamentals course; the difference between the two tutorial groups was also much smaller.

These results suggest that even though the mean self-efficacy decreased regardless of course and tutorial group, the decrease was more severe for the Fundamentals than for the Regular students. The results may also suggest that Map Meetings helped reduce the severity of this decrease compared to Workshop Tutorials.

6.3.2.2 Correlations

Scatter plots of students' change in self-efficacy against their initial self-efficacy provide another view of the data. The reasoning behind this method is that if students had a very high self-efficacy at the beginning of the semester it may have been healthy to reduce their self-efficacy to a more realistic level before the examination. Therefore, reduction in self-efficacy for students who initially had a very high self-efficacy is of less concern, whereas students who initially had very low self-efficacy would have benefitted from an increase in self-efficacy during the semester.

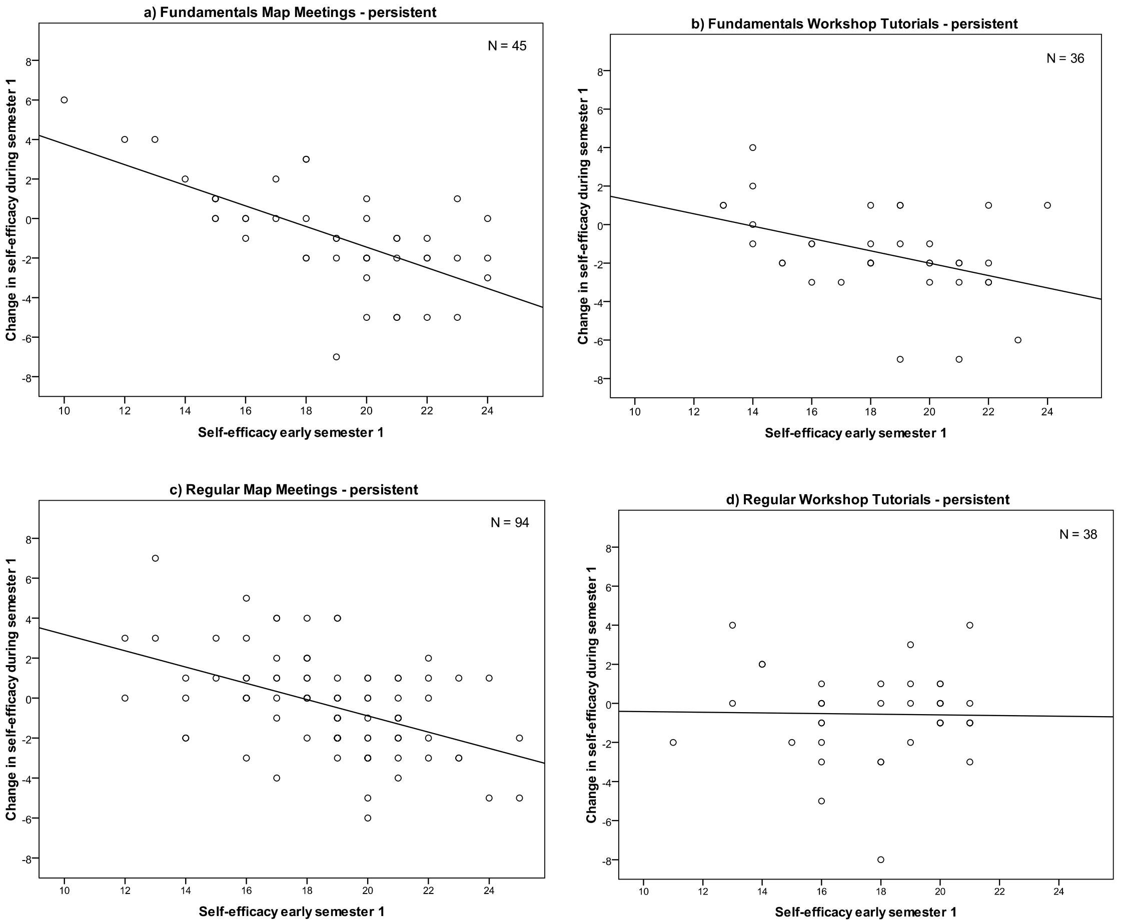


Fig. 6.5: Scatter plots of the change in self-efficacy against initial self-efficacy for the persistent students in a) Fundamentals Map Meetings, b) Fundamentals Workshop Tutorials, c) Regular Map Meetings and d) Regular Workshop Tutorials.

First, notice that for both courses Workshop Tutorials show a weaker correlation than Map Meetings (Table 6.9). This may suggest that Workshop Tutorials had less of a consistent effect on students' self-efficacy than Map Meetings did. The correlation between the change in self-efficacy with the initial self-efficacy for the persistent Fundamentals Map Meetings is very high: *r*(92) = 0.66, *p* = 0.000. The square of this value (R^2 = 0.43) represents the percentage of the variance in the change in self-efficacy that can be explained by the initial self-efficacy – 43% in this case, which is quite substantial. In comparison, there is essentially a complete lack of correlation for the Regular Workshop Tutorial students where the tutorial seems to have had no consistent effect on the students.

Three of the four scatter plots exhibit a negative trend as shown by the line of best fit. This reflects that, on average, the higher the initial self-efficacy of students, the more of a decrease they experienced. It also means that below a certain value of initial self-efficacy, the change experienced during the semester was positive. This occurs where the line of best fit crosses the axis where the change in self-efficacy is zero. Table 6.9 contains values of the intercepts and gradients of the lines of best fit.

Course	*Tutorial*	*N*	*Intercept*	*Gradient*	*r*	*Sig.*	R^2
FND	MM	45	17.1	-0.51	-0.66	0.000	0.43
	WT	36	13.9	-0.30	-0.42	0.011	0.18
REG	MM	94	18.0	-0.30	-0.46	0.000	0.21
	WT	38	-	-	-0.20	0.91	0.04

Table 6.9: Overview of intercepts and gradients of the line of best fit in Fig. 6.5.

The most noteworthy feature in the above table is the value of the intercept. For Map Meeting students in both courses the intercept has a similar value to the mean self-efficacies found at the beginning and end of the semester. This means that, on average, students with higher initial self-efficacies than the intercept tended to decrease in self-efficacy, whereas those with an initial self-efficacy lower than the intercept increased in self-efficacy. When the intercept roughly corresponds to the mean self-efficacy of all students, it in effect means that all students' self-efficacy was brought closer to the mean. The amount by which the self-efficacies changed is given by the gradient. For each unit value of self-efficacy a student is away from the intercept at the beginning of the semester, he or she is brought closer to the value of the intercept by the absolute value of the gradient. The difference between Map Meetings and Workshop Tutorials is very interesting. For Fundamentals Workshop Tutorials, the intercept is as low as 13.9, suggesting that any initial self-efficacy above this value (which is 1.14 standard deviations lower than the initial self-efficacy mean for this group) decreased during the semester. The complete lack of correlation in the Regular Workshop Tutorial scatter plot shows that there are no trends whatsoever in who experienced a change in self-efficacy; on average, all students reduced their self-efficacy by 0.34 units during the semester.

The most important results from the scatter plots are the different trends in *how* students' self-efficacy changed during the semester as a function of their initial self-efficacy. For the Map Meeting students the effect was to change the self-efficacy towards a central value that is similar to the mean initial self-efficacy for the group. This is a positive effect since a low self-efficacy is considered detrimental and an unreasonably high self-efficacy can also be unhealthy if not supported by strong performances. The relatively high correlations indicate that the effect of the Map Meetings is reasonably consistent on students. For the Workshop Tutorials, on the other hand, the effect is much less consistent and more negative. For the Fundamentals students, the effect was to reduce the self-efficacy of almost all students, even those who had a disconcertingly low self-efficacy in the first place. Map Meetings are therefore considered to be the most successful tutorial type in terms of producing both a positive and more consistent change in self-efficacy.

6.3.2.3 Self-efficacy ranges

A third way to look at the data is to consider groups of students rather than their calculated average behaviour. We can divide students into three broad ranges or categories:

- Low self-efficacy: score less than 15, i.e. on average less than neutral to the statements;
- Medium self-efficacy: score between 15 and 19 inclusive, i.e. on average between neutral and agree, but not agreeing to all statements; and
- High self-efficacy: score of 20 or higher, i.e. from agreeing to strongly agreeing to the statements on average.

Table 6.10 shows the percentage of students in each range of self-efficacy for Map Meeting students and Workshop Tutorial students in the Fundamentals and Regular courses respectively.

First we look at the group of low self-efficacy students. In the Fundamentals course, there was a higher proportion of low self-efficacy students in Workshop Tutorials than in Map Meetings at the beginning of the semester. By the end of the semester this proportion was the same in Map Meetings, whereas it had increased by 50% in Workshop Tutorials. The situation was similar in the Regular course: the two tutorial types began with the same fraction of low self-efficacy students, but whereas it remained unchanged in Map Meetings, it almost doubled in Workshop Tutorials.

				Self-efficacy					
		N		*Low*		*Medium*		*High*	
Course	*Tutorial*	*Week 3*	*Week 13*	*Week 3*	*Week 13*	*Week 3*	*Week 13*	*Week 3*	*Week 13*
FND	MM	49	71	8%	7%	41%	65%	51%	28%
	WT	49	66	14%	21%	24%	58%	37%	21%
REG	MM	117	125	8%	8%	48%	59%	44%	33%
	WT	79	43	9%	16%	47%	53%	44%	30%

Table 6.10: Percentage of persistent students belonging to different self-efficacy ranges at the beginning and at the end of first semester. Fundamentals and Regular students are separated by their tutorial groups.

For the high self-efficacy students, all four groups experienced a reduction in relative size. In the Fundamentals course, the two tutorial groups experienced the same percentage reduction in size of their high self-efficacy group, namely by 43% and 45% respectively. In the Regular course the reduction was smaller – 32% for Workshop Tutorials and 25% for Map Meetings. Since the Regular students were more experienced with physics, they were less likely to change their self-efficacy during the semester, so this is not surprising.

In summary, Map Meetings seem to have prevented an increase in the fraction of low self-efficacy students during the semester, unlike the Workshop Tutorials. Also, whereas all four groups decreased in the amount of high self-efficacy students, within each course the Map Meetings had somewhat more students with a high self-efficacy at the end of the semester.

6.3.2.4 Individual change in self-efficacy

The fourth and last analysis focuses on the self-efficacy change of each individual student by counting the number of students who increased, decreased and remained at the same self-efficacy from beginning to end of the semester (see Table 6.11).

For the Fundamentals students the same fraction of students increased in self-efficacy, but many more decreased in Workshop Tutorials than in Map Meetings. For the Regular course, on the other hand, roughly the same fraction of students decreased in self-efficacy, but many more increased in Map Meetings than in Workshop Tutorials.

Course	*Tutorial*	*N*	*Decrease*	*Stationary*	*Increase*
FND	MM	45	56%	18%	27%
	WT	36	72%	3%	25%
REG	MM	94	48%	18%	34%
	WT	38	47%	26%	26%

Table 6.11: Percentage of students who increased, decreased or did not change their self-efficacy from the beginning to the end of first semester, separated by course and tutorial type.

Consequently, this analysis tells a similar story to the previous ones. Map Meetings were more beneficial for students in both courses in terms of self-efficacy, but in slightly different ways: for Fundamentals students it seems that Map Meetings prevented something negative from happening because fewer students experienced a decrease in self-efficacy in Map Meetings than Workshop Tutorials, while there is no difference between the fraction of students who increased their self-efficacy; however, for the Regular students Map Meetings caused something good to happen as the same fraction of students decreased in self-efficacy, but more Map Meeting students than Workshop Tutorial students increased their self-efficacy.

6.3.3 Self-efficacy in second semester

Focusing on the Environmental course only, 163 students completed the first questionnaire in second semester, whereas 189 completed the second questionnaire. The difficulty in analyzing this data set arises from the large number of factors that may have affected students' self-efficacy given their varying experiences in first semester. Due to the relatively small number of persistent students, I decided to analyse the second semester self-efficacy data for persistent second semester students separating by first semester course and second semester tutorial group. This allows for the most direct comparison with the first semester results.

Regular students (MM: M = 18.83, SD = 2.59, N = 41; WT: M = 19.00, SD = 2.04, N = 13) had higher initial self-efficacies than the Fundamentals students (MM: M = 17.20, SD = 3.12, N = 41; WT: M = 17.95, SD = 2.36, N = 21). Within each course there was no statistically significant difference between the two tutorial groups. Note that a larger fraction of Map Meeting students than Workshop Tutorial students became persistent.

6.3.3.1 T-tests

None of the changes in self-efficacy in second semester were statistically significant. Redoing the analysis without splitting by course still did not produce any statistically significant results. However, unlike in first semester, all groups except the Fundamentals Workshop Tutorial students experienced a small *increase* in mean self-efficacy, with a stronger increase in self-efficacy for the Map Meeting students than the Workshop Tutorial students.

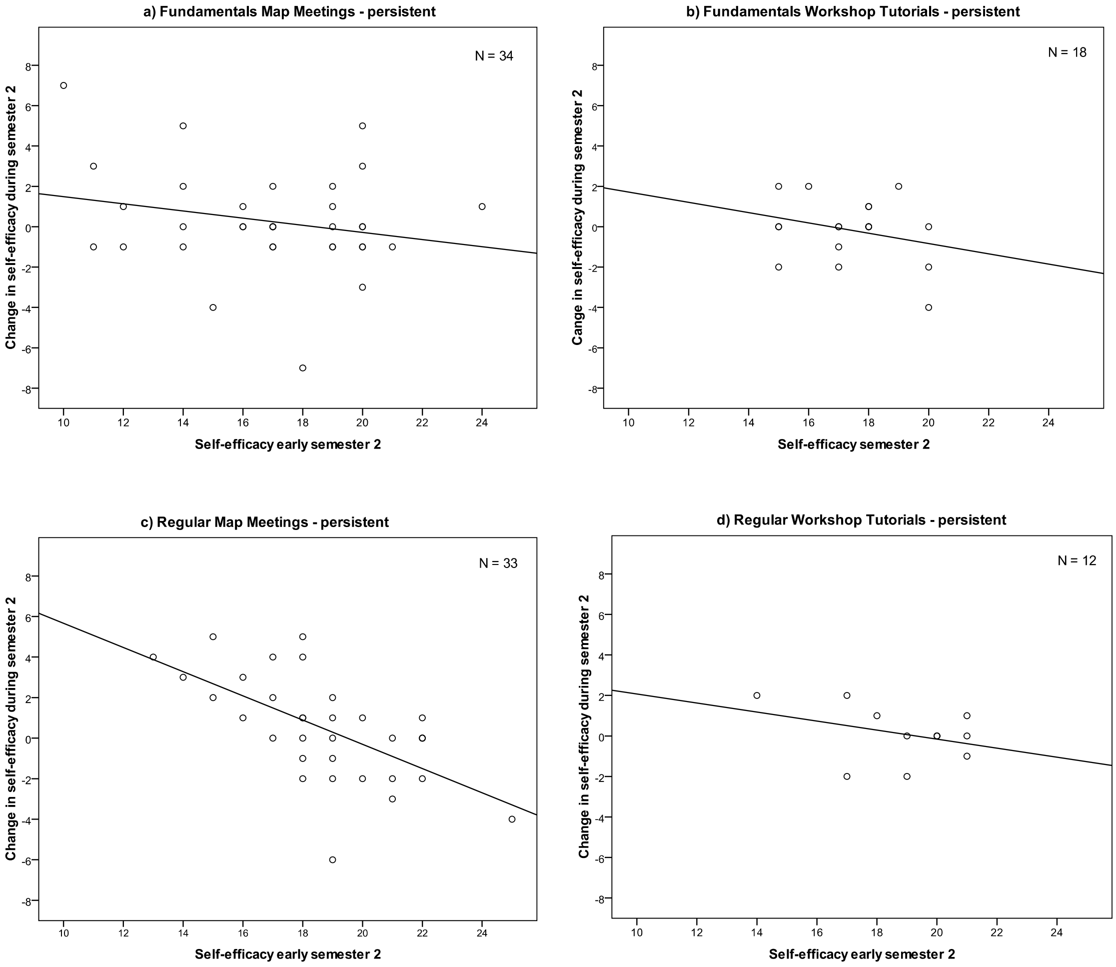


Fig. 6.6: Scatter plots of the change in self-efficacy against initial self-efficacy for the persistent Environmental students in second semester.

6.3.3.2 Correlations

Scatter plots for the second semester data (Fig. 6.6) show similar but not as clear results as those in first semester (partly due to smaller data sets, perhaps). Regular Map Meetings is the only group to show a clear trend and a statistically significant correlation (*r*(31) = 0.62, *p* = 0.000); low-self-efficacy students increased their self-efficacy and high-self-efficacy students decreased their self-efficacy, as seen in the first semester data.

6.3.3.3 Self-efficacy ranges

There are about twice as many Map Meeting students as Workshop Tutorial students contributing to this analysis, which probably reflects a strong self-selection. For the Fundamentals, there were *no* low-self-efficacy students in Workshop Tutorials at the beginning of the semester compared to 22% in Map Meetings (see Table 6.12). This may suggest that students with the lowest self-efficacy swapped tutorials to attend Map Meetings. Also, in Map Meetings the number of low-self-efficacy students did not change notably, whereas it increased to 11% in Workshop Tutorials. For the Regular students, there was a small increase in high self-efficacy students in Map Meetings, whereas there was a decrease in Workshop Tutorials, as seen in first semester.

				Self-efficacy					
		N		*Low*		*Medium*		*High*	
Course	*Tutorial*	*Week 3*	*Week 13*	*Week 3*	*Week 13*	*Week 3*	*Week 13*	*Week 3*	*Week 13*
FND	MM	41	41	22%	24%	51%	54%	27%	22%
	WT	21	28	0%	11%	76%	64%	24%	25%
REG	MM	41	45	5%	2%	61%	60%	34%	38%
	WT	13	25	8%	4%	39%	52%	54%	44%

Table 6.12: Percentage of persistent students belonging to different self-efficacy ranges at the beginning and end of second semester in the Environmental course. Fundamentals and Regular students are separated by their second semester tutorial groups.

6.3.3.4 Individual change in self-efficacy

Table 6.13 shows that Fundamentals students exhibited no clear trends, whereas Regular students displayed a similar trend to that in first semester with approximately the same fraction of students decreasing in self-efficacy between the tutorial groups, but many more Map Meeting students (over twice) increasing their self-efficacy.

Course	*Tutorial*	*N*	*Decrease*	*Stationary*	*Increase*
FND	MM	34	38%	27%	35%
	WT	18	28%	44%	28%
REG	MM	33	30%	21%	48%
	WT	12	25%	42%	23%

Table 6.13: Percentage of Environmental students who increased, decreased or did not change their self-efficacy from the beginning to the end of second semester, separated by first semester course and second tutorial type.

6.3.4 Self-efficacy and gender

Analysing the self-efficacy data with respect to gender showed that females self-reported lower self-efficacy than males in all cases in first semester, which was statistically significant in most analyses. Subsequently comparing females in Map Meetings with females in Workshop Tutorials and males in Map Meetings with males in Workshop Tutorials, there were no statistically significant differences between the tutorial groups in either the Fundamentals nor the Regular course at the beginning of the semester; but at the end of the semester the Regular females in Map Meetings exhibited a significantly higher self-efficacy than those in Workshop Tutorials (MM: M = 17.62, SD = 2.94, N = 47; WT: M = 15.83, SD = 3.43, N = 18; $t(63)$ = 2.09, p = 0.041).

Table 6.14 investigates the *change* in self-efficacy in first semester by reproducing Table 6.8 separating by gender. There were no differences in behaviour between genders for the Fundamentals students, but the results were somewhat different from those identified in Table 6.8: in Workshop Tutorials, both females and males decreased their self-efficacy statistically significantly from beginning to the end of the semester; however, in Map Meetings neither gender showed a significant decrease. Whereas the joint analysis had shown no significant decrease in self-efficacy in the Regular course, separating the analysis by gender showed that for both tutorial types females experienced a statistically significant decrease, whereas males did not.

Further analyses – similar to those not separating by gender – were hard to draw any clear findings from due to the small subsamples. Correlations between students' self-efficacy at the beginning of first semester and their change during the semester were statistically significant and large (r from 0.65 to 0.71) for all Map Meeting groups (except Regular females); none of the Workshop Tutorial subgroups showed significance. However, the lack of significance may have been due to the small number of students contributing to each subsample, and so no conclusions can be drawn beyond those discussed prior to the gender analysis.

				Mean self-efficacy				
Course	*Tutorial*	*Gender*	*N*	*Week 3 (SD)*	*Week 13 (SD)*	*ΔM*	*Sig.*	*Cohen's d*
FND	MM	F	26	17.77 (3.23)	17.04 (2.31)	0.73	0.17	0.26
		M	19	20.21 (3.07)	19.26 (2.38)	0.95	0.15	0.35
	WT	F	21	17.67 (2.83)	16.81 (2.75)	0.86	0.016	0.31
		M	15	19.27 (3.15)	16.93 (3.28)	2.33	0.009	0.73
REG	MM	F	35	18.63 (3.08)	17.57 (3.26)	1.06	0.003	0.33
		M	59	18.92 (2.51)	18.90 (2.13)	0.02	0.96	0.01
	WT	F	16	17.19 (2.83)	15.69 (3.63)	1.50	0.026	0.46
		M	22	18.23 (2.54)	18.36 (2.95)	-0.14	0.74	-0.05

Table 6.14: Reproduction of Table 6.8 grouping by gender in first semester.

Second semester data were not investigated for gender due to the low sample sizes and less clear results in the general findings.

Although this gender analysis confirms that there are differences between the genders, it does not suggest that the two tutorial types exhibit *different* effects on students' self-efficacy depending on gender.

6.3.5 Summary

Only the persistent students were used for the self-efficacy analysis. Separating students by course and tutorial group, all four groups experienced a decrease in self-efficacy in first semester. The decrease was only statistically significant for the Fundamentals students, and it was more severe for Workshop Tutorial students than Map Meeting students. Further analyses suggested that Map Meetings were quite consistent in increasing the self-efficacy of low-self-efficacious students and decrease the self-efficacy of high-self-efficacious students. Workshop Tutorials showed much weaker trends and did not offer as clear benefits to the students with the lowest self-efficacy. These findings were reproduced, although not as strongly, in second semester; a strong selection effect, fewer students and a wide range of experiences in first semester are likely to be the reasons why results in second semester are much less clear. An analysis considering gender did not suggest that Map Meetings and Workshop Tutorials affect females and males differently.

6.4 Examination results

Just as with self-efficacy, there are many ways to analyse the examination results. Recall that it is the final examination raw mark out of 90 that is analysed. Fundamentals and Regular students sat different examinations, so marks cannot be compared across courses. Also remember that extensive data exploration demonstrated that HSC Physics and HSC Mathematics were the HSC subjects that proved to be relevant for students' examination performance in first year university physics.

6.4.1 Comparing student backgrounds

Before comparing examination performances, students' backgrounds must be compared to investigate whether there were any academic differences between groups prior to entering university. All the following analyses were performed both for persistent students and all students.

For the Fundamentals students, HSC Mathematics was the only high school subject that impacted on their university physics examination, since these students did not study HSC Physics. Chi squared tests revealed that the distribution of students with different levels of HSC Mathematics was not statistically significantly different between Map Meetings and Workshop Tutorials. Students' HSC Mathematics marks within each mathematics level were not different either, although they neared significance when analyzing all students for the 2-unit group in favour of Map Meetings (MM: M = 81.30, SD = 6.24, N = 23; WT: M = 77.89, SD = 6.87, N = 35; $t(56)$ = 1.92, p = 0.060) and for the 4-unit group in favour of Workshop Tutorials (MM: M = 162.55, SD = 17.86, N = 11; WT: M = 172.47, SD = 10.02, N = 19; $t(28)$ = 1.96, p = 0.060).

For the Regular students, there were no statistically significant differences between the means of students' HSC Physics marks. Table 6.15 shows students' HSC Mathematics level for both the persistent group and for all students. Chi squared analyses show that Map Meeting and Workshop Tutorial students did not have similar mathematics backgrounds (persistent: $\chi^2(3, N = 212) = 10.68$, $p = 0.014$; all: $\chi^2(3, N = 281) = 10.79$, $p = 0.013$) – Workshop Tutorial students had, on average, a higher level of HSC Mathematics (see Table 6.15). Within each mathematics level, there were no statistically significant differences between HSC Mathematics examination performance, although the 3-unit students when analyzing all students neared significance in favour of Map Meetings (MM: $M = 128.13$, $SD = 9.98$, $N = 75$; WT: $M = 124.49$, $SD = 10.41$, $N = 49$; $t(122) = 1.96$, $p = 0.053$).

	Persistent students		*All students*	
HSC Mathematics	*MM*	*WT*	*MM*	*WT*
General	0	2	0	2
2-unit	24	7	35	13
3-unit	62	38	75	50
4-unit	39	40	52	54

Table 6.15: Overview of Regular students' HSC Mathematics backgrounds separated by their first semester tutorial groups.

This means that Fundamentals Map Meeting students and Workshop Tutorials students had comparable academic backgrounds, whereas in the Regular course the Workshop Tutorial students were mathematically stronger than the Map Meeting students, although there were no notable differences with respect to HSC Physics.

6.4.2 Overall analysis of examination results in first semester

6.4.2.1 Persistent students

This first section looks at persistent students' examination performance – to remove attendance as a variable – only separating by tutorial group.

Figure 6.7 shows histograms and descriptive statistics of first semester examination marks; none of the differences in means between Workshop Tutorial students and Map Meeting students are statistically significant. In general, students who achieve less than 30 marks in the final examination are at risk of failing. Other assessments (laboratory exercises, regular online assignments and two laboratory tests) do not distinguish particularly well between students – primarily because the laboratory exercises and online assignments rely on or allow for group work – although they do reflect students' commitment and effort. Map Meetings seemed to have a particularly positive influence on the students with the lowest self-efficacy, so a similar analysis was performed on the examination results.

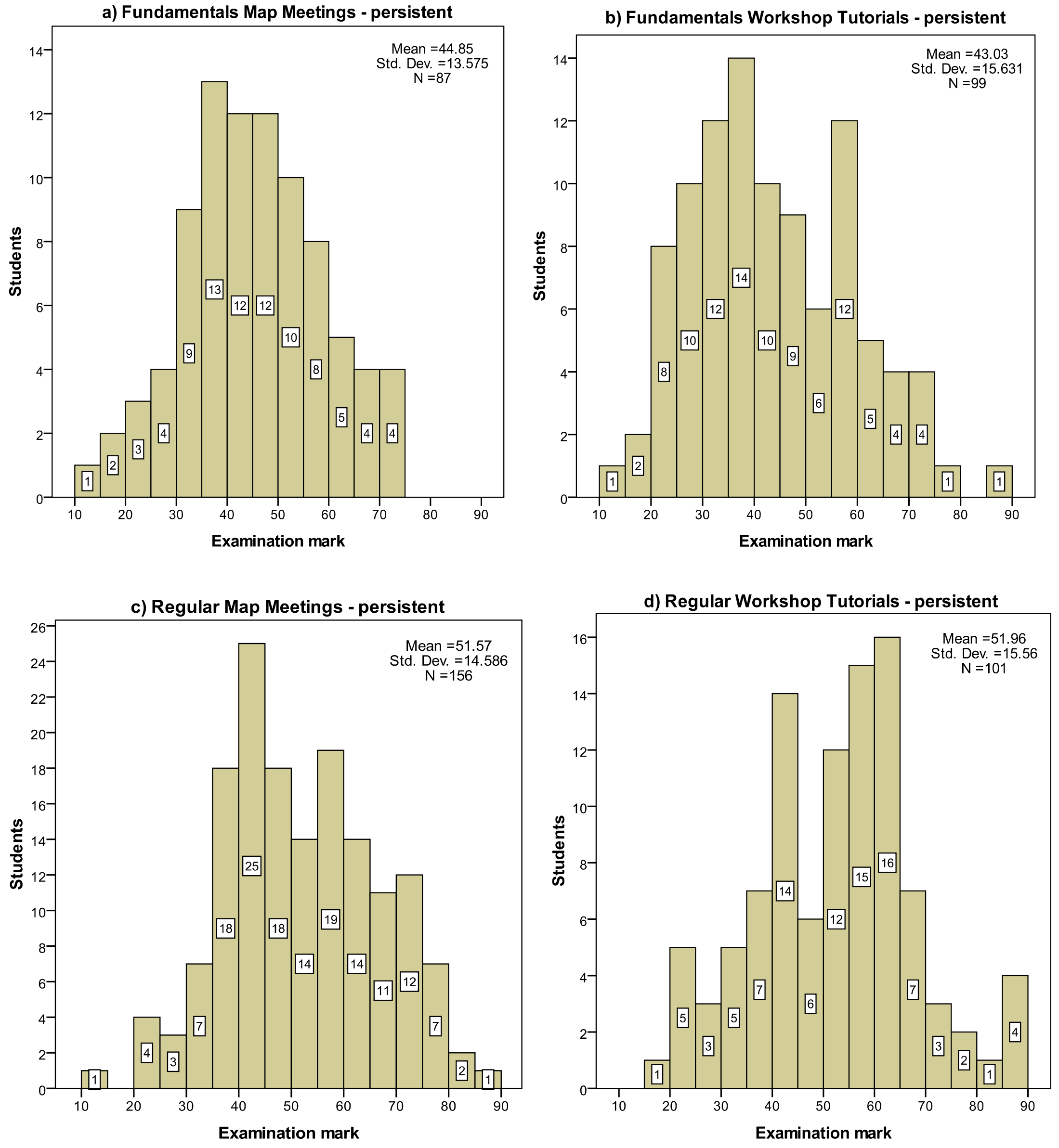


Fig. 6.7: Histograms of end-of-semester examination marks for persistent students: a) Fundamentals Map Meetings, b) Fundamentals Workshop Tutorials, c) Regular Map Meetings and d) Regular Workshop Tutorials. Note that each bin contains students who received marks from the lower mark inclusive to the upper mark exclusive.

Table 6.16 (which is based on Fig. 6.7) shows the percentages of students who fell into low, medium and high mark categories. Students in the low mark category achieved less than 30 marks and were at risk of failing, whereas the high mark category refers to students who achieved 60 marks or more. The high mark value was chosen because it represents two thirds of the total marks, while the potential fail mark is at one third.

Course	*Tutorial*	*N*	*Examination mark* *Low (< 30)*	 *Medium (30-59)*	 *High (≥ 60)*
FND	MM	87	11% (N = 10)	74% (N = 64)	15% (N = 13)
	WT	99	21% (N = 21)	64% (N = 63)	15% (N = 15)
REG	MM	156	5% (N = 8)	65% (N = 101)	30% (N = 47)
	WT	101	9% (N = 9)	58% (N = 59)	33% (N = 33)

Table 6.16: Overview of what fraction of persistent students received low, medium and high marks in the final examinations in first semester. Fundamentals and Regular students are separated by their tutorial groups.

It appears that whereas the two tutorial types were equally good at producing high scoring students, there was a real difference among the low scoring students. Almost twice the amount of Workshop Tutorial students were at risk of failing compared to the Map Meeting students. Since the distinction between pass and fail is much more important than that between a high mark and a not so high mark, Map Meetings seem to have made a difference where it really matters. The distinction between at risk and not at risk nears significance for the Fundamentals students with $p = 0.076$ when comparing the two tutorial types.

6.4.2.2 All students

A great tutorial environment that boosts students' examination marks is of no practical value if students choose not to attend. The above analysis showed that of students who attended at least 10 tutorials, there were fewer Map Meeting students than Workshop Tutorial students at risk of failing. However, perhaps several students who were at risk of failing in Map Meetings simply were not motivated to attend Map Meetings and therefore did not appear in the analysis that only included the persistent students?

Redoing the analysis with all students (except those who attended at least two of each tutorial type), the findings were not notably different. The mean examination marks were somewhat lower (by 0.19 to 2.07 marks), but the difference in effect sizes between tutorial types did not change much. For the Fundamentals students, the values in Table 6.16 did not change by more than one percentage point; and for the Regular students there were four percentage points more low mark students and fewer high mark students, without significantly altering the relative ratio between them. A chi squared analysis of at risk vs. not at risk students for the Fundamentals course revealed a boarderline significance (p = 0.056). This suggests that the motivational effects – whether students chose to attend – combined with the pedagogical effects of Map Meetings were more effective than Workshop Tutorials at preventing Fundamentals students from being at risk of failing the examination. For the Regular course there was no clear difference. In summary, the analysis of all students followed the same trend as the analysis of the persistent students, but showed even clearer results.

6.4.2.3 The teacher effect

Because I, the researcher, was also the tutorial supervisor in several of the Map Meetings, the teacher effect might be suspected to play a role – although research indicates that the instructor has minimum impact on basic knowledge gain at the tertiary level (Halloun & Hestenes, 1985). In the Regular course, the Map Meetings had two different supervisors: a fellow PhD student and me. Comparing the examination performances of the students who had each of these two supervisors, there were no statistically significant differences between the groups regardless of whether all students or only the persistent students were compared. Hence, it can be assumed that the effects seen are due to the tutorials themselves and not the tutorial supervisors.

6.4.3 The effect of HSC Physics and HSC Mathematics on university physics

Early data exploration showed that students' senior high school physics and mathematics backgrounds were influential in their university physics examinations marks. This section identifies how much HSC Physics and HSC Mathematics contributed, so that when the effect of tutorial type is included it is easier to understand their unique contribution.

6.4.3.1 Correlations

Table 6.17 shows correlations between the university physics examination marks in first semester and HSC Physics and HSC Mathematics marks. All correlations are high (r between 0.42 and 0.70) and are statistically significant (p = 0.054 is borderline significant).

HSC Physics exhibited the strongest correlation with university physics, which is not surprising. The correlation for the Fundamentals students, however, is somewhat misleading as only 16 students in this course did HSC Physics. Therefore, in the Fundamentals course, HSC Mathematics was the only relevant subject influencing university physics examination performance. Not considering General Mathematics, higher levels of mathematics exhibit stronger correlations with university physics in both courses; that the 2-unit groups show the smallest correlations for both courses may suggest that this course provided the least relevant mathematical basis for university physics students.

			HSC Mathematics			
Course		*HSC Physics*	*General*	*2-unit*	*3-unit*	*4-unit*
FND	*r*	0.70	0.53	0.50	0.53	0.58
	p	0.002	0.054	0.000	0.000	0.001
	N	16	14	63	67	31
REG	*r*	0.61		0.42	0.50	0.61
	p	0.000		0.004	0.000	0.000
	N	265	2	46	131	106

Table 6.17: Correlations between first semester physics examination marks and HSC Physics and Mathematics marks.

6.4.3.2 Multiple regression

In the Regular course, both physics and mathematics correlate strongly with the university examination. However, these two variables are themselves strongly correlated (r between 0.373 and 0.634, $p \leq 0.001$ for all the different HSC Mathematics groups). A simple two-variable multiple regression analysis showed that for 2-unit Mathematics students (N = 43), the mathematics mark did *not* contribute to the university examination mark beyond the effect of HSC Physics mark. However, for both 3-unit (N = 126) and 4-unit (N = 91) Mathematics the mathematics mark *did* contribute significantly (p = 0.000 for all correlations) beyond the effect of HSC Physics, with a predictive model explaining 38% (r = 0.62) and 56% (r = 0.75) respectively of the variance in the outcome variable. The standardized beta values for physics and mathematics were 0.42 and 0.30 respectively for 3-unit Mathematics and 0.53 and 0.33 respectively for 4-unit Mathematics. This indicates that physics is a stronger predictor than mathematics, but that 3- and 4-unit students' mathematics backgrounds contribute to their university physics performance *separately* from and in addition to their physics background.

6.4.3.3 Mean university examination marks

Figure 6.8 shows the mean examination marks for the Fundamentals and Regular students separated by HSC Mathematics. This analysis investigates the relative importance of the HSC Mathematics courses on the final examination, so only those Fundamentals students without HSC Physics and those Regular students with HSC Physics are included. Regular students with General Mathematics are excluded due to very small numbers.

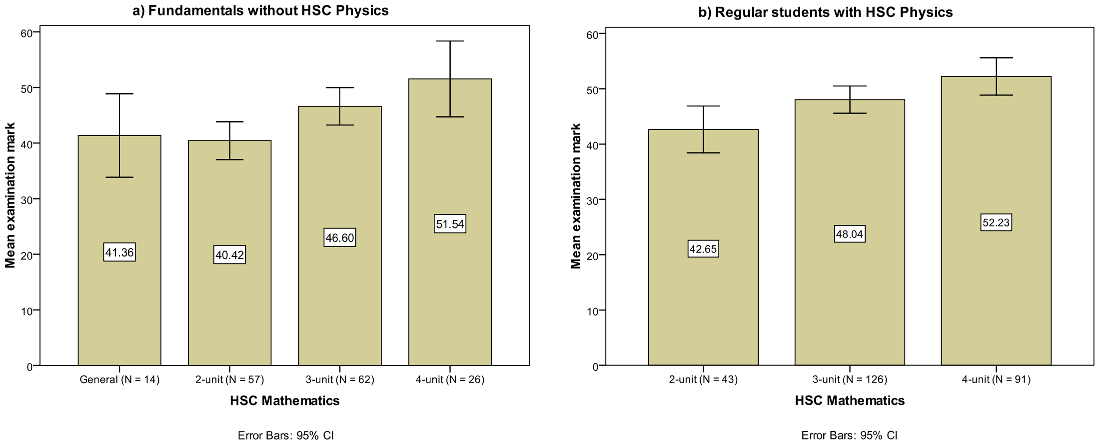


Fig. 6.8: Means of university physics examination performances splitting the courses by HSC Mathematics course.

In the Fundamentals course, the 3-unit and 4-unit Mathematics students appear to have a clear advantage over the General Mathematics and 2-unit Mathematics students (which are quite similar). An ANOVA revealed that the four groups indeed were not all the same ($F(3, 155) = 4.65$, $p = 0.004$). A Tukey post-hoc test showed, however, that the difference between the 2-unit group and the 4-unit group was the only one to reach significance ($p = 0.004$). Further, there is a trend from General to 4-unit Mathematics suggesting that a higher level of mathematics is valuable background for students without HSC Physics.

For the Regular students, the higher the level of HSC Mathematics, the higher the mean examination mark ($F(2, 257) = 6.34$, $p = 0.002$). As with the Fundamentals course, the only statistically significant difference was between the 4-unit and the 2-unit group ($p = 0.002$). Even though all students had HSC Physics, it appears that the level of mathematics is very relevant for these students as well.

6.4.4 Analysing examination marks controlling for high school variables

Because HSC Physics and HSC Mathematics significantly impacted on university physics performance, the following analyses take these high school subjects into account when investigating the effect of the tutorials. Only Fundamentals students without HSC Physics background and Regular students with HSC Physics who were persistent tutorial students are included in the analysis.

6.4.4.1 First semester physics examination result

No statistically significant differences in examination performances were seen between tutorial groups in the Regular course; in the Fundamentals course, the 2-unit and 4-unit students were noteworthy (Table 6.18).

HSC Mathematics	*Tutorial*	*N*	*Mean*	*SD*	*Sig.*	*Cohen's d*
General	MM	6	40.00	15.80	0.75	0.17
	WT	8	42.38	11.54		
2-unit	MM	20	46.35	14.03	0.037	-0.63
	WT	27	38.15	12.06		
3-unit	MM	27	46.26	10.76	0.36	0.03
	WT	26	46.62	14.57		
4-unit	MM	10	41.80	17.04	0.004	1.39
	WT	12	62.33	12.14		

Table 6.18: Mean examination marks for the persistent Fundamentals students, separated by tutorial group and HSC Mathematics course. Note that the negative value of Cohen's *d* for the 2-unit students reflect that Map Meeting students outperformed Workshop Tutorial students, opposite to the trends for the other mathematics groups.

The 2-unit Mathematics students show a statistically significant difference with a medium-large effect size in favour of Map Meetings. This suggests that Map Meetings were more helpful for these students to learn physics than Workshop Tutorials were. The real surprise is the result for the 4-unit Mathematics students in the Fundamentals course, where the Workshop Tutorial students outscored the Map Meeting students by an average of 20.53 marks! Not only were the 4-unit Map Meeting students outscored by the Workshop Tutorial students, they were also outscored by the 2-

unit and 3-unit Map Meeting students. Further analyses of this observation are carried out below in Section 6.4.4.2.

Two ANOVAs were carried out for the Map Meeting students and the Workshop Tutorial students respectively to investigate whether the mean Fundamentals examination marks differed between students with different HSC Mathematics backgrounds. For persistent Map Meeting students, there was no statistically significant difference between any the four different HSC Mathematics groups ($F(3, 59) = 0.62$, $p = 0.61$). For the Workshop Tutorial students, on the other hand, the groups were not all the same ($F(3, 69) = 9.82$, $p = 0.000$); the 4-unit Mathematics students had statistically significantly higher mean examination marks than the other mathematics groups ($p < 0.01$ for all). May this suggest that Map Meetings helped wash out the effect of prior mathematics knowledge?

6.4.4.2 Investigating the 2-unit and 4-unit Fundamentals students

The 2-unit and 4-unit Fundamentals students displayed statistically significantly different results between the two tutorial groups. To investigate these findings in greater detail, the scatter plots of examination marks against HSC Mathematics were studied.

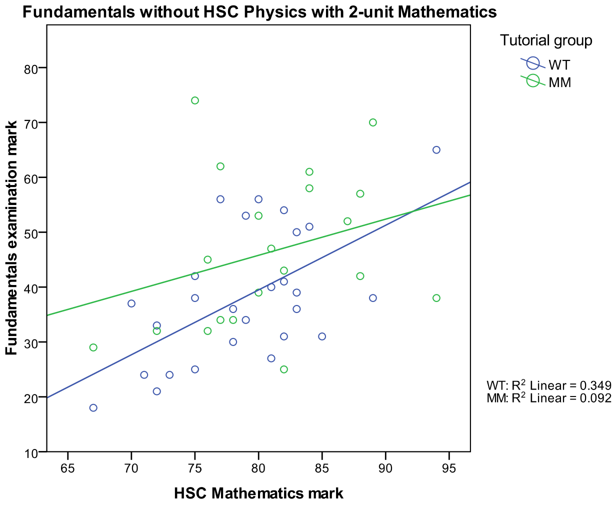


Fig. 6.9: Scatter plot of first semester examination mark against 2-unit HSC Mathematics mark for the persistent Fundamentals students without HSC Physics.

The trend lines in Figure 6.9 show that, on average, Map Meeting students performed better than Workshop Tutorial students, and the effect is greater for students with lower HSC Mathematics score. This suggests that the benefit gained by Map Meeting students with respect to Workshop

Tutorial students for 2-unit students is real, and that Map Meetings benefitted the mathematically weakest students in particular.

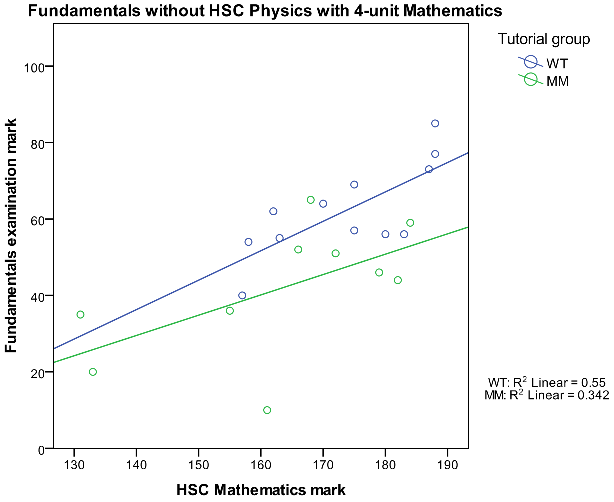


Fig. 6.10: Scatter plot of first semester examination mark against 4-unit HSC Mathematics mark for the persistent Fundamentals students without HSC Physics.

The scatter plot for the 4-unit students (Fig. 6.10) shows that the main complication with the comparison of Workshop Tutorial students with Map Meeting students is that the latter had two students with particularly poor HSC Mathematics marks. These students also performed poorly in the final first semester university physics examination. The students who are clustered in the upper right hand quadrant are more similar, even though Workshop Tutorial students, on average, did perform better than Map Meeting students. Comparing the mean marks when excluding the three outliers, however, still produced a statistically significant result (MM: M = 50.43, SD = 9.64, N = 7; WT: M = 62.33, SD = 12.14, N = 12; $t(17)$ = 2.21, p = 0.041). This suggests that for these mathematically strongest students in the Fundamentals course, Workshop Tutorials may have provided a more challenging and suitable learning environment. Note, however, that the sample size for this group was quite small. (Although the Map Meeting sample may not appear normal, it passed the Shapiro-Wilk normality test for both the 4-unit Mathematics marks and the examination scores.)

6.4.5 Gender

Separating correlations between HSC Mathematics mark, HSC Physics mark and university physics mark by gender revealed no clear trends with respect to differences between females and males.

Comparing mean examination marks for females and males separating by course (using only Fundamentals students without HSC Physics and Regular students with HSC Physics), there were no statistically significant differences between genders when analysing all students – even though it neared significance for the Fundamentals students (*p* = 0.080) in favour of males – whereas there was a difference in favour of males for Fundamentals when analyzing only the persistent students (4.84 marks higher for males: females: *M* = 41.80, *SD* = 14.19, *N* = 106; males: *M* = 46.64, *SD* = 14.99, *N* = 80; *t*(184) = 2.25, *p* = 0.026). Separating by HSC Mathematics course as well (investigating both all students and persistent students only) the only statistically significant difference occurred in the Regular 2-unit Mathematics group (11.14 marks higher for males: females: *M* = 35.14, *SD* = 7.66, *N* = 14; males: *M* = 46.28, *SD* = 14.65, *N* = 29; *t*(40.64) = 3.27, *p* = 0.002, equal variances not assumed, Cohen's d = 0.95) (significance reached both for all students and for persistent students only).

6.4.6 Self-efficacy and the examinations

An important role of self-efficacy, as portrayed in literature, is its correlation with academic performance; I therefore investigated correlations between self-efficacy (both at the beginning and at the end of the semester) with the end of semester examination in both semesters. Only students who were persistent in the semester for which each analysis was performed were included, as with the previous self-efficacy analyses. In addition, only Fundamentals students *without* HSC Physics and Regular students *with* HSC Physics were included. All analyses were performed separating by first semester course, and all combinations of separating and not separating by gender and tutorial type were carried out.

The results revealed very few trends. The Fundamental students showed no correlations, neither when analysed all together nor for any subgroups. The only clear finding was that in first semester, there were statistically significant correlations between Regular students' self-efficacy – both at the beginning and at the end of the semester – and the final examination (Table 6.19). When dividing the Regular students into subgroups, the only statistically significant subgroup was the Regular male Map Meeting students (week 3: *r*(60) = 0.32, *p* = 0.011; week 13: *r*(61) = 0.33, *p* = 0.009).

		Self-efficacy	
		Early semester 1	*End semester 1*
FND examination	Pearson correlation (*r*)	0.10	0.11
	Sig. (2-tailed) (*p*)	0.368	0.256
	N	79	106
REG examination	Pearson correlation (*r*)	0.28	0.24
	Sig. (2-tailed) (*p*)	0.001	0.006
	N	152	134

Table 6.19: Correlations between self-efficacy at the beginning and end of first semester and the first semester examination for persistent Fundamentals students without HSC Physics and Regular students with HSC Physics.

Performing the same analyses on the second semester Environmental students, keeping the Fundamentals and Regular students separate, showed no clear results. The Regular students exhibited correlations that were almost significant (week 3: $r(44) = 0.25$, $p = 0.098$; week 13: $r(59) = 0.24$, $p = 0.059$), whereas the Fundamentals students still did not show any clear correlations. Analyses of the subgroups did not yield any noteworthy results.

6.4.7 Examination results in second semester

Because there was an element of self-selection with respect to which tutorial students attend in second semester, the second semester results did not solely reflect the effect the tutorials had on the students. Whether all students or just the persistent students were analysed, there was no difference in the story told by the data.

There were no statistically significant differences between Map Meetings and Workshop Tutorials in second semester, reflecting what was seen in first semester. Redoing the analysis for certain subgroups (all students or only persistent students), splitting by second semester tutorial group or not did not, reveal much more. Neither histograms of second semester examination marks nor correlations between first and second semester examination marks showed any clear differences between persistent students in the two tutorial types. This lack of difference may suggest that students' level of competency (regardless of high school physics background) in second semester was at the level where the tutorial type did not significantly affect student performance.

The second semester data did, however, show two interesting results that are not related to the tutorials. First, there was a clear difference between the courses – Regular students outperformed the Fundamentals students (FND: $M = 44.24$, $SD = 13.43$, $N = 132$; REG: $M = 50.27$, $SD = 12.29$, $N = 128$; $t(257.14) = 3.78$, $p = 0.000$, equal variances not assumed).

Second, examination performance increased with increasing level of HSC Mathematics course, except for General Mathematics in the Fundamentals course. However, this group has very few students. The following discusses this issue.

Table 6.20 shows mean examination marks in first semester for all students and for those students who enrolled in the Environmental course in second semester (but didn't necessarily sit the examination), and mean examination marks in second semester for the Environmental course. Students are split by first semester course and HSC Mathematics.

		First semester mark for all students			*First semester mark for ENV students*			*ENV students' exam marks*		
	HSC Mathematics	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*
FND	General	14	41.36	13.01	9	45.67	11.23	9	43.22	12.71
	2-unit	63	40.32	12.48	34	43.12	13.21	34	40.03	11.78
	3-unit	67	46.85	13.06	51	46.22	12.94	49	46.22	12.52
	4-unit	31	48.16	17.74	21	47.05	17.17	18	50.22	15.60
REG	2-unit	46	41.85	13.98	15	47.00	15.26	15	47.13	11.66
	3-unit	131	47.79	13.91	58	48.41	13.05	59	49.44	10.83
	4-unit	106	53.50	16.99	41	53.73	14.28	40	51.45	14.52

Table 6.20: Descriptive statistics of examination marks in first semester (all students and only those who entered the Environmental course) and second semester (Environmental course only).

Comparing the examination marks of all first semester students with only those students who enrolled in the Environmental course in second semester, the main difference lies within the 2-unit group. There is a trend of poor-performance students to not continue on to second semester. The same is not seen for the 3- and 4-unit students. Considering first semester analyses found that students with a weaker academic background benefitted more from Map Meetings than Workshop Tutorials, the absence of many of these weak students in second semester may partly explain the lack of observed differences between tutorial types.

For the Environmental course there is a wide spread in marks for the Fundamentals students. This may reflect that those with more mathematics were better equipped to handle the pace at which the course progressed in second semester, similar to results seen in first semester for both courses. There is a very small difference in mean examination marks between the mathematics groups for the Regular students – perhaps these students had reached the stage where they had enough physics skills that their high school mathematics level was not as influential anymore, or that they had enough mathematics to cope with the Environmental course?

HSC Mathematics	*First semester mark for all REG students*			*First semester REG mark for TEC students*			*TEC students' exam marks*		
	N	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*
2-unit	46	41.85	13.98	15	45.80	10.34	19	37.84	11.32
3-unit	131	47.79	13.91	46	50.93	13.45	50	42.62	11.95
4-unit	106	53.50	16.99	42	54.93	15.69	54	42.56	13.56

Table 6.21: Descriptive statistics of examination marks in first semester (all students and only those who entered the Technological course) and second semester (Technological course only).

The Technological students exhibited a similar trend (Table 6.21): the 2-unit students achieved the lowest examination marks, whereas the 3- and 4-unit Mathematics courses appear to have been equally useful for the students in second semester.

6.4.8 Summary

Analysis of examination results showed that there were not statistically significant differences between the means of Map Meeting students compared to Workshop Tutorial students. However, when comparing students at risk of failing versus those who were not at risk of failing between the tutorial types, including all students, borderline significance was reached in the Fundamentals course ($p = 0.056$). This suggests that Map Meetings helped the academically weakest students.

Further analysis revealed that the students with no HSC Physics and 2-unit HSC Mathematics – the weakest prepared – in Map Meetings outperformed those in Workshop Tutorials. In addition, the lack of difference between Regular Map Meetings students and Workshop Tutorial students is also a positive result given that the Regular Workshop Tutorial students had a statistically significantly stronger HSC Mathematics background. This strengthens the earlier findings that Map Meetings are particularly beneficial for students with little background relevant for university physics studies.

For the remaining students, Map Meetings were found to be at least as helpful as Workshop Tutorials for learning physics, perhaps with the exception of the 4-unit Fundamentals students where the Workshop Tutorial students performed better than the Map Meeting students.

The results also showed that 3- and 4-unit HSC Mathematics contributed towards the university physics examination performance separately and in addition to students HSC Physics background, and that, on average, the higher the level of mathematics, the stronger the performance in physics at university for all courses. However, HSC Physics was still a stronger predictor of university physics mark than HSC Mathematics, as expected.

No clear trends were found with respect to gender; and analysis of correlations between self-efficacy and examination performance did not exhibit unsurprising trends. The Fundamentals students did not show any statistically significant correlations either in first or second semester, whereas the Regular students did – in line with literature stating that developing a well-calibrated self-efficacy requires several experiences with performance feedback (cf. Section 2.5.4.1).

6.5 Results of observations and discussions

The qualitative feedback on Map Meetings and Workshop Tutorials provide a valuable and detailed insight into how students themselves viewed these two learning environments. The additional observations by physics education experts add an interesting perspective where the tutorials are viewed in light of the experts' extensive knowledge of physics teaching and physics education over decades.

6.5.1 Tutorial observations

To obtain objective feedback, observations of both types of tutorials were undertaken by two physics education research experts not associated with the project – one observer for each course.

The observers were asked to comment on the level of involvement of both tutors and students, and provide an overall impression of each tutorial.

The observers reported comparable levels of tutor activity in both tutorial types, with supervisors and tutors being active most of the time. However, in both Fundamentals tutorials it was noted that the tutors did more talking than listening. No differences with respect to engagement or competency were seen, and the Fundamentals observer explicitly stated that "[a]ll three tutors appear to be well-prepared and appreciative of techniques for promoting effective learning" in the Workshop Tutorial. The only clear difference regarding tutors in the two courses was the higher tutor to student ratio in the Workshop Tutorial.

In terms of the students, the observers again found that the two tutorial courses were not notably different. The Fundamentals observer noted similar amounts of on-task behaviour, although there was a great variety of styles in group behaviour in both tutorials, with a higher level of interaction in the Workshop Tutorial than in the Map Meeting. The Regular observer also reported similar amounts of on-task behaviour, but in Workshop Tutorials many students arrived late and left early, whereas in Map Meetings all students stayed until the end. During the summary lecture, about 20% of the Fundamentals students seemed to be 'switched off', whereas the Regular observer stated that student attention during this period was 'high'. The Fundamentals observer commented that he "did not notice any group making explicit use of [the Link Map]", in agreement with the Regular observer.

Overall, two key differences between the two tutorial types were noted. First, the Map Meetings were more teacher-centred ("I was a little surprised at the amount of didactic instruction" commented the Fundamentals observer), whereas the Workshop Tutorials were more student-centred. Second, the Workshop Tutorials were more casual than the more structured Map Meetings. Still, both types of tutorials appeared valuable to both observers; the Regular observer commented about Map Meetings that "At the end several groups seemed to have an air of having achieved something" and of Workshop Tutorials that "a majority of students worked consistently, used the tutors and stayed to the end. Can you ask more?"

6.5.2 Focus group discussions and interviews

Midway through second semester, students were invited to participate in a focus group to discuss their experience with tutorials. Eleven students attended across four focus groups/interviews (a focus group technically requires at least four attendees) (see Table 6.22). Names are pseudonyms, but reflect gender, and all students were around 18 years old. Note that Belinda had no experience with Map Meetings, but was familiar with the Map Meeting materials, and Leon was not familiar with Workshop Tutorials. Students were asked to comment on the individual aspects of Map Meetings, as well as compare them to Workshop Tutorials.

Students	*Semester 1 course*	*Semester 2 course*	*Interview duration*
Andrew	FND	ENV	32 mins
Belinda	FND	ENV	
Diane	FND	ENV	
Ellen	None	TEC	15 mins
Fred	REG	TEC	50 mins
Guy	REG	TEC	
Hank	REG	TEC	40 mins
Ida	REG	TEC	
Julie	REG	TEC	
Kathryn	REG	TEC	
Leon	REG	TEC	

Table 6.22: Details of course enrollments of the eleven students who attended focus groups or interviews, and the duration of these. All names are pseudonyms.

Regardless of students' course enrollments, all focus groups and interviews produced similar comments about the tutorials. No distinction between groups is therefore made in the following discussion.

One of the clearest themes to emerge was how the students were motivated by the end of semester examination. Not once did any of the students mention issues not related to learning physics for the examination, such as personal interest or the importance of understanding physics in light of their other subjects or career. When discussing the tutorial problems, Andrew said

> If you say that they're based on past exam questions, most kids would work. Because they'd want to know how to do the exam questions, in the tute.

Ellen had such a strong examination focus that she requested ‘marking scheme’ type solutions:

> For the discussion part [of problem solutions] I want to know which part counts and why... is better, I think. Because you have a really long passage and you don’t know which part is really important and which part is not that important. (…) I think, for me, I like the type of marking scheme style of solution rather than just a passage.

Students saw how all the different aspects of Map Meetings were directed towards learning examination relevant material and this encouraged them to do work. In fact, the three Environmental students claimed that they spent more time working in Map Meetings than in Workshop Tutorials, even though there was more time devoted to problem solving in the latter. When students felt that the problems were either too difficult or not relevant, they would revert to talking to each other.

All students felt that the primary advantage of coming to Map Meetings was the Link Maps and the summary lecture. No one made it clearer than Ida how motivating the Link Maps could be.

> Ida: It’s colourful! *[Her eyes light up, everybody laughs.]* No, that’s really important! You don’t get coloured sheets anywhere else.
> Hank: Yeah, I think it’s the only subject I’ve ever had coloured sheets for.
> Ida: In the tutes, it makes you go: Oh, colours! Now I can actually do some work!

Ellen pointed out that the summary lecture provided a very important complement to the maps.

> Interviewer: What do you see as the primary advantage of coming to tutorials?
> Ellen: The primary advantage is the mind mapping.
> Interviewer: That you get the maps?
> Ellen: Yes, and that you explain everything.
> Interviewer: Ok, so with the explanation. How do you feel that it would be if you were just given the maps but didn’t come to tutorials?
> Ellen: I think would not be that helpful. I think is better to go through it step by step is more helpful than just the map.

This was seconded by Hank:

> The thing is, if you didn’t go to the tute, (…) you’d also miss out on the fact that you explain through it all. And you do some derivations on the board. You don’t have the

> opportunity to ask questions. It would still be definitely and advantage to go to the tutes [even if Link Maps had been provided on the web].

With respect to the summary lecture, all students were happy with the duration of it (10-15 minutes) and made it clear that it should not be any longer nor shorter. The summary lecture was liked for several reasons, one being that it put the students in the 'right frame of mind' for working on problems:

> Guy: I think they're actually really good at the moment, the explanations at the start. (…)
> Fred: Also, particularly if you've, you know, been lax over the weekend and not done any work, which I've pretty much been all semester, coming to the tutorials and having the recap gets you in the right frame of mind to 'brief recap, oh yeah that's right, that's what we learnt last week' and you're in the mindset to be answering the problems.
> Guy: Yeah, I think that. Cause when I went to the workshop it's just 'do it' and 'all right, what do we do now?'

The summary lecture also helped students reinforce material covered in lectures; in particular, it helped them see the connections between different elements.

> Guy: The tutes will be reinforcing what we're doing in the lectures. (…)
> Fred: The tutes can, sort of, be a good opportunity to link those concepts which, in the lectures, you may have phased in and out of concentration, so they'll be this sort of disparate collection of ideas. Whereas the tutes, brief summary, you get to make all the connections again.

Revisiting the material a few days after it was covered in lectures was important. When I asked the group of five Technological students whether Link Maps should be introduced in lectures, they strongly disagreed.

> Interviewer: Would it be better to go through the map in lectures so that you get it right at the end of a topic? Maybe even before the topic started?
> Ida: No, I think in the tutes is better because in lectures you've already listened to him or her for an hour, and if it's in a tute it's something new so it's reinforcing on a different day so you can actually remember. So you're doing physics more often.
> Hank: To have also a different person's perspective as well. With the lecturer you're only getting the one perspective on things, whereas in the tutorials maybe you're getting just a slightly different method for doing things.

> Ida: And a different speed.
>
> Leon: It's also a trivial point but, it's also a different voice after an hour. Especially if they're really monotonous you don't pick up their summary, and it's a different voice. It may be the same point, but it's refreshing.

Andrew said that if he took notes during the summary lecture, the concepts were very easy to understand, and the formulae on the map were extremely useful during the problem solving session. The lack of a formula sheet in Workshop Tutorials was given as a reason why students often stopped working in these; they simply didn't have the relevant formula. Although the provision of formulae may appear to have removed the necessity to *think* and *understand* the material, Andrew claimed this was not the case.

> There's, like, at least one question for each of them [the formulae] on the sheet, so you've just got to work out which formula goes where. (...) I know it sounds bad, like, just putting a formula into a question, but also it helps you really understand the concept behind the formula, it's not just putting the formula in. Because you just know where the formula came from, which helps you understand the concept of that question.

Whereas the tutorial problems were designed to draw on the Link Maps, students found the Link Maps a useful reference when doing their online assessments and examination study as well – they served as useful reference sheets, both for equations and quick overviews of each topic.

> Kathryn: Just a quick summary, just to look at things. It's easy.

> Guy: Yeah, they were really good for studying for the exam. (…) I'm a reader learner, so I'd go to the textbook and I'd find the right sheet for it and then, all right, so this is how they link together and you could just see it, right there. And it's just a quick refresher of what you just read or you've just summarised in your notes anyway, so yeah, they're really good to study. They're much better than just having just a massive textbook there that's just a bit too daunting.

The latter quote highlights how students – or some students, at least – used the Link Maps to see how concepts and ideas in physics linked together. As discussed in Chapter 4, the numerous links in physics is strongly related to its abstractness, and Ellen pointed out that she felt Link Maps were particularly clear and useful for learning physics:

> I think Map Meeting is really good. I think is the most helpful to learn about abstract ideas compared to other subjects. (…) for chemistry the tutor also have important parts... she'll have little notes prepared for us, but not as clear as mind mapping.

However, students only consciously saw the links within each map – they did not see how the fundament sheet allowed different maps to be linked.

> Interviewer: It's like going three dimensionally down the weeks...
> Guy: I can see that... That, honestly, that hadn't occurred to me.
> Fred: I hadn't noticed that.
> Guy: I hadn't noticed, but now I will.

Several students pointed out that tutorials were very important for learning how to solve problems.

> Guy: It's really like labs you just plug and chug, plug in numbers and you don't come away with any understanding. Lectures you just sit there and listen, and in our case we may not listen too closely. But in tutes we actually sit down and we do problems.

The mixture of problem difficulty was appreciated by the students: introducing students to a topic by giving them a relatively simple problem before a harder one was provided had a positive effect on their motivation.

> Hank: At the beginning you know sometimes you have the handwritten questions and things that are just to get into using the formulas; they're also helpful if you haven't really used all the formulas before at all. It's a good way to see a situation where you could use the formulas for. So that's really helpful.
>
> Guy: I guess the consequence of that is you, say you just skipped a lecture or you're just beginning to grasp the concept, so even if you got the sheet there, if you're still sort of learning what's going on, then starting off with an exam sort of hard question is not really the best thing to motivate people to work during the thing, so like, they see this and even if they get a tutor to come around and explain it, they say 'Aw, yeah, it's too hard, I'm not gonna bother.'

Given the strong examination focus of the students, an important difference between the problem sheets in Map Meetings and Workshop Tutorials was the inclusion of past examination problems in the former.

> Fred: I like the way also that the questions for the mapping tutorials have come straight from the exams, most of them. So there are exam style questions. So right from the beginning we're knowing what sort of stuff we'll be asked later on.
>
> Julie: It's good that they're from the past papers. In that way when we go and do the past papers, we've seen it before and we're not so scared of it.

Students also liked the large font and handwritten style of the problem sheets, whereas they disliked the layout of the Workshop Tutorial problem sheets.

> Andrew: I find it's good because you know that they've thought about the question because they've had to hand write it, whereas [in Workshop Tutorials] they could've just copied it out of a textbook without thinking that it's gonna be in the exam or these are the concepts you need to know.

Two students also commented on the lack of conciseness of many Workshop Tutorial problems compared to the Map Meeting problems.

> Ida: I prefer when there's not so much reading before you get to the information.
> Interviewer: So keep it short and sweet?
> Ida: Yeah, cause then I'm like: Yes, done, next! Instead of going: hmf, still going…
> Hank: Half an hour later, still the same one.
>
> Diane: …there's this really long paragraph of, like, these two theories of the universe, or something, and, like, we couldn't work out, like, what the answer was, and the answer was, like, no one knows, like, what the answer is. Because we don't know enough about physics yet, or something. They just have, like, stupid questions like that [in Workshop Tutorials].

Both Map Meetings and Workshop Tutorials had demonstration questions, but these were generally disliked, primarily because students were not interested, had seen them before in lectures, didn't want to wait for the demonstration to become available or had experienced that they had not worked as intended in the past. Several students said they usually ignored the demonstration problems or simply guessed what they expected to see.

> Ida: We see it in the lectures, (…) it's kinda like: Seen that. (…) And even if you don't know what happens, often it doesn't work, so you've got to read the textbook definition anyway. Here's physics, this is what it's *supposed* to do.

Of all the topics discussed, group work received the most mixed response. Some students thought it was very useful, whereas others felt that they learned less because they ended up talking about other things.

> Julie: When you're in a group you can help each other out. That's the main thing.
> Ida: And it's less awkward. In the maths one you have to ask someone to help you out, so you're often inclined to just sit there.
>
> Belinda: I find it easier to just work through it myself and just do it at my own pace. Whereas with the group I just talk to them about other stuff.

Most importantly, however, students acknowledged that there were individual differences and appreciated the ability to make their own choices as to how to use their time in Map Meetings.

> Guy: In theory, the idea of having groups (…) is good, but when it comes down to it you really end up just talking together. I think group work is good, but it has its limitations.
>
> Ida: I'd say it'd be detrimental to the other three that you sat with if you've got someone there who's not working. *[All nod]*
> Hank: If they're just sitting there.
> Ida: No, just sitting there would be better than distracting.
> Interviewer: Yeah, I know there are a lot of people who sit by themselves, and they actually get a lot of work done. But they don't have the support of the group if they get stuck.
> Ida: That's also a personal choice. Lots of people don't like group work.
> Interviewer: Do you think it's a good thing that people can sit by themselves if they want to?
> *[All say yes and nod.]*

All students agreed that tutors must be approachable, knowledgeable and clear, but they differed in their preferences for whether they wanted Socratic dialogue or 'just-in-time' teaching.

> Interviewer: I'm interested to know what makes a good tutor.

> Leon: Someone who knows what their talking about.
>
> *[All agree.]*
>
> Julie: Or they can explain. Sometimes they try to explain, but…
>
> Ida: Clarity.
>
> Hank: Also being a bit friendly, so I don't feel like: Oh, do I have to ask a question… But not overfriendly.
>
> Ida: My maths tutor is like, 'I don't want to ask you, you just wanna talk to me and smile funny.'
>
> Hank: But they still have to be somewhat friendly.
>
> Ida: Approachable. Rather than friendly. (…)
>
> Interviewer: What about the way they answer questions. (…)
>
> Ida: It depends how much you know when you ask the question. Because when you get repeated something, you just say 'yep'.
>
> Leon: Bits and pieces leads to thinking more. But then again, if you have no idea, people tend to just sit there and wait for the answer. And, I think, if he/she explains the answer, someone else and another student will see a line and figure out: ah, I know how to do it now, and they'll just do it themselves. So I think you'll probably better off to give the whole answer. (…)
>
> Ida: You've also got to ask the question the right way, because when you do have no idea and the tutor's asking you a question, you're like: 'I don't know, that's why I'm asking!' type issue, which was the other physics tute type [Workshop Tutorials]… 'Stop asking *me* questions.' I wouldn't ask if I didn't know.

Although the students liked the tutors, some students found that the tutors did not always appreciate the problems they faced, in particular with respect to mathematics knowledge.

> Andrew: They're really good, but they just need to come down to our level, maybe. Of understanding. (…) I'm not very mathematically minded, but people can just, like, look at a formula and work out, you know, why things are, like, where they are. Apart from me... I need concepts, but that's because I haven't done physics in year 12 and stuff.

Students were generally positive towards the plenary session. However, if a problem was discussed that the students had already understood, they would not pay attention.

> Interviewer: Going through the problem at the end, is that helpful?

> Fred: If it's a problem that's been tricky – yes. (…) If it's a problem that's, in a sense, basic, or that we consider basic, you're like, you sit there wondering why they bother explaining it.
>
> Guy: I think the hardest one is definitely the best one to go through. Because that's the one people are gonna have trouble with. The people, if they are interested, then they will listen to find out. Because if they (…) could just do it, they're like 'all right, we won't listen.'

Seeing a different way of approaching a problem that they had already worked on was considered most useful.

> Interviewer: The way I go through a problem at the end, how does that work, is it useful? What's useful about it?
>
> Ida: The fact that often there's different ways to do the problems. Often you [reflecting herself] might have done it one way and you do it an easier way, and then 'Oops'. It saves so much more time. It's another approach.
>
> Interviewer: And do you think it's good that I go through the problem after you have actually tried it out yourself?
>
> *[All nod.]*
>
> Hank: Yep, definitely. (…)
>
> Ida: Yep, cause maths (…) go through the problems before you even try them, and… argh, let me try first, cause then you've already got the idea of how they do it, not how you'd do it.

Still, they acknowledged that which problems students had solved during the tutorial varied, so the plenary session would not benefit all equally. Students found the solution sheets in both types of tutorials useful – if they actually looked at them, which not all did. In particular, students liked how they could understand the question by reading the solutions, had they not initially understood it.

When asked how Map Meetings could be improved, the students did not have many suggestions. However, they did request more than two tutors in Map Meetings, receiving the Link Maps at the beginning of the tutorial so they could make annotations during the summary lecture and said that in some cases it would be beneficial with even more explanations on the solution sheet.

The overall verdict was that Map Meetings were very well liked, and all students who attended focus groups preferred them over Workshop Tutorials because they felt a greater sense of purpose in Map Meetings. Several students who had been allocated to Workshop Tutorials in second semester had even made efforts to change their tutorial times.

> Interviewer: What would you say is the main difference, the most important difference between the two types of tutorials?
>
> Andrew: You know what you have to do in the Map Meetings, and you don't really know what you have to do in the [Workshop Tutorials]... Well, you know you have to answer the questions but you don't know what to use and how and how to do it, and the concepts behind it.
>
> Belinda: Yeah, you don't know *why* you're doing it.

Students clearly liked the structure and scaffolding the Map Meetings provided. Fred pointed out that such scaffolding was particularly helpful for novices – using the plenary session as an example.

> Particularly in first semester when (…) most people don't quite know how things are handled. Seeing how the answer's supposed to be laid out could be really useful. And the techniques that are included in that.

Compared to tutorials in other subjects, Map Meetings also received high praise.

> Fred: Physics is probably the one I enjoy more than the others… (…) Maybe it's a bit to do with the group thing because… and the way it' structured… it has a good balance between structure and just being able to do what you want.

In the end, however, the effectiveness of tutorials depends largely on the individual students' willingness to learn; there is only so much the tutors can do.

> Fred: If the motivation for turning up is to get the sheets I think there's gonna be a bit more that they'll get. Depends how keen they are to get involved with whatever happens. I mean, if you're not keen to work you're not going to work, if you're not keen to listen, you're not going to listen.

6.5.3 Short answer responses in questionnaire

The questionnaire handed out in tutorials in the last week of first semester contained two short answer questions: *If you attended at least one of each type of tutorial offered this semester (Map Meeting and Workshop Tutorial), which style did you prefer, and why?*; and *What have you liked/disliked about the type of tutorial you are attending today?* Table 6.23 shows an overview of the responses. Note that most students who responded to the first question had not attended both types of tutorials, which may explain why the student preference is strongly biased.

	FND		*REG*	
	MM	*WT*	*MM*	*WT*
Total	74	34	103	34
Question 1	35	8	24	7
Question 2	71	31	98	31
Prefer MM	30	0	21	3
Prefer WT	4	8	3	3

Table 6.23: Overview of responses to the two short answer questions in the questionnaire at the end of first semester. Not all students responded to both questions. In some cases, even though students responded to the first question, they indicated no clear preference for either tutorial type.

Only eight students in the Fundamentals course and one student in the Regular course had clearly attended both types of tutorials and could thus provide any informed feedback on which tutorial type they preferred. Of these students, seven preferred Map Meetings (six Fundamentals students and one Regular student) whereas the remaining two preferred Workshop Tutorials. The following quotes are representative of the first group.

> Definitely the Map Meeting, as it made physics make so much more sense than the Workshop Tutorial, as everything was explained really basically so that it was easily understood, which then helped in being able to apply it to the problems. Also, the Workshop Tutorial questions were often too hard, especially when you don't fully understand the concepts. (FND)

> Definitely mapping as the concepts were discussed prior to the questions to remind you of the concepts. They presented the concepts in logical and really well-presented manner. They were very very helpful. The problem in [Workshop Tutorials] seem too difficult and the tutors quite often say "this is a tough question don't worry too much". (FND)

> Workshop tutorials are hopeless, I would much prefer [Map Meetings], the mind maps would allow us to have a better overview of the topic and as such apply the theory to questions. Workshops did help to some degree, but mind maps would be better. (REG)

However, one of the students who preferred Workshop Tutorials provided an important reminder that one size does not fit all.

> [I preferred] Workshop: mind maps aren't useful to me. I prefer working through questions, and identifying where my weaknesses are. (…) [I]t would be better to work through the problems and then build a mind map, rather than the reverse. (FND)

When asked about what they liked or disliked about the tutorial they were attending when filling in the questionnaire, the responses overwhelmingly targeted what the students had liked. Table 6.24 shows how many times each tutorial feature was mentioned. Note that the students were not prompted to mention any feature in particular and could list as many or as few as they liked.

	FND				*REG*			
	MM		*WT*		*MM*		*WT*	
	Like	*Dislike*	*Like*	*Dislike*	*Like*	*Dislike*	*Like*	*Dislike*
Link Map	47	0	N/A	0	63	0	N/A	5
Summary	27	1	N/A	4	34	4	N/A	1
Group work	3	0	12	0	10	0	4	0
Tutors	10	0	8	0	10	0	5	1
Problems	9	0	7	2	6	0	4	4
Demonstrations	1	0	3	2	2	2	0	1
Plenary/Solutions	8	0	0	0	3	2	0	0

Table 6.24: Overview of student feedback regarding individual aspects of tutorials. Note that several students in Workshop Tutorials requested that they be given maps or 'formula sheets' and that there be a summary lecture at the beginning of the tutorial; these appear under the column 'dislike' because students disliked the lack of these features in the Workshop Tutorials.

In both Fundamentals and Regular Map Meetings, students primarily mentioned the Link Maps and the summary lecture – both of which are strongly scaffolding activities.

> I like the maps/handouts that were given. Info is presented graphically, in colour and is easy to interpret and nicer to look at than a plain block of text or equations. (REG)

> The maps are extremely helpful. The good use of colours make it clearer. (FND)

> The maps are a good study guide as they give an easy summary of concepts and formulas and how they are integrated. (FND)

> Contentwise [the map] is perfect as it is not too brief and not too complicated and cluttered. (FND)

> The map provided simple and essential summaries that provided guidelines to approach problems. (FND)

> I have liked the summary lecture as it is very helpful to consolidate what I have learned through week. (REG)

> The explanation of concepts and lecture material at the beginning of the Map Meeting tutorial was so incredibly helpful, as before I was really struggling to get my head around it all but now it makes so much more sense, and is easier to apply to the physics problems. (FND)

Interestingly, the majority of the negative feedback provided by Workshop Tutorial students also referred to these features: several students requested that Workshop Tutorials have Link Maps or 'formula sheets' and that a tutor give a brief summary of the weekly topic prior to working on the questions. In fact, of the Workshop Tutorial students who had never attended Map Meetings several mentioned that they would like more structure in the form of a summary lecture at the beginning and/or going through a problem at the board at the end:

> It is good to be able to work in a group and solve problems together. But the tutorial needs a bit more structure, it would be better if the tutors revised lecture material with us and then worked through the problems. (FND)

> I prefer the demonstrators write something on the board first eg. (review of lessons, what we should have learnt, formulas, etc…) before we start the tutorial. (FND)

> [P]erhaps some general explanations of an approach to answering the specific questions because sometimes it is difficult to know where to begin. (FND)

> I am in the Workshop tutorial and dislike the way it is structured. I have heard the mapping tutorial is more useful as it makes the problems clearer to understand. (REG)

Of the remaining tutorial features, group work and the tutors received positive feedback – even though some Map Meeting students requested more tutors. Students were particularly appreciative of tutors who took the time to explain concepts simply and clearly until students had understood them.

> I really enjoy the tutors, they really help me grasp concepts. (FND, WT)

> The tutors are really helpful and explain things really clearly. (REG, WT)

> Tutors were very helpful and changed my attitude towards the subject. (FND, MM)

> If I have a question the tutor answers in a very simple way. (FND, MM)

> Tutors are very patient and explain concepts thoroughly and until it is understood. (FND, MM)

In Workshop Tutorials the problem sheets received both positive and negative comments. The negative comments primarily referred to the questions not being clear enough or not appearing to be relevant.

> Many problems are irrelevant for exam preparation. (FND)

> Sometimes the questions don’t make much sense. (REG)

> The questions can be misleading at times. I believe the tutorials could improve if more practical questions that were exam style could be given. (REG)

The demonstrations received very little mention, and when they were mentioned, the comments were just as often negative as positive. Comments about the demonstrations usually targeted that students had seen them before, they were too complex or simply didn’t work.

> Many [demonstrations] were inferior versions of those seen in lectures. (REG)

> The demonstrations [are] either so easy there's no point getting up or so irrelevant/complex it seems too much effort. (FND)

As an aside, even though there were more responses from students in Map Meetings than Workshop Tutorials, I was surprised to find that more students in the former mentioned that the tutorials were 'interactive'. Whereas the Fundamentals observer had commented that Workshop Tutorials were more interactive, five students in Map Meetings compared to only one Workshop Tutorial student mentioned this word.

> [Map Meetings have] more interactive learning between students and tutors, more effective teaching style [than Workshop Tutorials]. (REG)

6.5.4 Other qualitative feedback

Other qualitative feedback about the tutorials came via emails and the Student Staff Liaison Meeting at the end of the semester. Through emails (as well as verbally) several Workshop Tutorial students asked if they could receive the material handed out in Map Meetings.

> I was involved with the mapping tutorials last semester and found the maps that were handed out each week really helpful in terms of studying for the exams. This semester I'm in a workshop tutorial, and so don't get the maps each week. Is there some way we could get the maps if we wanted to? (Email from student, August 2007)

All such requests were denied to try to keep the two tutorial groups as separate as possible. The extent of these requests is unknown, but physics students generally work together outside of class, and in particular in the residential colleges at the university, there is a strong culture of sharing any material that may be useful for peers. It is therefore uncertain how many Workshop Tutorial students ended up with the Map Meeting material, which could reduce the contrast between the two groups.

In the Student Staff Liaison Meeting at the end of the semester, two students from each course are invited to provide feedback on the course. In the Fundamentals course the feedback on tutorials was very positive towards Map Meetings, which were referred to as 'fantastic'.

> [The tutorial supervisor] clearly explains things prior to starting and revises essentials and runs through difficult problems at the end. I have found them better than the lectures!! I can learn and remember so much more from them. And in comparison to the [Workshop Tutorials] they have been far more beneficial.

6.5.5 Summary

What emerges most clearly from the qualitative feedback is the overwhelming student preference for Map Meetings, due to the Link Maps and the summary lecture. The structure these features bring is emphasized and many students in Workshop Tutorials explicitly requested maps and summaries. However, the Workshop Tutorial-like problem solving session with the associated group work was also essential to the tutorials. Students frequently commented that the Link Map and summary lecture were very useful *for solving problems*, so although the problem solving session was not mentioned as much, Map Meetings would have been far less useful without it.

Nearly all the negative comments from students concerned the lack of structure across different features. The criticisms of the Workshop Tutorial problem sheets targeted unclear, longwinded or seemingly irrelevant problems, and the criticisms of the demonstrations similarly referred to demonstrations that did not work, had been seen before or were not tried out and explained in a structured way.

Still, individual choice of whether to work in groups or alone, which problems to work on, when to talk to tutors, etc. was pointed out as valuable, especially in the focus groups and interviews.

Consequently, the qualitative feedback reveals that students want a tutorial learning environment that is balanced between structure and individual freedom. However, note that this seemingly substantial difference in student preference was *not* evident to the observers, who commented that both Map Meetings and Workshop Tutorials appeared to be valuable learning environments.

7 Discussion

In this chapter I first tie together the findings reported in the previous chapter. These will subsequently be discussed with respect to literature. The third section reflects on and summarises the study, whereas the fourth section discusses further work. The final section is a metadiscussion reflecting on Education and Physics and the interdisciplinary realm spanning the two.

7.1 Summary of findings

The main difference between the two tutorial types was that Map Meetings were much more scaffolding than Workshop Tutorials. First, Map Meetings had a clear time and activity structure, which was controlled by the tutorial supervisor – the tutorial began at five past the hour with the summary lecture, which was followed by a relatively informal problem solving session, and was concluded by the tutorial supervisor discussing an issue with the whole class. Hence, whereas Workshop Tutorials were completely student-centred, giving the students control of when to arrive and leave, Map Meetings had a *balance* between student- and teacher-centred activities, where the student-centred part of the tutorial – which was similar to Workshop Tutorials – was bounded by teacher-centred activities. Second, each part of the Map Meeting was also clearly scaffolding. The Link Maps were scaffolding with respect to the students' existing knowledge structures, clearly and coherently presenting a relatively large amount of physics knowledge. The summary lectures discussed the map section by section and brought students to the often abstract knowledge on the map by giving them concrete examples. Although the problem solving session was student-centred, this activity was also strongly scaffolding: the problem sheets contained a mixture of simple and complex problems so that students were introduced to using the relatively new information through a simple problem before they were expected to combine several pieces of knowledge to solve a more complex problem. Lastly, the topic and presentation of the plenary was also carefully scaffolding: information considered to be useful to extend students' knowledge was discussed in such a way that students could follow the explanations and logical links made.

Students liked the level of scaffolding in Map Meetings, and the higher attendance in Map Meetings across all four courses appears to be a direct consequence of this. Permanent swaps were observed from Workshop Tutorials to Map Meetings, whereas there were no swaps the other way, and student interviews confirmed that at least some of these swaps were deliberate. In particular, swaps were prevalent among students who had been in Map Meetings in first semester and were allocated to Workshop Tutorials in second semester. Qualitative feedback revealed that Map Meetings were preferred primarily because of the Link Maps and the summary lecture. Students liked the structure these features brought to the tutorial environment, and several students in Workshop Tutorials who did not have any experience with Map Meetings independently requested such scaffolding activities. In the more structured Map Meetings, students felt a stronger sense of purpose: they knew *what* they were doing and *why*.

The same reasons that increased the attendance at Map Meetings are likely to have contributed to the positive effect on self-efficacy. When students felt that they understood the material and managed to solve the weekly problems, including past examination problems, they felt more confident in their ability to pass the examination. Separating students by stream and tutorial group, all four groups experienced a decrease in self-efficacy in first semester. The decrease was only statistically significant for the Fundamentals students, however, and it was more severe for Workshop Tutorial students than Map Meeting students. A similar decrease was not seen in second semester; there were no statistically significant changes, but all groups except for the Fundamentals Workshop Tutorial students exhibited a small *increase* in mean self-efficacy.

Comparing the two tutorial types, Map Meetings quite consistently helped low self-efficacy students increase their self-efficacy and high self-efficacy students decrease their self-efficacy somewhat; as indicated in the interviews, Map Meeting students had a more realistic view of the final examination by the end of the semester because of their experience with past examination problems. Workshop Tutorials showed much weaker trends and did not offer as clear benefits to the students with the lowest self-efficacy. These findings were reproduced, although not as strongly, in second semester; a strong selection effect, fewer students and varying levels of tutorial experiences in first semester are likely to be the reasons why second semester results are less clear.

Even though students preferred Map Meetings and students *felt* that these tutorials prepared them better for the examination than Workshop Tutorials did, there were no statistically significant differences between the mean examination marks of the two tutorial groups in any course. However, when investigating students at risk of failing, some interesting results were found in the Fundamentals course. Of the persistent students, fewer Map Meeting students were at risk of failing compared to Workshop Tutorial students – a nearly statistically significant result. However, when *all* students in the Fundamentals course were included, boarderline significance was reached ($p =$

0.056). This indicated that the *combined* motivational and pedagogical effects of Map Meetings resulted in fewer (indeed half the number of) students at risk of failing the course in which students had the weakest academic background in terms of physics. A similar effect was not found in any of the other courses, but it should be noted that there was no difference in examination performance between Regular Map Meeting students and Workshop Tutorial students even though the Regular Workshop Tutorial students had a statistically significantly stronger HSC Mathematics background.

Further investigating the effect of students' academic backgrounds showed that senior high school physics and mathematics performances positively, strongly and statistically significantly correlated with performance in first semester first year university physics. HSC Physics correlated more strongly than HSC Mathematics for the Regular students (the Fundamentals students did not have HSC Physics), and a multiple regression revealed that 3- and 4-unit Mathematics contributed towards the first semester university physics examination mark separately and in addition to HSC Physics. Mean examination marks for each mathematics group further revealed that the more HSC Mathematics units students had taken, the higher the mean university physics examination mark both in the Fundamentals and Regular courses. Further analysis revealed that the students with no HSC Physics and 2-unit HSC Mathematics – the weakest prepared – in Map Meetings outperformed those in Workshop Tutorials, strengthening the earlier findings that Map Meetings are particularly beneficial for students with little background relevant for university physics studies. For the remaining students, Map Meetings were at least as helpful as Workshop Tutorials for learning university physics, perhaps with the exception of the 4-unit Fundamentals students where the Workshop Tutorial students outperformed the Map Meeting students.

Gender was not a major focus in this project, and no clear trends were observed with respect to this variable in terms of performance. With regards to self-efficacy, males consistently exhibited a higher self-efficacy than females, but there was no indication that the tutorials affected the genders unequally. This lack of difference suggests that neither type of tutorial was more beneficial for one gender than the other.

7.2 Findings and theory

Having summarized the findings, it is time to return to the literature to explain the results and reflect on how the outcomes of this study may further inform literature.

The results clearly indicate that the higher attendance at Map Meetings was directly related to their stronger scaffolding. To understand why this is the case, we draw on theory. Map Meetings are more scaffolding because they manage the cognitive load imposed on students in various tasks. Qualitative feedback stating that the Link Maps were 'simple' and 'clear' and the summary lecture was 'easy to follow' suggests that students stayed within the limits of working memory. Conversely, in Workshop Tutorials students said they 'didn't know where to start' or the problems were 'hard', 'complex' or 'confusing' – indicating very high cognitive load or cognitive overload. When cognitive load was managed, students felt that they understood the material that was covered and worked with; as a result, they were more likely to *perceive* the tutorials as beneficial learning environments, which, however, did not necessarily correspond to how useful they proved to be for their examination performance. Given the strong focus on the final examination, this presumably motivated students to attend tutorials.

However, if Map Meetings successfully reduced cognitive load, why did we not see a clearer improvement in examination performance for all students? Recall that the cognitive load imposed by the different activities in Map Meetings differs for different students depending on their existing knowledge structure. This is supported by the observation that a real effect in examination performances between tutorial types is only seen among the academically weakest students – and potentially the very best students. These two groups of students display opposite trends – Map Meetings are more beneficial for academically weaker students, whereas Workshop Tutorials are possibly more beneficial for the academically strongest students. This is in line with the expertise reversal effect: teaching methods that are beneficial for students with low levels of knowledge can be detrimental for students with higher levels of knowledge.

Although avoiding cognitive overload is necessary to learn, it is not sufficient. Ultimately, learning is an individual active constructive process, and although educators can do much to facilitate the learning process, alteration of long-term memory can only be done by the students themselves. Management of cognitive load affects working memory, which may – but is not guaranteed to – lead to learning. In fact, presenting material to students in a way that is easy to follow may incorrectly lull students into a false sense of security thinking that they have learnt and understood the material when they have not. This may explain why the strongest Map Meeting students performed somewhat worse in the final examination compared to the strongest Workshop Tutorial students.

The amount of knowledge covered in the first year syllabus is quite extensive and requires countless hours to be learnt. Recall from Section 2.5.2.2 that ‘expertness’ is strongly related to the amount of principled knowledge and specific problem states stored in schemata in long-term memory. Given the limited capacity of working memory, generating such sophisticated schemata or knowledge structures is necessarily time consuming, regardless of how efficiently students use their time. Link Maps present each topic in the first semester course in a very integrated way to help form principled knowledge. However, the specific problem states are primarily learnt by solving problems to build a diverse and extensive set of exemplars. All physics educators know that while some students ponder physics problems on the bus, others don’t even pay attention when they are in physics lectures. The total amount of time students spent working with physics and the efficiency with which this time was used was not measured in this project and may not even have been possible to measure. Students may have learnt more efficiently in Map Meetings than Workshop Tutorials, but this effect is likely to be swamped by the time spent learning outside tutorials. An unavoidable consequence of longitudinal naturalistic studies like this one is that all relevant variables are not perfectly measured or controlled; theoretical accounts of learning therefore become all the more important to understand the observations.

In this study, Map Meetings were more motivational for students as seen by the higher attendance rates. However, just like management of cognitive load, neither motivation nor tutorial attendance directly produces learning; they only increase the likelihood that learning may occur. Attendance does not necessarily mean that students engage with the material, and some students may have chosen to not attend because they felt they could study more efficiently outside the tutorial. Still, students are, overall, more likely to learn when they are in the tutorial than not. Consequently, it is important that tutorials are motivating enough for students to attend them. A pedagogically excellent tutorial is of no use if no students attend. However, it is important to realize that these are two separate features of tutorials. Although it is the combination of the two that are relevant to consider in practice, they should also be studied independently to evaluate the features of each theoretically.

Whereas neuroscience and cognitive psychology provide valuable insights into the individual’s constructive learning process, Alexander’s Model of Domain Learning views the learner with a wider lens within the educational environment. The MDL considers the interplay between prior knowledge, interest and strategic processing. Prior knowledge corresponds to the state of long-term memory; interest is an aspect of motivation that encourages students to spend time learning. Interest increases with increasing levels of prior knowledge: rarely is one interested in something one knows hardly anything about. Consequently, students with low prior knowledge require stronger external motivation. This may have contributed to the improved performance of the academically weakest Fundamentals students – the low-performing students benefitted significantly from Map Meetings because they had very low personal motivation. Strategic processing concerns how to learn new material, which corresponds to metacognitive knowledge in Bloom's revised taxonomy – i.e. *how* students use their working memories. Novices in particular need to be taught which strategies to apply for effective learning. In the plenary session of Map Meetings, such metacognitive knowledge has a particular focus as part of scaffolding students' knowledge, but also when interacting with tutors, in both types of tutorials, the students implicitly learnt what strategies experts use.

This project strongly supports the current standing in constructivist discussion: it is not a debate of teacher-centred vs. student-centred learning that is relevant; it is to find the right *balance* between teacher- and student-centred activities. However, as is clear from both cognitive load theory and the Model of Domain Learning, what constitutes the optimal balance depends strongly on prior knowledge. I agree with Sweller and his colleagues that in addition to searching for the right balance, we must aim to theoretically explain why various activities work and are more beneficial than other alternatives. To explain practices theoretically, the description of knowledge and of how new knowledge is learnt and stored are practical and useful. However, it must be emphasized that they do not represent a complete and exhaustive theory. Further research into the development and refinement of theory for education is necessary.

This project sheds some light on the question of what level of scaffolding is optimal at different levels of student competency. As proposed by both Alexander and Sweller and colleagues, the greater the competency, the lower the necessary scaffolding. However, no quantitative details are offered, for good reason, given that it is impossible to accurately quantify a person's level of domain knowledge. However, this study suggests that the level of competency for which a strongly scaffolding tutorial environment is *more* beneficial than a relatively minimally scaffolding one (left-most part of Fig. 7.1) is relatively low in tertiary education. As indicated by the results in this experiment, students with the lowest level of mathematics benefitted most clearly from Map Meetings as compared to Workshop Tutorials. For most students in this study, however, the two tutorial types were *equally successful* at helping students learn. Where the minimally scaffolding tutorial environment was more beneficial than the strongly scaffolding environment appears to lie amongst the top performing students – the 4-unit Fundamentals students. This is not surprising. Whereas the academically strongest students *with* HSC Physics enrolled in the Advanced course and therefore were not part of this study, the academically strongest students without HSC Physics still enrolled in the Fundamentals course and *were* part of the study. Most Advanced students were expected to have a high school background similar to or stronger than the strongest students that were part of this study. This was the original reason behind excluding them from the study: they were expected to benefit more from a less scaffolding environment. This assumption is in agreement with the findings in that the academically strongest students do better if they have attended Workshop Tutorials than Map Meetings. What must be noted, though, is that the scaffolding appeared to be preferred by students at a higher level of competency than where a clear effect on the final examination performance was detected. This may have significant positive effects on factors not measured, such as attitude towards physics and choice of further studies.

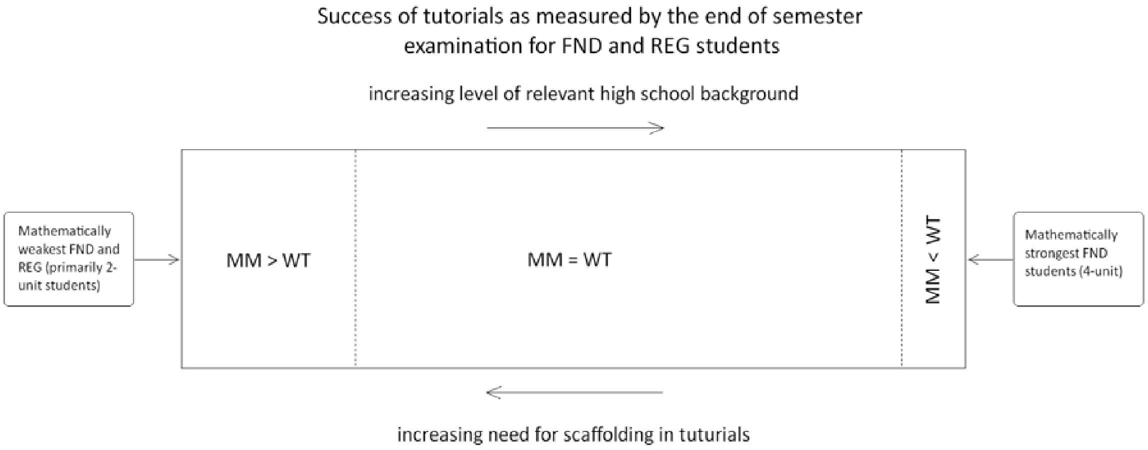


Figure 7.1: Schematic presentation of the success of the two different types of tutorials as measured by the end of semester examinations in first semester. The mathematically weakest students benefitted statistically significantly more from Map Meetings, whereas the mathematically strongest students benefitted most from Workshop Tutorials.

The implication for learning and teaching from this study is first and foremost that educators must carefully consider the level of competency their students are at when they choose learning environments and strategies. One size does not fit all. A corollary is that the range of competencies in one class should not be so large as to span groups who would benefit from different types of learning environments, i.e., this study supports streaming of students with respect to prior knowledge as is done in the School of Physics at the University of Sydney.

7.3 Ex post facto

Ex post facto is Latin for *after the fact*; with the wisdom of hindsight the project is further illuminated. This section discusses the strengths and limitations of the study, the flow-on effects the project has had and ends with an overall summary of my work.

7.3.1 Strengths and limitations of the study

The lack of truly randomized treatment and control groups was unfortunate, but unavoidable. On the other hand, the naturalistic setting of the experiment is also a strength because the results represent how students act in a *real and extended* learning situation – which is where such environments as Map Meetings are meant to be implemented – rather than an artificial and contrived laboratory experiment in which the students are not invested for the reasons intended for such an environment.

Another limitation is the lack of a clear boundary between the two tutorial environments. Due to the naturalistic nature of the study, it was impossible to guarantee that students in Workshop Tutorials did not acquire Map Meeting material outside of the tutorials, and that Map Meeting students did not get the Workshop Tutorial sheets. This primarily reduces the validity of the comparison of examination marks if a considerable fraction of the Workshop Tutorial students acquired and used the Link Maps in their examination preparation.

A third limitation is the potential confounding factor of the Hawthorne effect: that my presence in Map Meetings (but not in Workshop Tutorials) may have affected the results of the study. Although this cannot be completely ruled out, recall that students in their feedback primarily referred to the tutorial structure (rather than the tutorial supervisor) when highlighting which aspects of the tutorial they liked, and that in the objective observation of both types of tutorials the observer did not note any difference between the enthusiasm or quality of tutors in the two different types of tutorials. In addition, there was no statistically significant difference in mean examination marks between my Map Meeting classes and the other Map Meeting supervisors’ classes in the Regular stream.

7.3.2 Flow-on effects

After the full one-year trial of Map Meetings in 2007, the School of Physics decided to replace Workshop Tutorials to let Map Meetings be the only tutorial type offered in the Fundamentals and Environmental courses. Halfway through 2010, Map Meetings are still very popular with the students and enjoy better attendance rates than the other courses. To ensure that Map Meetings will continue to be run and supervised as originally intended, Associate Professor John O'Byrne – an astronomer and physics education researcher – obtained a University Teaching Improvement and Equipment Scheme (TIES) Grant to film all summary lectures. These video clips will be made available for students on the web and will also function as demonstrations of my original intent with this part of Map Meetings.

The project has also spawned new research. In 2009–2010, Nigel Kuan, a Physics Honours student with the SUPER group, is developing Link Maps for senior high school physics topics in his Honours project. Extending the work into high school, in which students have even lower prior knowledge than the Fundamentals students and the topics are often more horizontally structured than at university, will provide interesting insights into the validity and applications of the ideas developed here.

The most surprising flow-on effect of the project has been the frequent discussions and burgeoning collaboration with Dr. Karl Maton from Sociology of Education. Without much work done on characterizing hierarchical knowledge structures, I am not the only one to derive new insights from these discussions; I am also contributing with my experience of the knowledge structure of physics and have been invited to write a book chapter based on Chapter 4 of this thesis.

7.3.3 Quod erat demonstrandum

This thesis marks the end of a nearly five year long journey. Near the end of 2005 the ideas for this project were born; 2006 saw the first pilot study; and since 2007 the large-scale investigation of Link Maps and Map Meetings have been carried out.

The ideas to this project were based on my own experiences with learning and teaching, not on literature. Only when I became acquainted with the literature did I realize that the current trends in science education did not support my views. Neither did a large fraction of staff in the School of

Physics; I explicitly recall a staff member commenting about Map Meetings that 'I thought we didn't do those kinds of tutorials because they don't work.' However, although the project grew out of my own ideas, extensive literature search – often in less obvious places – has given the study a solid theoretical foundation. But, more importantly, the results of the study itself provide the most compelling evidence for the validity of my approach.

Ultimately, Link Maps and Map Meetings were successfully developed and implemented, and their reception by both students and staff was better than anticipated. The only difference the intervention brought was to replace 20-25 minutes of problem solving time with a teacher-centred summary lecture and plenary, a slightly different problem sheet and a Link Map per week. Given the complexity of student learning over a whole semester, it is remarkable to see such clear differences between the tutorial types at all. Many factors contribute to a final examination mark, but it's clear that Map Meetings were as good as, or possibly better than, Workshop Tutorials, even though they offered nearly 50% less student-centred problem solving time. The boarderline significant effect seen in the number of students at risk of failing between the two tutorial types is quite astounding – and very pleasing. The positive feedback and results thus provide further support for the theory discussed in Chapter 2.

7.4 Further work

Most research discovers ten new questions for each question it answers; this project is no exception.

7.4.1 Further practical work

Further practical work of great interest would be to extend the study to include students of higher levels of competency and investigate whether the trend of less required scaffolding for higher prior knowledge can be detected. It would also be worthwhile to design a scenario where the treatment and control groups had no interaction so that students could not swap tutorials groups nor exchange material. Lastly, an aspect that was not investigated in this case, but that may reveal interesting results is to measure how much *time* students spent on their physics studies. If more strongly scaffolding environments allows students to reach the same level of competency in a shorter period of time than less scaffolding environments, this is a considerable benefit that cannot be measured by examination performance alone.

7.4.2 Further theoretical work

I believe that the most important further work that can come of this project is theoretical. In Chapter 2 I integrated neuroscience with cognitive psychology and constructivism, showing that this is possible – even desirable, as suggested by the results. Extending this integrated understanding of human learning, and thereby teaching, is essential if we are to make significant progress within Education.

One avenue of further research could be to attempt to merge the characterization of knowledge structures with cognitive load theory. Perhaps a careful and accurate description of individual pieces of knowledge can help quantify knowledge in terms of the cognitive load they impose on learners?

Motivation is another area that can both contribute to and benefit from being merged with the cognitive account of learning. Neuroscience already has some links to motivation, and there are many other paths to pursue, such as the origins of motivation and how and why motivation differs with varying levels of prior knowledge. This study showed how managing cognitive load was motivating for students, but exactly why was this the case?

Social aspects must also be included in a coherent theory of learning. In particular, the importance of language should not be underestimated. If teacher and student do not speak the same language – meaning that their shared words are not understood in the same way – they cannot communicate accurately. Neither can practitioners within and across fields, which frequently gives rise to a significant amount of confusion: for example, the definitions of *knowledge* and *learning* appear to be as numerous as there are individuals using these words.

By strengthening the theoretical basis of Education in general and Physics Education in particular, I believe the field has the opportunity to advance significantly and rapidly. Much valuable experimental results are available and much theory exists – what is needed is for them to be integrated into a coherent whole. I am arguing for a move towards making Education a hierarchical rather than a horizontal field – one in which researchers agree on the theoretical foundations so efforts can be focused on progress, rather than defending old battle ground. How can this be anything but constructive?

7.5 My journey: A reflection on the fields of Physics and Education

This project, to me, has been more than a study into how to improve first year physics education – it has been a meta-study of the fields of Physics and Education. When I began my Honours project, I had never engaged academically with Education; all I had were my experiences of learning and teaching; I was an educated ‘Education’ novice. A little over four years later, I have progressed considerably on my path towards enculturation into this field. With a solid grounding in Physics, I have gained some insights into the *cultural differences* between the two fields – of which there are many. I will discuss what I consider to be the three most severe differences here.

The first difference I noticed was *epistemological*. At the very beginning of Chapter 2, which reviewed relevant literature, I brought to light Kitcher’s (2002) argument on what is accepted as knowledge. If the requirements are too stringent, hardly any new information will be included in the corpus of knowledge and the field will not progress; however, if the requirements are too liberal, too much new information will pass as knowledge – much of which will turn out to be at best unhelpful, at worst plain wrong.

Physics, indeed science in general, has clear rules as to what new information passes as knowledge. Careful critical reviews and reproduction of results represent the key to the advancement of the field. There is a wide-spread agreement about what constitutes new knowledge. In Education, on the other hand, I have had a different experience. The bar for what passes as new knowledge is set very low – at times, it appears virtually indistinguishable from the ground. Education seems to suffer from some of its own constructivist teachings: because everyone constructs their own knowledge, no knowledge is wrong. When almost any information is accepted as knowledge, the field quickly loses its path – which is what I believe is occurring in Education.

This leads me on to the second major difference between Physics and Education: their theoretical frameworks. Physics has a very clear theoretical framework, where a theory only reaches the status of theory if it has stood the ‘test of time’. This, however, does not mean that it represents ‘the truth’ and may never change – it is simply the best explanation we have at present for a certain set of phenomena. Physicists aim to account for observations in terms of a few fundamental variables, thereby explaining seemingly complex phenomena by a few simple theories. In Education there are no solid theoretical frameworks – there are only ideas (which may develop into theories) and possible explanations for observations. Very few of these, however, are in terms of anything that resembles fundamental variables. Like the sea weeds in the Sargasso Sea, some ideas may appear internally consistent and coherent, but they are not anchored to solid ground. Educationalists would, of course, disagree; they would bring out their trump card – constructivism. However, as I argued in Chapter 2, that each individual mentally constructs her own knowledge is not a theory – it is a statement of a fundamental fact; a basic principle of learning; the kind that Education needs more of. Given what a complex system human learning is and how many different areas that can offer some insight into various aspects of this, a theory of education should draw on *all* relevant fields – more than what I have drawn on in this thesis. The complexity and challenge of this task should not be seen as a hindrance, but rather as a compelling reason for extensive collaboration. Considering the interest both Vygotsky and Skinner showed for the budding study of neuroscience in the early twentieth century, this would likely have pleased the pioneers of the field.

Many, however, argue that Education cannot follow the same processes and procedures as Physics because it is not an exact science. This is not a valid argument. Physics may be more exact in certain sub-fields, but it also contains sub-fields that have been proven to *not* be exact. Quantum mechanics is inherently probabilistic – it is theoretically impossible to predict the outcome of a single quantum event. The reason quantum mechanics is such a successful theory is not related to the accuracy of the subject matter being studied, but to the accuracy of the methods with which the subject matter is being studied. Physics has clear rules and guidelines for how to deal with assumptions and uncertainties. Assumptions, boundaries and limitations are clearly articulated specifying when and under which conditions various theories apply. Uncertainties are treated in an equally rigorous manner – however ironic that may sound to a person not enculturated into the natural sciences. The inherent variance among learners is not an excuse to make blanket statements either pretending that variance does not exist or that it makes it impossible to characterize a population – it simply represents another system to be understood. Education has a very important role in evaluating how to best help students learn given various constraints – such as large classroom teaching, how to motivate students to do 'boring' work and how to best evaluate what has been learnt – but these findings must rest on a solid theoretical framework that considers the roles played by the brain, student motivation, knowledge presentation and social and cultural context.

But, regrettably, I am not optimistic that Education will pursue such a path. The reason for this lies in the third main difference I see between Physics and Education, namely their *knowledge structures*. Physics has a hierarchical knowledge structure, which formed the basis for the development of Link

Maps. Education has a horizontal knowledge structure, witnessed by the plethora of perspectives within constructivism. Recall that a horizontal knowledge structure refers to a corpus of knowledge that comprises several non-overlapping sub-fields with different languages. The problem, however, is not that there are different ideas – rather, that is essential for the evolution of the field – the problem is that there is little or no effort to integrate the existing sub-fields together. An excellent example is the fifteen different types of constructivism identified by Good (1993). These do not represent fifteen completely different sub-fields within Education; they represent slightly different variations on the same theme. To any novice in Education, this is nothing but confusing and extremely unhelpful – and a severe hindrance to learning. Rather, if the ideas within these different perspectives could all be integrated into the one idea of constructivism, the knowledge contained within the field would be so much more accessible and useful. During the integration process, certain diametrically opposing views would be highlighted. This could either lead to two truly different sub-fields – such as the study of the individual or the social in constructivism – or they could highlight an area in need of research to prove that either one way or another is valid – e.g., motivation is or is not relevant when teaching tertiary physics. This would not devalue any of the ideas within each current perspective – it would make them part of a greater and more coherent whole with a greater power to advance teaching and learning.

However, an additional hindrance to the likelihood of this occurring is the *knowledge/knower code* associated with a culture – a concept related to the knowledge structure. Hierarchical knowledge structures are associated with knowledge codes: knowledge *is*, regardless of who discovered or created it (whichever way you wish to look at it). In physics, this is evident in how the whole field of physics can be taught without necessarily ever referring to any individuals. We choose to keep some names in laws and principles – such as Newton's laws – but these names are not important, they are merely of historical interest. In horizontal knowledge structures, on the other hand, there is a much more prevalent preoccupation with the individuals who fathered knowledge – there is Skinner's transmissionism, Piaget's constructivism and Vygosky's sociocultural ideas. Even more so, researchers often define themselves adjectivally through the knowledge constructor, such as the Bernstinians. This schism in fundamental belief in knowledge between believing that knowledge *is* and that knowledge is inextricably linked to its originator is another cultural difference rarely highlighted. It also perpetuates the divide between the knowledge structures, because whereas the integration of knowledge should be unproblematic, it is not clear how one would deal with the integration of the associated originators of that knowledge. What is needed in such an instance is to demote the creating individual to secondary to the knowledge itself. As long as the originators are seen as primary and defining the knowledge, the horizontal knowledge structures will remain.

I am not hopeful that Education will pursue a path towards a hierarchical knowledge structure. The reason for this is the immense cultural differences between the fields. Culture is learnt, and it is learnt over very many years. However, culture is primarily learnt implicitly. Implicit knowledge is that which is used unconsciously, so those within a culture are often not even aware of many features of the culture – it is just how it is. Having moved from Norway to Australia to undertake my tertiary education, I have not only experienced the Physics to Education culture shock, I have also experienced a culture shock in the more traditional sense. I fully appreciate that it is extremely hard to move away from the culture you were reared into – even after more than seven years in Australia, I still feel entirely and completely Norwegian. I do not see why it would be different in academic cultures. Education researchers who are enculturated into a horizontal knowledge structure with knower codes and liberal knowledge criteria are unlikely to 'convert' to a scientific culture with a hierarchical knowledge structure with knowledge codes and stringent knowledge criteria. I must be open to the possibility that my science enculturation has made me overly biased and blind to the values of the 'Education' culture, but I do feel that the enormous success and advance of science since the scientific revolution gives its culture some credence. However, instead of approaching the issue by trying to convert those already enculturated into Education, I believe that using those enculturated into Science to work on integrating the knowledge within Education into a coherent theoretical framework will be much more efficient. The way I see it, this may be the most important contribution to Education that we, as Physics Education Researchers, can make, because culture is harder to acquire than semantic knowledge.

In Section 2.1.3 I posed the question "is the knowledge structure of a field a reflection of the nature of the domain itself, or is it a cultural artifact?" I am now in a position to give a tentative answer. I believe knowledge structures of fields are primarily cultural artifacts and that most – if not all – fields can become hierarchical, at least to a certain degree. However, I also believe that culture is stronger than knowledge. This is why I still consider myself a physicist rather than an educationalist – not because there is physics in what I do, but because what I do, I do as a physicist.

A Neuroscience

Neurons are signal processors, the collection of which is referred to as the nervous system. The nervous system extends throughout the body, and is divided into the peripheral and the central, where the latter refers to the brain and the spinal chord. The brain is the organ with the highest concentration of neurons, and it is the information processing unit of animals.

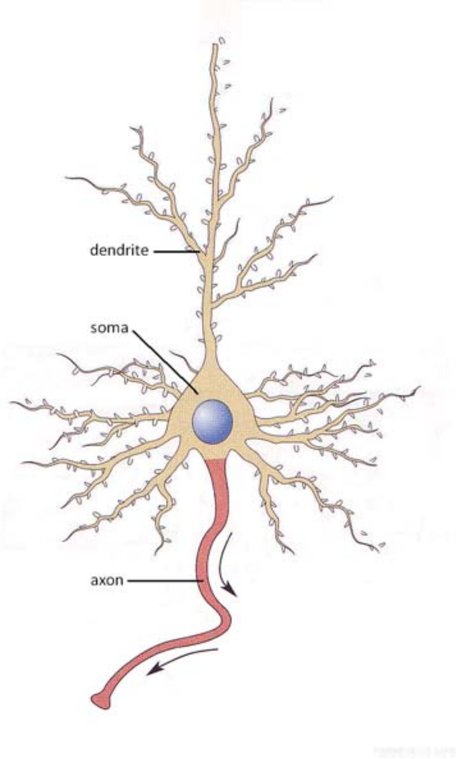


Figure A.1: The general structure of a neuron (adapted from Bear et al., 2007, p. 98).

Neurons come in many different shapes and sizes, but they share certain characteristics (Bear et al., 2007). Figure A.1 shows a schematic of a neuron; its structure can broadly be divided into three parts: soma, dendrites and axon (Bear et al., 2007). The *soma* is the cell body, which contains the cell nucleus. As I shall discuss later, it plays a key role in the actual processing of information that passes through the neuron. The *axon* is the ‘output cable’ of a neuron; it can be very long, up to 1 m in humans. Information from the soma travels down the axon allowing the neuron to communicate with other neurons (usually) or other cells. Each neuron has only one axon emanating from the cell body, but this axon may branch to enable communication with more than one other cell. The third part of the neuron is the *dendrites*. These are the antennae or ‘input cables’. Unlike axons, dendrites are very short, rarely more than 2 mm. As illustrated in Figure A.1, the dendrites are a collection of neuronal protuberances – often referred to as the dendritic tree – composed of a multitude of dendritic branches (Bear et al., 2007). It is here, primarily, that the neuron receives information from other neurons at points referred to as synapses.

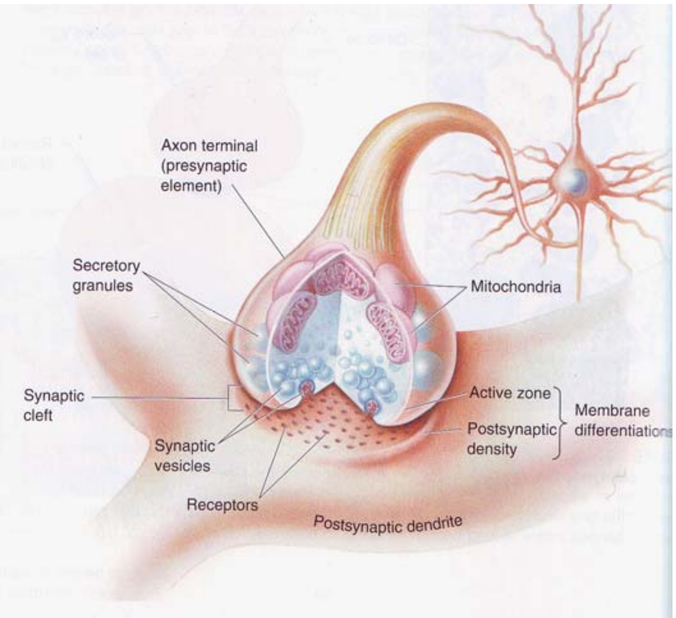


Figure A.2: The components of a chemical synapse (Bear et al., 2007, p. 106). Note that the figure contains more labels than is discussed here.

Synapse is the name given to the connecting point between two neurons (or a neuron and another type of cell) (Bear et al., 2007). To understand the information processing ability of neurons, it is essential to be familiar with how neurons communicate.

At a synapse, the end of an axon (the *axon terminal*) connects with a dendrite (Bear et al., 2007). (Synapses can also form between an axon terminal and a soma or even another axon, but these connections are less common and will not be discussed here.) The connection, however, in most cases in the mature human brain, is not a physical one (Bear et al., 2007). The axon (the *presynaptic element*) is separated from the dendrite (the *postsynaptic element*) by the *synaptic cleft*, a space only 20-50 nm wide. As illustrated in Figure A.2 the presynaptic element communicates with the postsynaptic element by releasing molecules that bind to receptors at the opposite side of the synaptic cleft. The communication molecules are collectively referred to as *neurotransmitters* and range from simple amino acids to relatively large and complex molecules. Once the neurotransmitters are detected by the postsynaptic element, ions are released to produce the dendritic ionic current.

Functional neuroanatomy is the study of how the neuron operates as a signal processor. Axons behave differently to dendrites, so axons will be discussed first.

The boundary of a neuron is defined by the neuronal membrane, which separates the fluid on the inside (*cytosol*) from the fluid on the outside (*extracellular fluid*) (Bear et al., 2007). Ions are found on both sides of the membrane but cannot penetrate the membrane itself. Rather, ions are selectively transferred across the cell membrane by a variety of means, resulting in a net imbalance of charges. This gives rise to a potential difference across the membrane – much like a capacitor. At rest the potential inside the neuron is at -65mV with respect to the outside.

Certain input into the neuron, most commonly from the dendrites via the soma, can disrupt this potential at the beginning of the axon where it is connected to the soma (called the *axon hillock*) (Bear et al., 2007). If the potential is increased to above a certain threshold, a sequence of processes are initiated that allow for the selective flow of ions across the membrane at the axon hillock for a very short period of time. These processes have the net effect of increasing the potential locally within the neuron to about +40mV before it is again restored to the resting potential (see Fig. A.3). The whole process lasts for about 2 ms.

Because the axon can be thought of as a long cylindrical capacitor, when this process occurs at the axon hillock, ion diffusion raises the potential of the cytosol immediately next to the area. This neighbouring area then experiences an increase in the potential to above the threshold, thus initiating the same type of process in this next segment along the axon. Because these voltage gated ion channels are found along the whole axon, the net result is that a region of increased potential travels reliably down the whole axon. The travelling region of increased potential is referred to as the *action potential* – the key method of passing information between neurons (Bear et al., 2007).

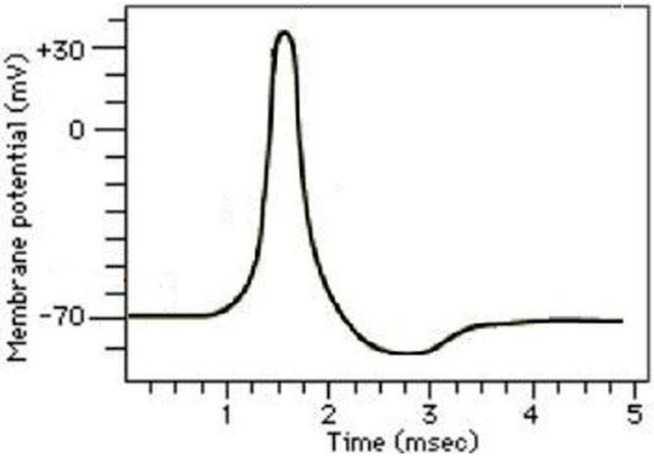


Figure A.3: The action potential (Stark, 2010).

Dendrites, on the other hand, are different. Unlike axons, dendrites do not have voltage gated ion channels along their whole length (Bear et al., 2007). Hence, information is passed from synapses to the soma mostly via passive ionic currents. These currents decay as they travel along the dendrite, but the rate of decay is highly variable both spatially and temporally. However, *some* voltage gated ion channels exist, and at these locations they act as amplifiers of synaptic signals travelling towards the soma as in axons (Bear et al., 2007). Whereas action potentials travel reliably from the axon hillock to the axon terminals, information travelling through the dendritic tree to the soma is much more complicated because each neuron can be connected to up to 10,000 other neurons (Bear et al., 2007). The key feature to consider is the effect of the sheer number of synapses on any one given dendritic tree. In addition, synaptic connections come in different types: some synapses simply relay information from one neuron to another; other synapses may change the conductive properties of a certain part of a dendrite, making it more or less conductive to *other* signals travelling towards the soma, leading to selection of information. Thus, the signal that reaches the soma is not simply the sum of all inputs into the neuron, but rather the product of a complex interplay between all the synapses on the given neuron (Bear et al., 2007).

Ultimately, the information output of the neuron based on this complex input can only be an action potential (a *spike*) or no action potential (Bear et al., 2007). In the end, neurons communicate with each other by encoding information into spatial and temporal variability of spikes, which makes apparent the difficulty involved in integrating the microscopic world of neurons (of which we all have about 100 billion) with the macroscopic world of an undergraduate student trying to learn physics.

B Statistical analyses

This section describes the statistical procedures used in this thesis (see for example Phipps & Quine, 2001 for a general source on statistics).

Statistics aims to establish and compare group parameters. The entire group is the *population*, but often this is impossible or impractical to measure. Thus, a *sample* – a subset – is taken from the population. A randomly chosen sample is representative of the population and allows sample parameters to be generalized to the population.

B.1 Parametric vs. non-parametric data

Data sets are either parametric or non-parametric. To be parametric, the data must meet four *assumptions.*

B.1.1 Normality

A data set is normal if it is distributed as shown below in Fig. B.1. 68% of the data points lie within one standard deviation, 95% within two standard deviations, and 99.7% within three standard deviations of the mean.

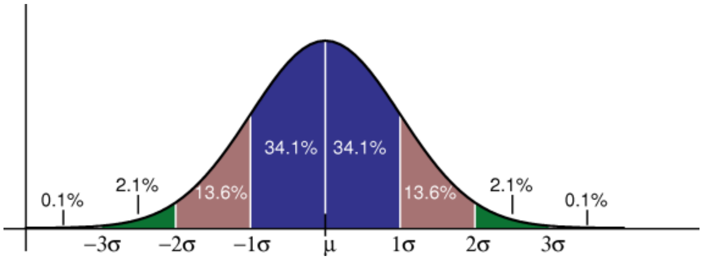


Fig. B.1: The normal distribution (Wikipedia, 2006b).

B.1.2 Homogeneity of variance (homoscedasticity)

If there is more than one variable, where each variable is described by a normal distribution of data points so we can assign a mean and standard deviation can be assigned, homoscedasticity refers to the variances of individual variables being (roughly) equal. Homoscedasticity is tested for in SPSS using Levene's test.

B.1.3 Levels of measurement

Levels of measurement refer to the degree of accuracy a variable is measured at. Parametric data must be continuous.

Nominal data is categorical, where each category is independent of the others. An example is the streaming of students in first year physics: students are enrolled in the Fundamentals, Regular or the Advanced course.

Ordinal data has order but no regularity in the measurement scale. Level of education is an example, as we clearly have *HSC* < *Bachelor* < *PhD*, but the increase in education from the HSC to a Bachelor is not necessarily the same as from a Bachelor to a PhD.

Continuous data *does* have both order and regularity of measurement scale – the difference between two consecutive points is always the same. Continuous data is generally divided into two categories depending on whether it has an absolute zero; an absolute zero refers to a complete absence of the construct measured, and negative values cannot occur. *Interval* data does not have an absolute zero (but it can have an arbitrary zero, like the Celsius temperature scale) whereas *scale* data does have an absolute zero (like the Kelvin temperature scale).

B.1.4 Independence

Variables are independent if they are uncorrelated, i.e., if a change in one variable does not imply any systematic change in another variable.

B.2 Types of analyses

Tests of difference and tests of association are the two main types of analyses. Tests of difference test whether there is a significant difference between the means of different groups. Each group of individuals is first described collectively, followed by comparison of groups. Tests of association, on the other hand, focus on the individuals and the relationships between their measures on each variable and compares one individual’s data to the data of other subjects.

B.2.1 Measures of central tendency and spread

The *mean* is the average value of the data set; the *median* is the middle value when all data points are organized in ascending or descending order; and the *mode* is the value that occurs most frequently.

When calculating the mean, the *sum of squares (SS)* is the most fundamental way to describe the spread in the data. As the name indicates, the sum of squares is the sum over all differences between individual values and the mean squared:

$$SS = \sum_{i=1}^{N} (x_i - \bar{x})^2 \tag{1}$$

where x_i is the value of the i^{th} data point, $\bar{x}$ is the mean, and N is the number of data points. The *variance (s^2)* is roughly the average squared deviation from the mean:

$$s^2 = \frac{SS}{N-1} \tag{2}$$

To obtain a measure of spread in the same units as the mean, the *standard deviation (s)* is the positive square root of the variance.

B.2.2 Tests of difference

Tests of difference estimate the probability that the difference between the means of two or more distributions occurred by chance. For between-group experiments, where independent groups are compared with respect to the same variable, both distributions are required to be normal; however, for repeated measures, where one group is measured twice, only the distribution of differences between the samples needs to satisfy the parametric assumptions.

Simply put, a t-test determines the degree of overlap of two sample distributions. Fig. B.2 shows three distributions with the same difference in means but with different standard deviations (reflected in the spread of the distributions). In the second case we would conclude that the distributions are not significantly different, whereas in the thrid case we would.

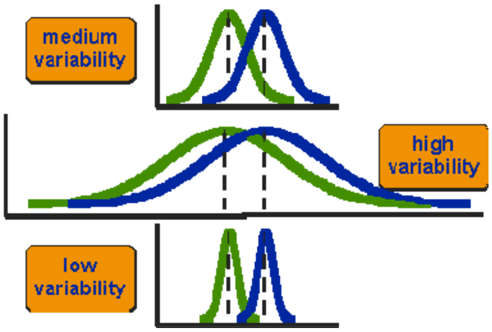


Fig. B.2: Three sets of distributions may show the same difference in means, but the significance of this difference depends on the variance in the distributions (Trochim, 2006).

The t-test is based on Student's t-distribution (Fig. B.3), which describes the probability that two different normal samples come from the same normal distribution. Two parameters are required to determine this probability: *k* and *t*. *k* is the degrees of freedom – equal to $n-1$ where *n* is the sample size; this determines which curve in the t-distribution to use. The curves converge towards the normal distribution, and are essentially identical for $k > 30$.

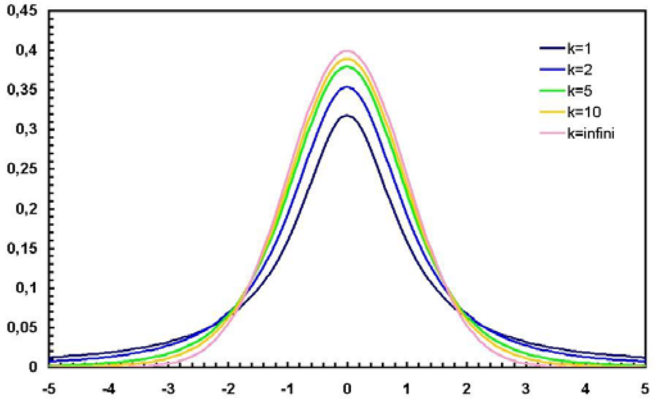


Fig. B.3: Student's t-distribution plotted for several values of degrees of freedom, *k.* The x-axis represents t. (Wikipedia, 2006c)

t is calculated slightly differently depending on whether we have a repeated measures or a between-group design. For repeated measures, x_1 and x_2 (measurements for variables 1 and 2) are known for each subject. We calculate $x_2 - x_1$ for each subject to obtain a normal distribution of differences and determine the mean, $\bar{x}$, and standard deviation, *s*, of this distribution. *t* is calculated by

$$t_{n-1} = \frac{\bar{x} - \mu_0}{s/\sqrt{n}} \tag{3}$$

where μ_0 is the mean that we want to test whether our distribution is equal to. If the hypothesis is that the means for variables 1 and 2 are identical, then $\mu_0 = 0$.

For independent samples, *X* and *Y*, in a between-groups design, the following determines t_{n-1}.

$$t_{n-1} = \frac{\bar{x} - \bar{y}}{s_p\sqrt{\frac{1}{n_x} + \frac{1}{n_y}}} \tag{4}$$

Where

$$s_p{}^2 = \frac{(n_x - 1)s_x{}^2 + (n_y - 1)s_y{}^2}{n_x + n_y - 2} \tag{5}$$

t_{n-1} is then used with the t-distribution to find the probability that the two samples have similar means.

The probability, or p-value, is the area under the curve from *t* to infinity for positive *t* or from *t* to negative infinity for negative *t*. The sign of *t* reflects which sample mean is greater, so if a prediction were made as to which mean would be greater we only use one side of the distribution to determine the p-value. This is called a one-tailed significance. However, if no prediction were made, the p-value is the area under the graph for $|t| > |t_{obtained}|$, and we term the significance two-tailed. Because the t-distribution is symmetric, $p_{two\text{-}tailed} = 2p_{one\text{-}tailed}$.

The ANOVA (ANalysis Of VAriance) is used when more than two means are compared. The term one-way ANOVA is used to emphasise that only one independent variable is used. Performing repeated sets of t-tests between every pair of means may seem a logical way to investigate the differences between means, but this increases the probability of detecting a result when there is none, referred to as a type I error.

If the samples don't fulfill the parametric assumptions, the non-parametric equivalent to the t-test must be used. For independent samples, the *Mann-Whitney test* is used; for repeated measures the

Wilcoxon Signed-Rank test should be applied. The non-parametric equivalent to the ANOVA is the Kruskall-Wallis test.

Lastly, the Cohen's d *effect size* (Cohen, 1988) is a measure of the *magnitude* of difference between two samples, calculating how many standard deviations the means differ by:

$$d = \frac{\overline{x_2} - \overline{x_1}}{\sqrt{0.5({s_1}^2 + {s_2}^2)}}$$

A statistically significant difference between two means does not reflect whether this difference is large enough to be of any real interest: very large sample sizes can reach statistical significance with small effect sizes, in which case the result may not be of much relevance, whereas very small sample sizes may not reach significance when comparing means, but a large effect size may still suggest that the result should not be discarded immediately. Values of d = 0.2, 0.5 and 0.8 are referred to as small, medium and large.

B.3 Tests of association

B.3.1 Scatter plots and trend lines

Of repeated measures data one can create a scatter plot where the axes represent the independent variables and each subject, who has a score per variable, can be represented by a point. The scatter plot gives valuable information that correlation coefficients and trend lines (or regression lines) do not, and so should always be investigated prior to calculating such parameters. Flooring and ceiling effects, in particular, are only evident from the scatter plot, and may in many cases be more interesting than average trends. The trend line is the line of best fit to the data. It is very sensitive to outliers, so the scatter plot should be investigated before calculating a regression line.

B.3.2 Correlation

Correlations require parametric data and describe whether there is a linear relationship between two variables in repeated measures experiments (see Fig. B.4). The *Pearson product-moment correlation coefficient*, or *Pearson's r* for short, indicates the strength of a correlation and whether it is positive or negative. For non-parametric data one can calculate the *Spearman's rho* or, when the data set is small with a large number of equal scores, the *Kendall's tau.*

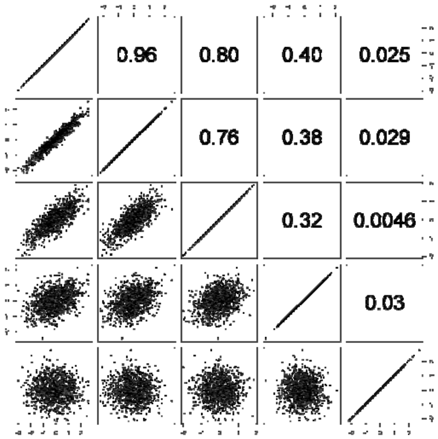


Fig. B.4: The lower triangle shows scatter plots whereas the upper triangle gives the *r*-values for the plots mirror imaged across the diagonal (Wikipedia, 2006a).

In two dimensions we can describe the linear trend or correlation by the *covariance*, given by

$$\mathrm{cov}(x,y)=\frac{\sum_{i=1}^{N}(x_i-\overline{x})(y_i-\overline{y})}{N-1} \tag{6}$$

The covariance is very similar to the sum of squares, except that terms can be negative. All points that vary in a similar direction, i.e., if $x_i > \overline{x}$, then $y_i > \overline{y}$, will contribute positively, whereas those that vary in opposite directions will be negative. Thus, the more points that vary in a certain direction the larger the covariance. To obtain a standardized value, we divide through by the standard deviations of the samples to obtain the Pearson's *r*.

$$r=\frac{\mathrm{cov}(x,y)}{s_x s_y} \tag{7}$$

r can take on values between -1 and +1, but it is more fruitful to think of it as $|r| \leq 1$, with either a positive or negative sign. The absolute value of *r* reflects how strong the correlation is (see fig. 4), with *r = 0* for independent variables and *r = 1* for completely dependent variables, where the value of *Y* is perfectly described by the value of *X*. The sign merely reflects whether the variables are positively or negatively correlated – it is the sign of the gradient of the line of best fit.

B.3.3 Linear regression

Linear regression applies to repeated measures data with one outcome variable and at least one predictor variable. These correspond to dependent and independent variables, but to emphasize that there is no implied cause and effect, different names have been chosen.

Linear regression has several assumptions:

- The predictor variables must be continuous or categorical, and the outcome variable must be continuous.
- The predictor variables should not correlate strongly.
- No predictor variable should correlate strongly with external variables that have not been measured.
- The variance of the residual terms at each level of the predictor variables should be constant.
- The residuals in the final model should be normally distributed.
- The outcome variable should be linearly related to the predictor variables (as we are trying to fit a linear model).

Linear regression extends the concept of correlation. Whereas the correlation coefficient describes the strength of the correlation – how closely the scatter plot resembles a straight line – the regression line describes this linear relationship (fig. B.5).

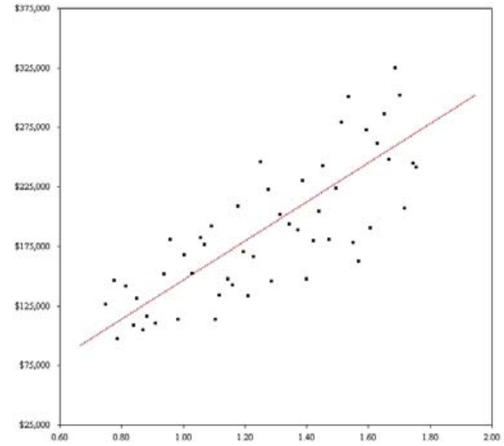


Fig. B.5: A regression line is fitted to a scatter plot that shows a positive correlation (Appian Analytics, 2006).

The regression line can be described by the equation for a straight line and can be used to predict the value of one variable based on the other.

$$\hat{y} = \beta_0 + \beta_1 x \tag{8}$$

where $\hat{y}$ is the predicted value of the outcome variable for a value x of the predictor variable. The convention is to label the coefficients with β.

Clearly, the line of best fit does not perfectly fit the data, so each individual point, y_i, can be described as

$$y_i = \hat{y} + \varepsilon_i \tag{9}$$

where ε_i is the residual at point *i*, i.e., the vertical distance from any point to the regression line. The regression line of *best fit* is the line that minimizes the value of the *residual sum of squares*, SS_R, given by

$$SS_R = \sum_{i=1}^{N} {\varepsilon_i}^2 = \sum_{i=1}^{N} (y_i - \hat{y})^2 \tag{10}$$

Recall that the *total sum of squares* is given by

$$SS_T = \sum_{i=1}^{N} (y_i - \bar{y})^2 \tag{11}$$

This calculates the sum of squared residuals with respect to the simplest model we can fit to the data, namely the mean, whereas equation (10) calculates this value with respect to the new (and hopefully improved) model, i.e., the regression line. R^2 is a measure of how much the regression line improved the model: it quotes the percentage of original variance that is now explained by the model

$$R^2 = 1 - \frac{SS_R}{SS_T} \tag{12}$$

The square root of R^2 reproduces Pearson's *r*. Conversely, by squaring Pearson's *r* we find how much of the variance in the outcome variance can be explained by the predictor variable by the regression line.

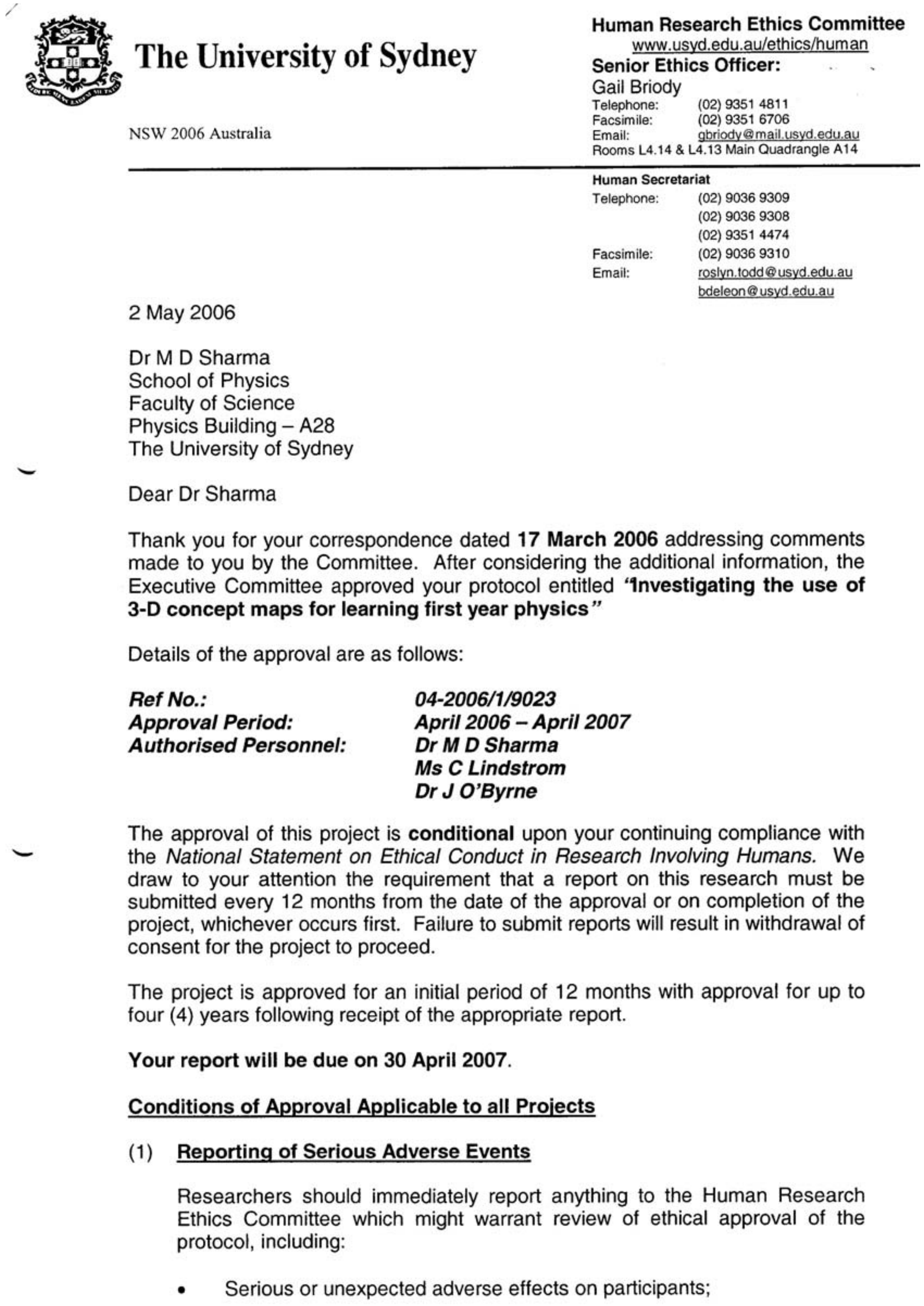
When there is more than one predictor variable, the procedure is termed *multiple regression*. Even though we cannot picture a space with more than three dimensions, we can work with it mathematically. A regression *line* is a 1D space embedded in a 2D scatter plot, and a regression *plane* is a 2D space in a 3D scatter plot. These cases correspond to having one or two predictor variables, still linearly related to the outcome variable. In the general case with *k* predictor variables, we will have a (*k* + 1)D 'scatter plot' to which we will fit a *k*D regression space described by

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k \qquad (13)$$

where x_k is the k^{th} predictor variable. Equations 9-12 can be used to determine the model fit in the same way as the simple example above.

C Human Ethics

C.1 Human Ethics Research approval



The University of Sydney
NSW 2006 Australia

Human Research Ethics Committee
www.usyd.edu.au/ethics/human
Senior Ethics Officer:
Gail Briody
Telephone: (02) 9351 4811
Facsimile: (02) 9351 6706
Email: gbriody@mail.usyd.edu.au
Rooms L4.14 & L4.13 Main Quadrangle A14

Human Secretariat
Telephone: (02) 9036 9309
(02) 9036 9308
(02) 9351 4474
Facsimile: (02) 9036 9310
Email: roslyn.todd@usyd.edu.au
bdeleon@usyd.edu.au

2 May 2006

Dr M D Sharma
School of Physics
Faculty of Science
Physics Building – A28
The University of Sydney

Dear Dr Sharma

Thank you for your correspondence dated **17 March 2006** addressing comments made to you by the Committee. After considering the additional information, the Executive Committee approved your protocol entitled **"Investigating the use of 3-D concept maps for learning first year physics"**

Details of the approval are as follows:

Ref No.:	***04-2006/1/9023***
Approval Period:	***April 2006 – April 2007***
Authorised Personnel:	***Dr M D Sharma*** ***Ms C Lindstrom*** ***Dr J O'Byrne***

The approval of this project is **conditional** upon your continuing compliance with the *National Statement on Ethical Conduct in Research Involving Humans.* We draw to your attention the requirement that a report on this research must be submitted every 12 months from the date of the approval or on completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of consent for the project to proceed.

The project is approved for an initial period of 12 months with approval for up to four (4) years following receipt of the appropriate report.

Your report will be due on 30 April 2007.

Conditions of Approval Applicable to all Projects

(1) **Reporting of Serious Adverse Events**

Researchers should immediately report anything to the Human Research Ethics Committee which might warrant review of ethical approval of the protocol, including:

- Serious or unexpected adverse effects on participants;

- Proposed changes in the protocol or any other material given to the participants in the study must be known prior to being actioned, including participant information and consent forms; and
- Unforeseen events that might affect continued ethical acceptability of the project.

(2) Modifications to the protocol cannot proceed until such approval is obtained in writing. (Refer to the website www.usyd.edu.au/ethics/human under 'Forms and Guides' for a Modification Form).

(3) The confidentiality and anonymity of all research subjects is maintained at all times, except as required by law.

(4) All research subjects are provided with a Participant Information Sheet and Consent Form, unless otherwise agreed by the Committee.

(5) The Participant Information Sheet and Consent Form are to be on University of Sydney letterhead and include the full title of the research project and telephone contacts for the researchers, unless otherwise agreed by the Committee.

(6) The following statement must appear on the bottom of the Participant Information Sheet. ***Any person with concerns or complaints about the conduct of a research study can contact the Senior Ethics Officer, University of Sydney, on (02) 9351 4811.***

(7) The standard University policy concerning storage of data and tapes should be followed. While temporary storage of data or tapes at the researcher's home or an off-campus site is acceptable during the active transcription phase of the project, permanent storage should be at a secure, University controlled site for a minimum of seven years.

(8) A report and a copy of any published material should be provided at the completion of the Project.

Yours sincerely

John Watson

Associate Professor J D Watson
Chairman
Human Research Ethics Committee

Encl:
Participant Information Statement
Participant Consent Form

cc Ms C Lindstrom, School of Physics, Faculty of Science, Physics Building – A28, The University of Sydney

C.2 Participant consent and information forms

The University of Sydney
School of Physics, A28
NSW 2006, AUSTRALIA

PARTICIPANT CONSENT FORM

I, ... , give consent to my participation in the research project **Concept maps for learning physics.**
Name (please print)

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.
2. I have read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.
3. I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher(s) now or in the future.
4. I understand that the researchers will be obtaining my UAI and individual high school marks, and that only the researchers will have access to this data.
5. I understand that my involvement is strictly confidential and no information about me will be used in any way that reveals my identity.

Signed: ....

Name: ....

Date: ....

The University of Sydney
School of Physics, A28
NSW 2006, AUSTRALIA

PARTICIPANT INFORMATION STATEMENT

Research Project

Title:Concept maps for learning physics

(1) What is the study about?

The study is about how concept maps can be used to learn skills and knowledge in first year physics. We are investigating two different ways of running tutorials, Map Meetings and Workshops Tutorials, to see which helps you learn physics best.

(2) Who is carrying out the study?

The study is being conducted by Christine Lindstrom and will form the basis for the degree of PhD in Physics at The University of Sydney under the supervision of Dr Manjula Sharma, Senior Lecturer, head of the Sydney University Physics Education Research group.

(3) What does the study involve?

The study involves participating in drawing concept maps and using the concept maps for problem solving and understanding concepts. You will also complete 2 surveys. Christine will take notes of how each tutorial progresses. The researchers will be obtaining participants' UAI and individual high school marks, and none other than the researchers will have access to this data.

(4) How much time will the study take?

One hour tutorial per week for twelve weeks for all students (whether they attend Map Meetings or Workshop Tutorials). The surveys will be completed during the tutorials.

(5) Can I withdraw from the study?

Being in this study is completely voluntary - you are not under any obligation to consent and - if you do consent - you can withdraw at any time. Whatever you decision, it will not affect your relationship with the University of Sydney.

(6) Will anyone else know the results?

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(7) Will the study benefit me?

Participating in this study will give you an opportunity to study your physics using 3-D concept maps. The tutorials may help you learn you physics or think about physics differently. Also if you are interested in discussing the results of the study, you are invited to contact us, see details below.

(8) Can I tell other people about the study?

Yes, by all means. There is no reason to keep this study a secret.

(9) What if I require further information?

When you have read this information, *Christine Lindstrom* will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Ms Christine Lindstrom, 9351 2533, Honours student; Dr Manjula Sharma, 9351 2051, Room 226E, Physics Building, m.sharma@physics.usyd.edu.au, Senior Lecturer in Physics, or Dr John O'Byrne, 9351 3184, Director of First Year Physics.

(10) What if I have a complaint or concerns?

Any person with concerns or complaints about the conduct of a research study can contact the Senior Ethics Officer, Ethics Administration, University of Sydney on (02) 9351 4811.

This information sheet is for you to keep

The University of Sydney
NSW 2006 Australia

Human Research Ethics Committee
www.usyd.edu.au/ethics/human
Senior Ethics Officer:
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Telephone: (02) 9351 4811
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Human Secretariat
Telephone: (02) 9036 9309
(02) 9036 9308
Facsimile: (02) 9036 9310

7 June 2007

Dr M D Sharma
School of Physics
Faculty of Science
Physics Building – A28
The University of Sydney

Dear Dr Sharma

Title ***Investigating the use of 3-D concept maps for learning first year physics***

Reference: 04-2006/9023

Regarding your Request for Modification dated 30 January 2007, thank you for responding to the concerns of the Executive Committee in your correspondence dated 26 April 2007. The Committee found that there were no ethical objections to the modifications and therefore recommends approval to proceed.

Additionally, thank you for providing the Annual Report Form, as requested, for the above referenced study. Your protocol has been renewed to **30 April 2008**.

NOTE:
Any changes to the authorised personnel must be advised and new staff must complete Section 1.4 and the Declaration of Researchers on the application form. Return both forms to the Senior Ethics Officer, Ethics Administration.

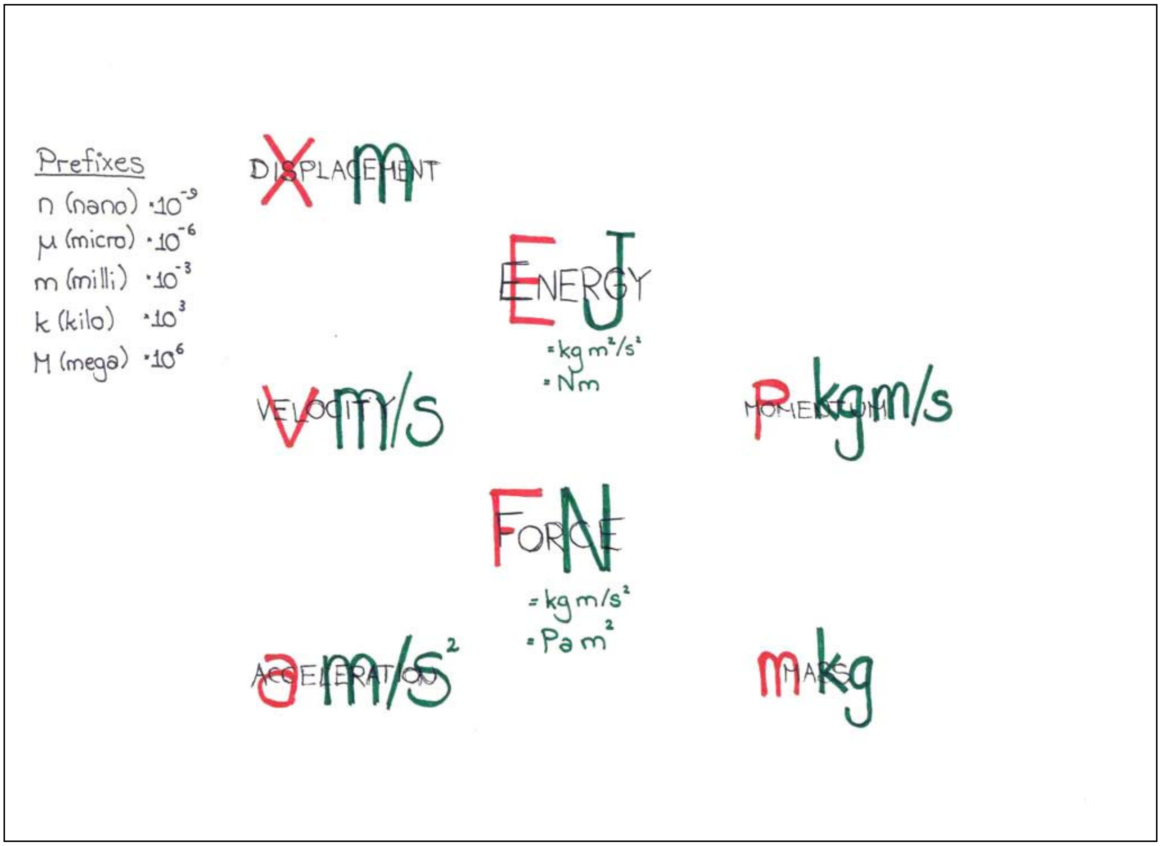
Yours sincerely

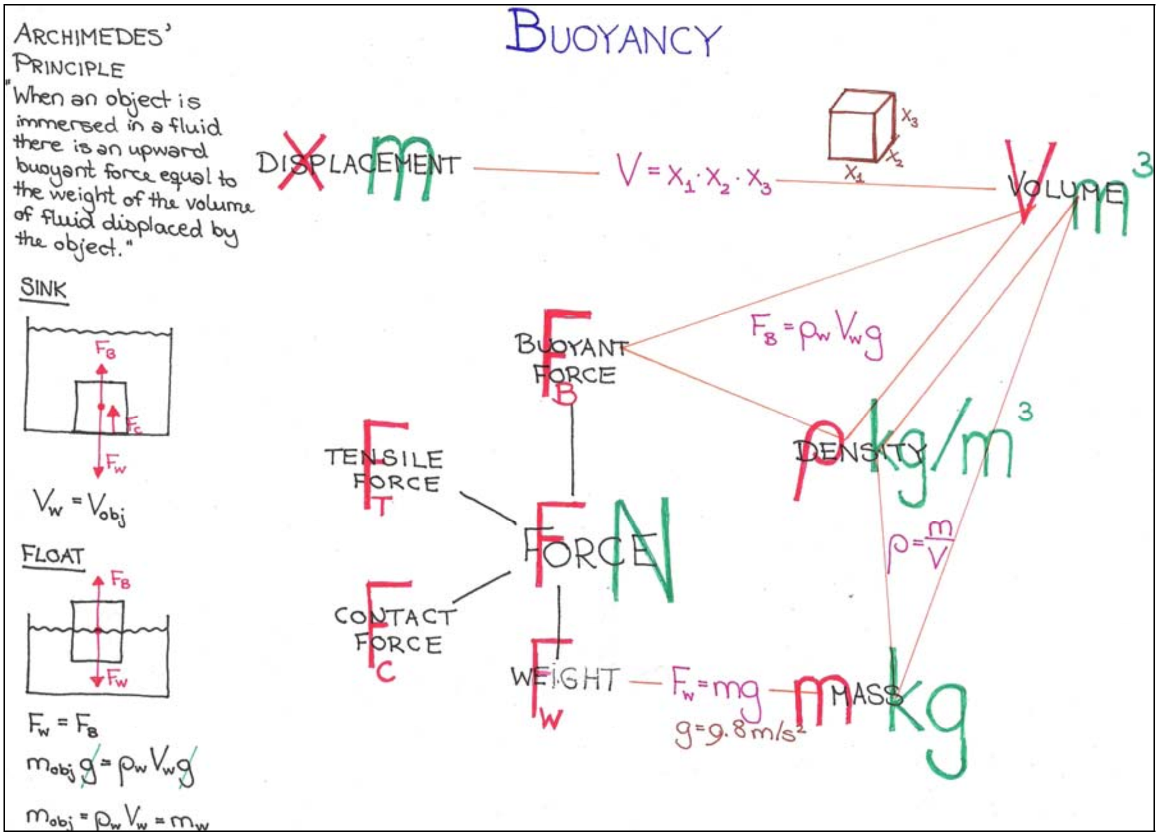
Professor D I Cook
Chairman
Human Research Ethics Committee

Encl.: Modified Participant Information Statement; Modified Participant Consent Form

D Link Maps

D.1 The Fundamentals course

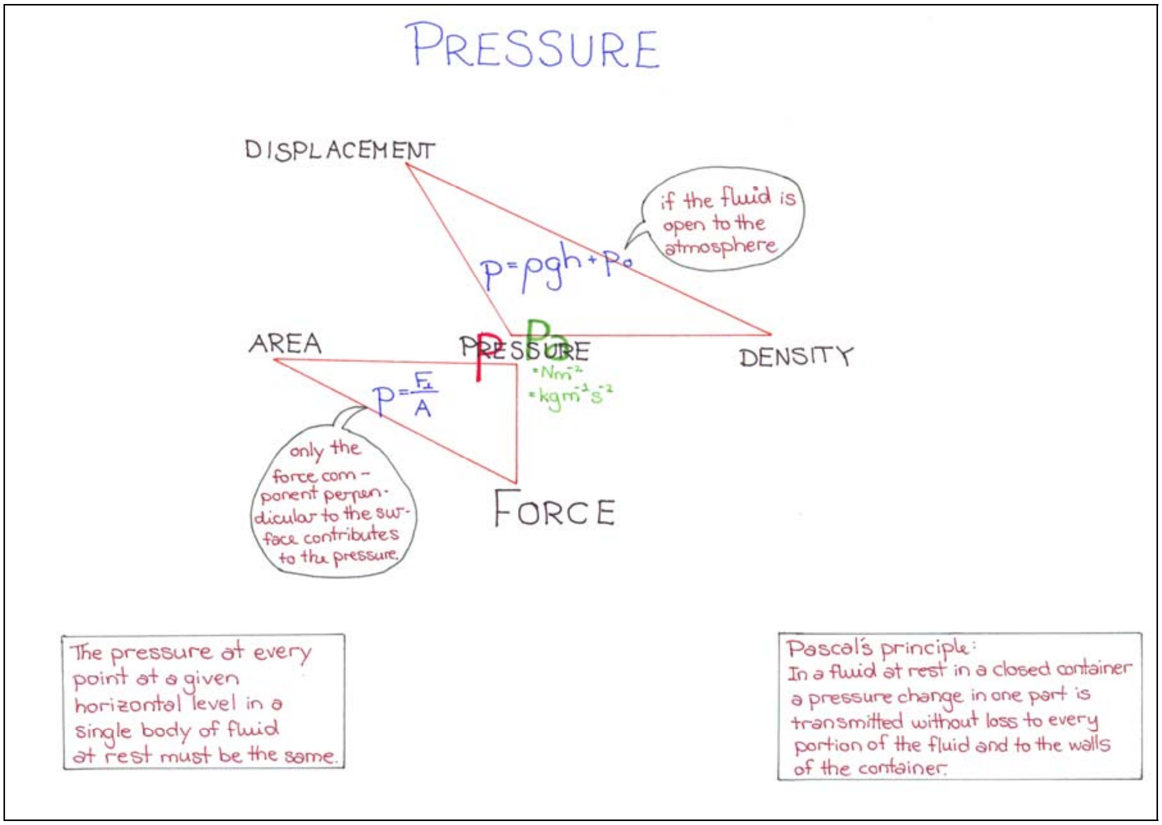




BUOYANCY

ARCHIMEDES' PRINCIPLE

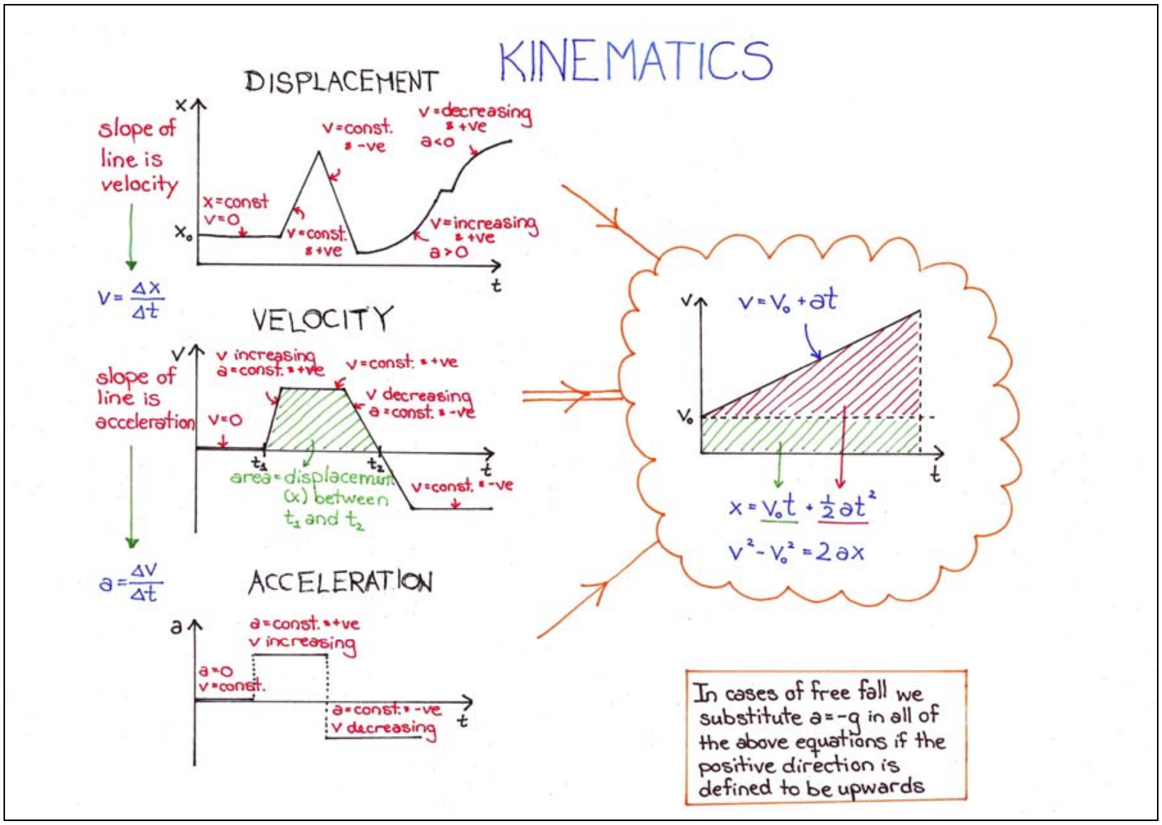
"When an object is immersed in a fluid there is an upward buoyant force equal to the weight of the volume of fluid displaced by the object."



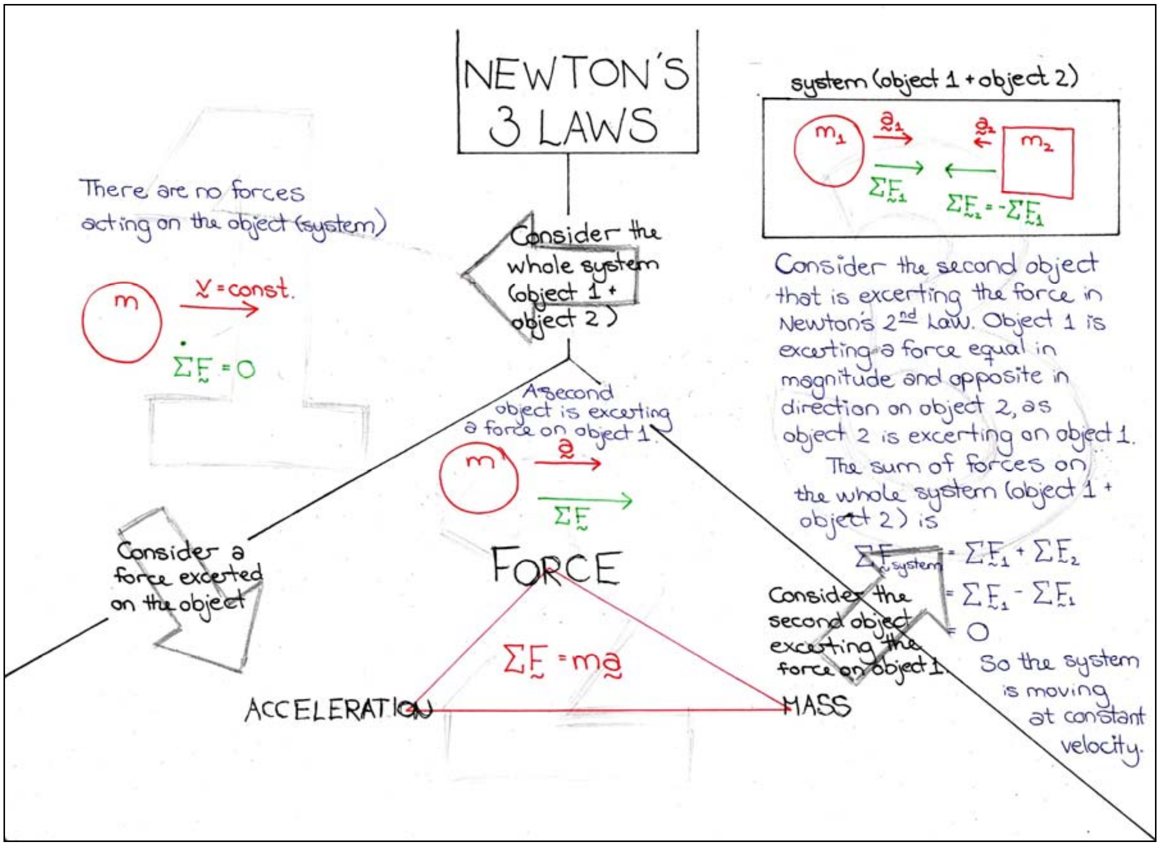
PRESSURE

The pressure at every point at a given horizontal level in a single body of fluid at rest must be the same.

Pascal's principle:
In a fluid at rest in a closed container a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container.



In cases of free fall we substitute $a=-g$ in all of the above equations if the positive direction is defined to be upwards

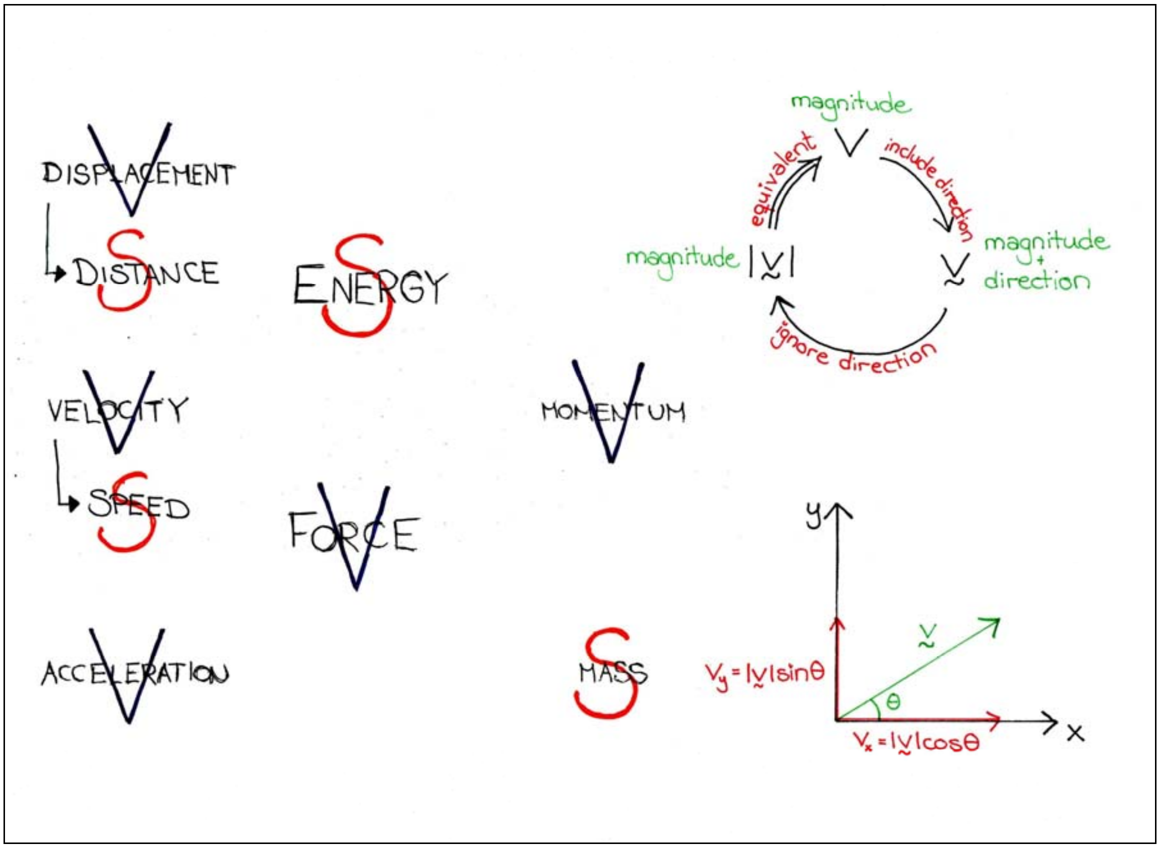


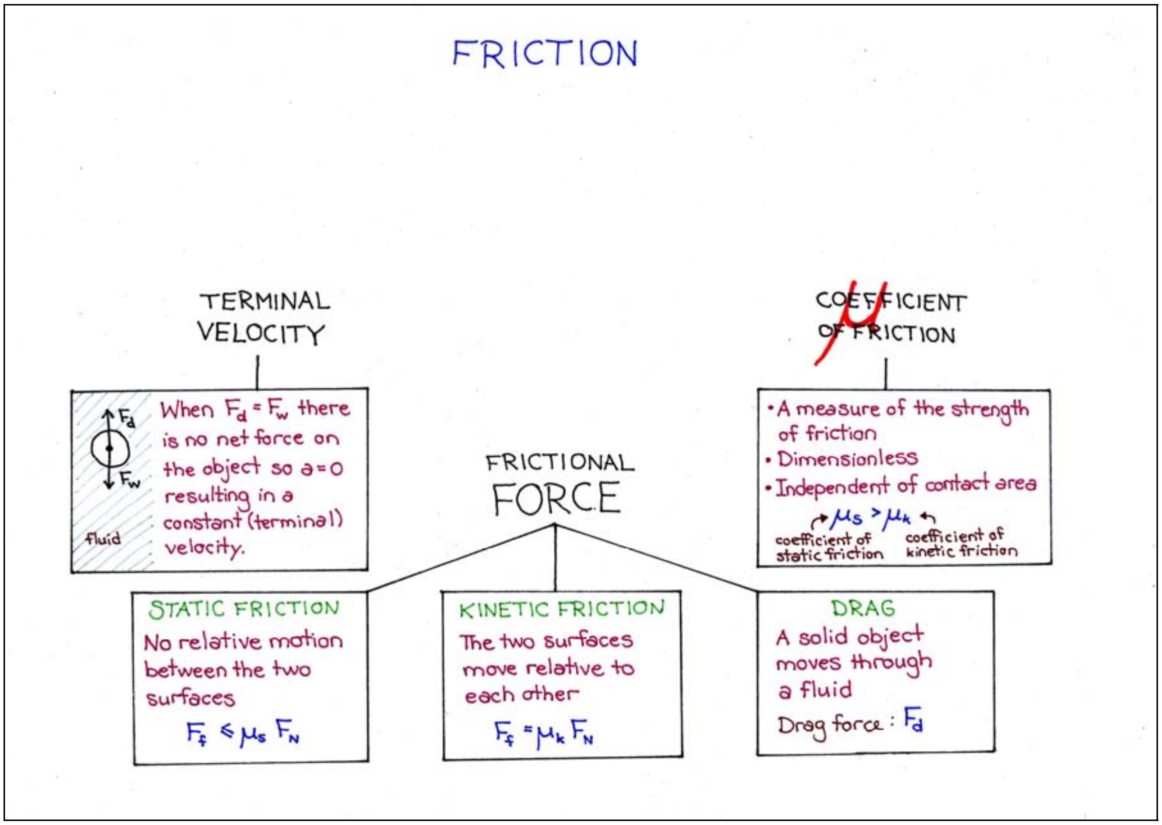
There are no forces acting on the object (system)

Consider the second object that is excerting the force in Newton's 2nd Law. Object 1 is excerting a force equal in magnitude and opposite in direction on object 2, as object 2 is excerting on object 1. The sum of forces on the whole system (object 1 + object 2) is

$$\Sigma \underset{\sim}{F}_{system} = \Sigma \underset{\sim}{F}_1 + \Sigma \underset{\sim}{F}_2 = \Sigma \underset{\sim}{F}_1 - \Sigma \underset{\sim}{F}_1 = 0$$

So the system is moving at constant velocity.





FRICTION

FRICTIONAL FORCE

TERMINAL VELOCITY

When $F_d = F_w$ there is no net force on the object so $a = 0$ resulting in a constant (terminal) velocity.

COEFFICIENT OF FRICTION (μ)

- A measure of the strength of friction
- Dimensionless
- Independent of contact area

$\mu_s > \mu_k$

coefficient of static friction

coefficient of kinetic friction

STATIC FRICTION

No relative motion between the two surfaces

$F_f \leqslant \mu_s F_N$

KINETIC FRICTION

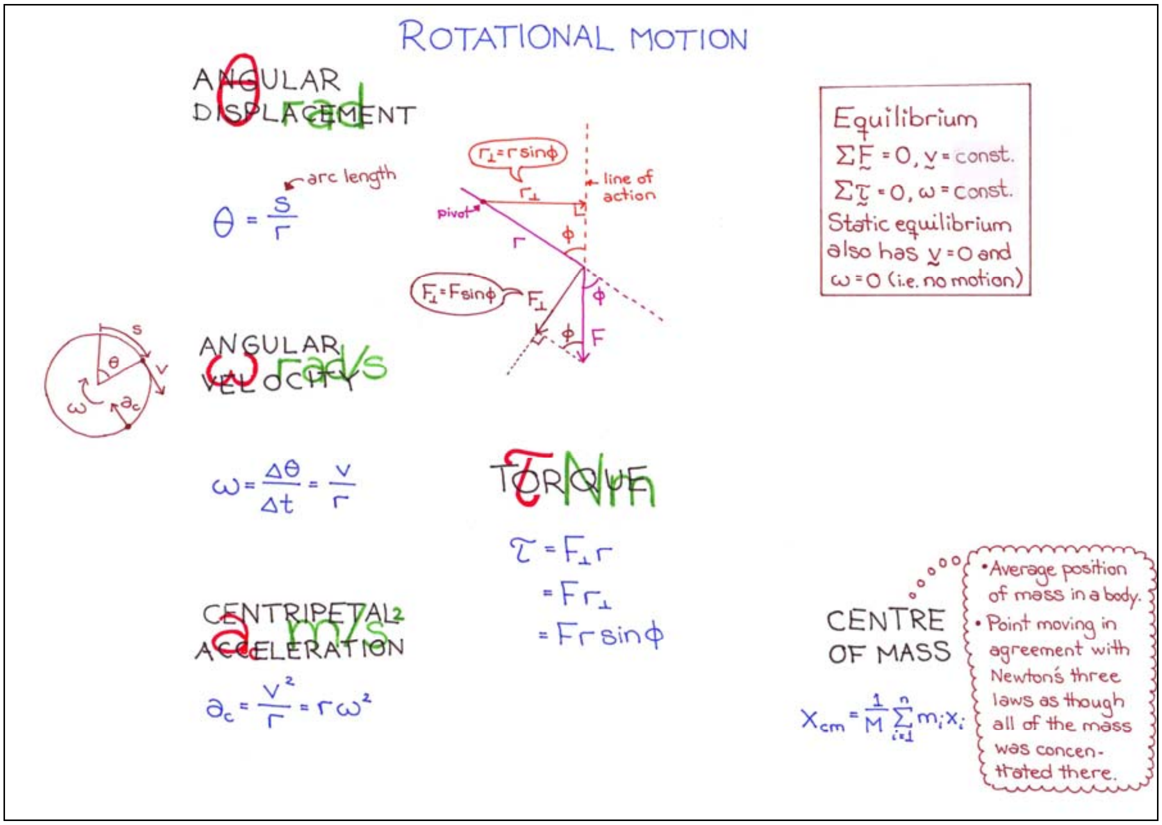
The two surfaces move relative to each other

$F_f = \mu_k F_N$

DRAG

A solid object moves through a fluid

Drag force : F_d



ROTATIONAL MOTION

ANGULAR DISPLACEMENT θ rad

$\theta = \frac{s}{r}$ ← arc length

ANGULAR VELOCITY ω rad/s

$\omega = \frac{\Delta\theta}{\Delta t} = \frac{v}{r}$

CENTRIPETAL ACCELERATION a m/s²

$a_c = \frac{v^2}{r} = r\omega^2$

TORQUE τ Nm

$r_\perp = r\sin\phi$

$F_\perp = F\sin\phi$

$\tau = F_\perp r$

$= F r_\perp$

$= F r \sin\phi$

Equilibrium

$\Sigma \underset{\sim}{F} = 0$, $\underset{\sim}{v}$ = const.

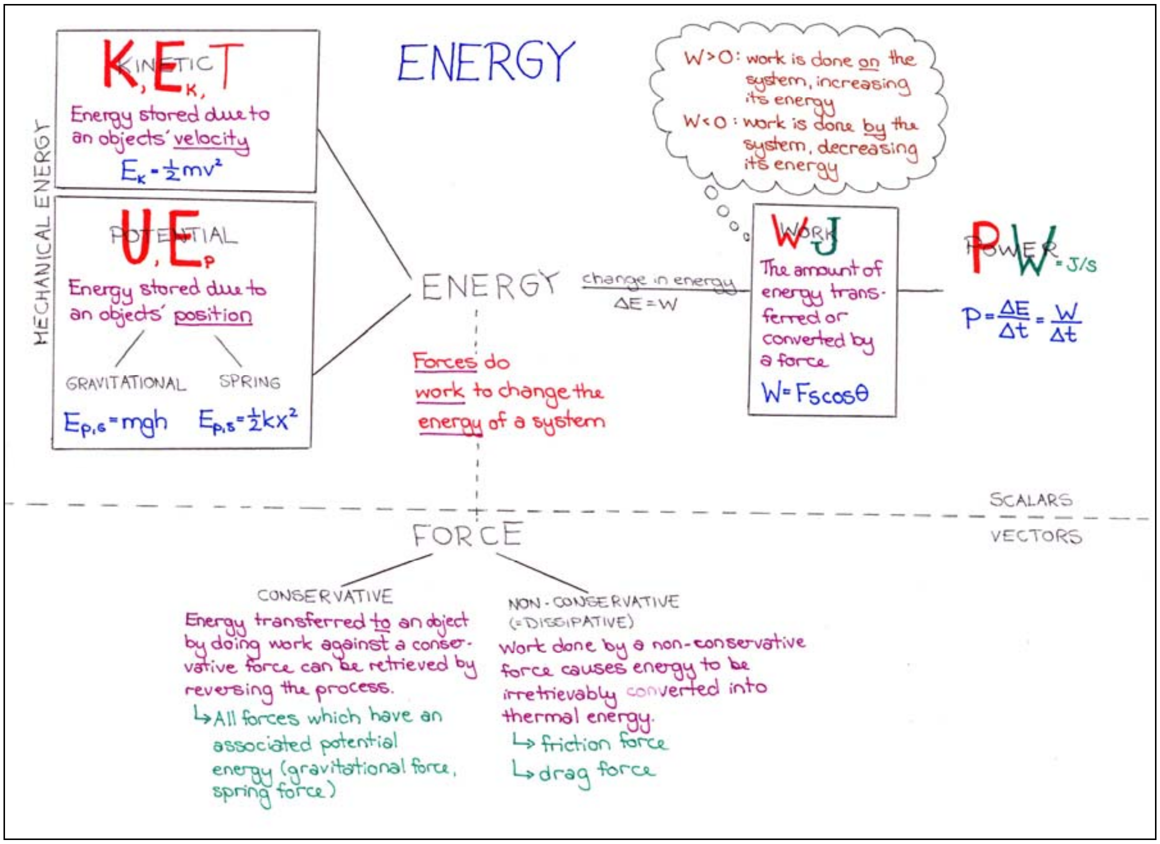
$\Sigma \underset{\sim}{\tau} = 0$, ω = const.

Static equilibrium also has $\underset{\sim}{v} = 0$ and ω = 0 (i.e. no motion)

CENTRE OF MASS

$x_{cm} = \frac{1}{M}\sum_{i=1}^{n} m_i x_i$

- Average position of mass in a body.
- Point moving in agreement with Newton's three laws as though all of the mass was concentrated there.



ENERGY

KINETIC K, E_K, T

Energy stored due to an objects' velocity

$E_K = \frac{1}{2}mv^2$

POTENTIAL U, E_P

Energy stored due to an objects' position

GRAVITATIONAL

$E_{P,G} = mgh$

SPRING

$E_{P,S} = \frac{1}{2}kx^2$

ENERGY

change in energy

$\Delta E = W$

Forces do work to change the energy of a system

WORK W J

The amount of energy transferred or converted by a force

$W = Fs\cos\theta$

W > 0 : work is done on the system, increasing its energy

W < 0 : work is done by the system, decreasing its energy

POWER P W = J/s

$P = \frac{\Delta E}{\Delta t} = \frac{W}{\Delta t}$

SCALARS

VECTORS

FORCE

CONSERVATIVE

Energy transferred to an object by doing work against a conservative force can be retrieved by reversing the process.

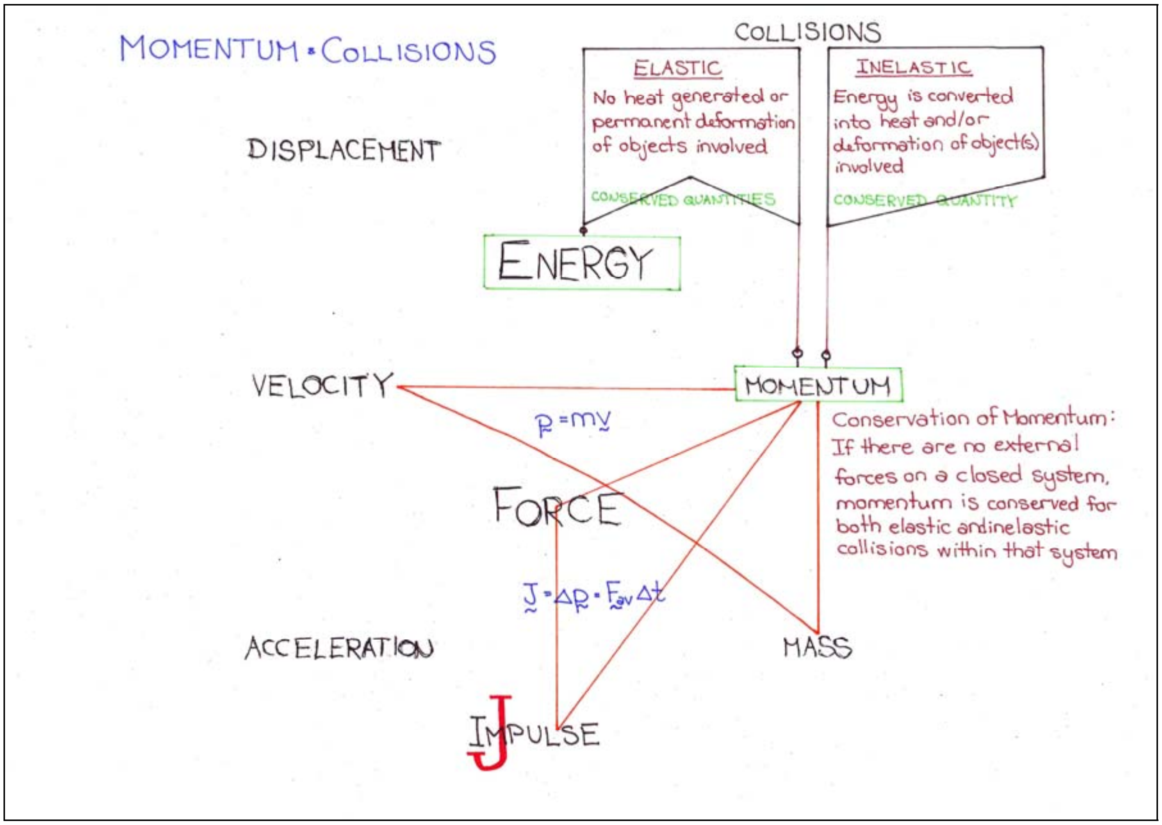
↳ All forces which have an associated potential energy (gravitational force, spring force)

NON-CONSERVATIVE (=DISSIPATIVE)

Work done by a non-conservative force causes energy to be irretrievably converted into thermal energy.

↳ friction force

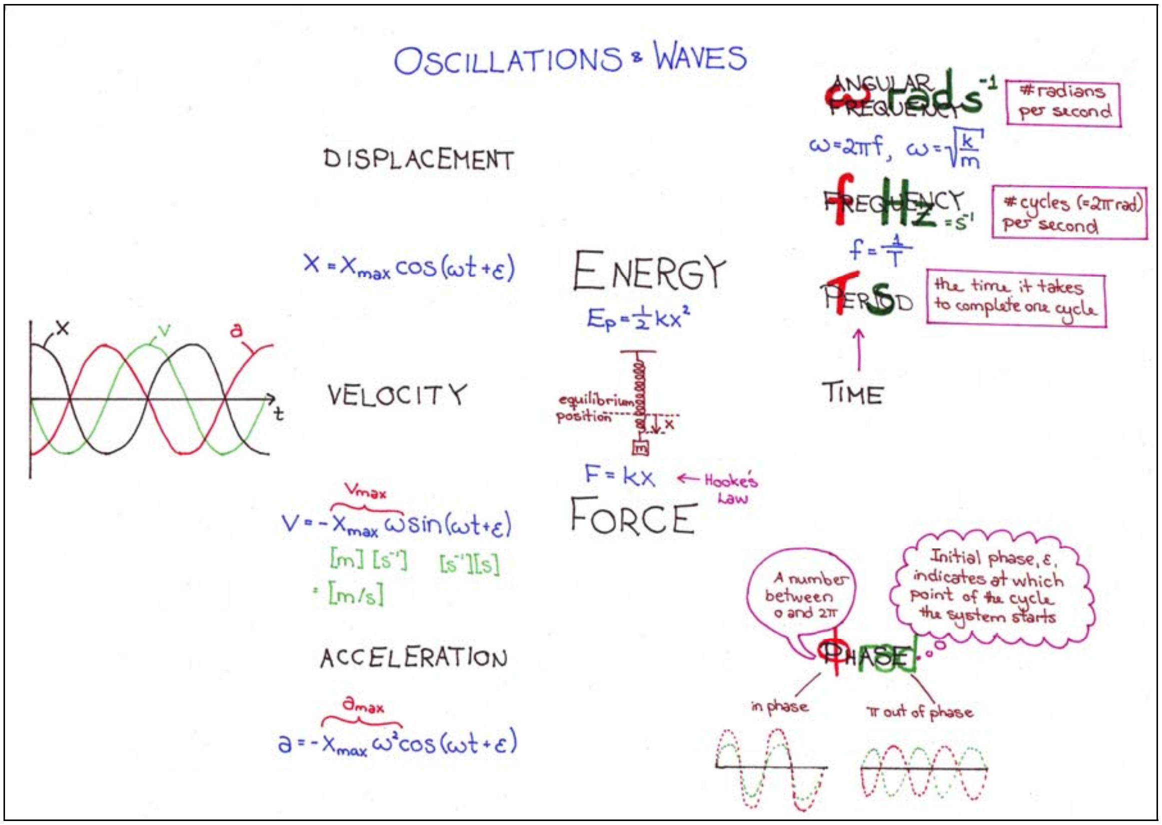
↳ drag force

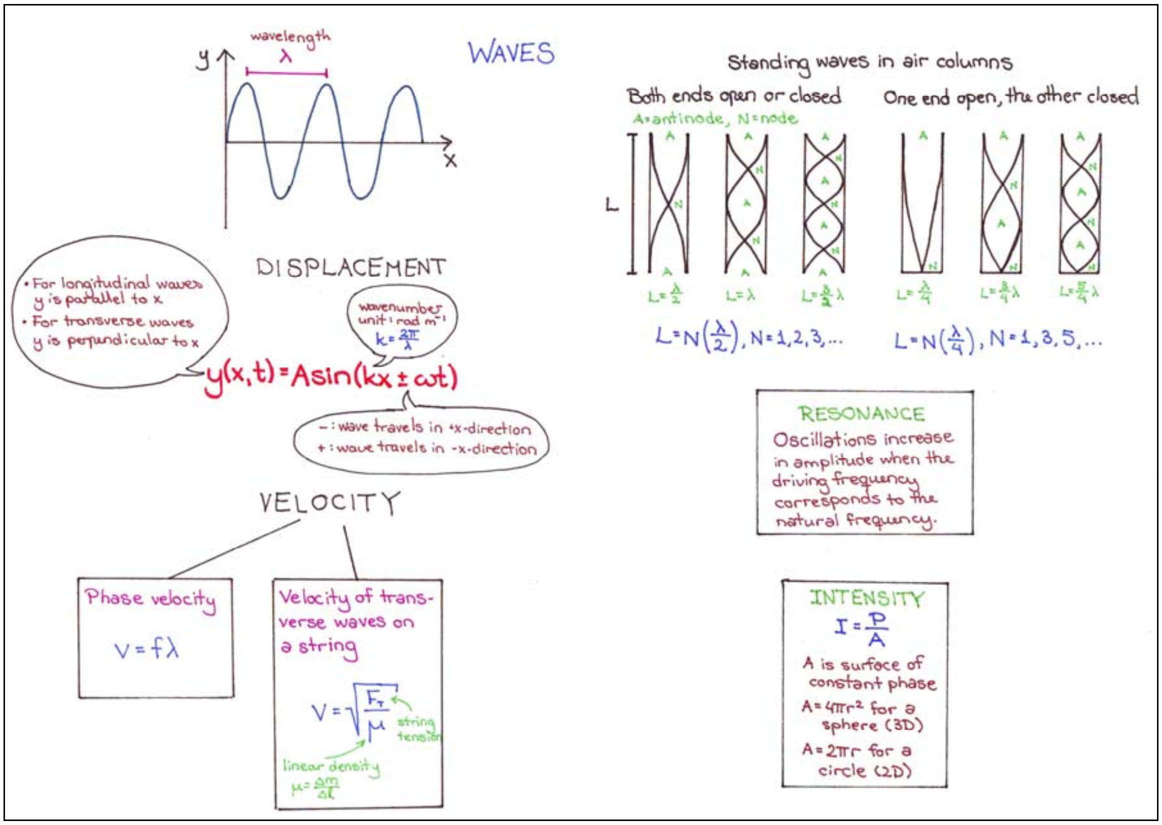


No heat generated or permanent deformation of objects involved

Energy is converted into heat and/or deformation of object(s) involved

Conservation of Momentum: If there are no external forces on a closed system, momentum is conserved for both elastic and inelastic collisions within that system





WAVES

wavelength λ

DISPLACEMENT

- For longitudinal waves y is parallel to x
- For transverse waves y is perpendicular to x

wavenumber
unit: rad m^{-1}
$k = \frac{2\pi}{\lambda}$

$$y(x,t) = A\sin(kx \pm \omega t)$$

−: wave travels in +x-direction
+: wave travels in -x-direction

VELOCITY

Phase velocity

$$v = f\lambda$$

Velocity of transverse waves on a string

$$v = \sqrt{\frac{F_T}{\mu}}$$

string tension

linear density $\mu = \frac{\Delta m}{\Delta l}$

Standing waves in air columns

Both ends open or closed

A = antinode, N = node

$L = \frac{\lambda}{2}$ $L = \lambda$ $L = \frac{3}{2}\lambda$

$L = N\left(\frac{\lambda}{2}\right), N = 1, 2, 3, \ldots$

One end open, the other closed

$L = \frac{\lambda}{4}$ $L = \frac{3}{4}\lambda$ $L = \frac{5}{4}\lambda$

$L = N\left(\frac{\lambda}{4}\right), N = 1, 3, 5, \ldots$

RESONANCE

Oscillations increase in amplitude when the driving frequency corresponds to the natural frequency.

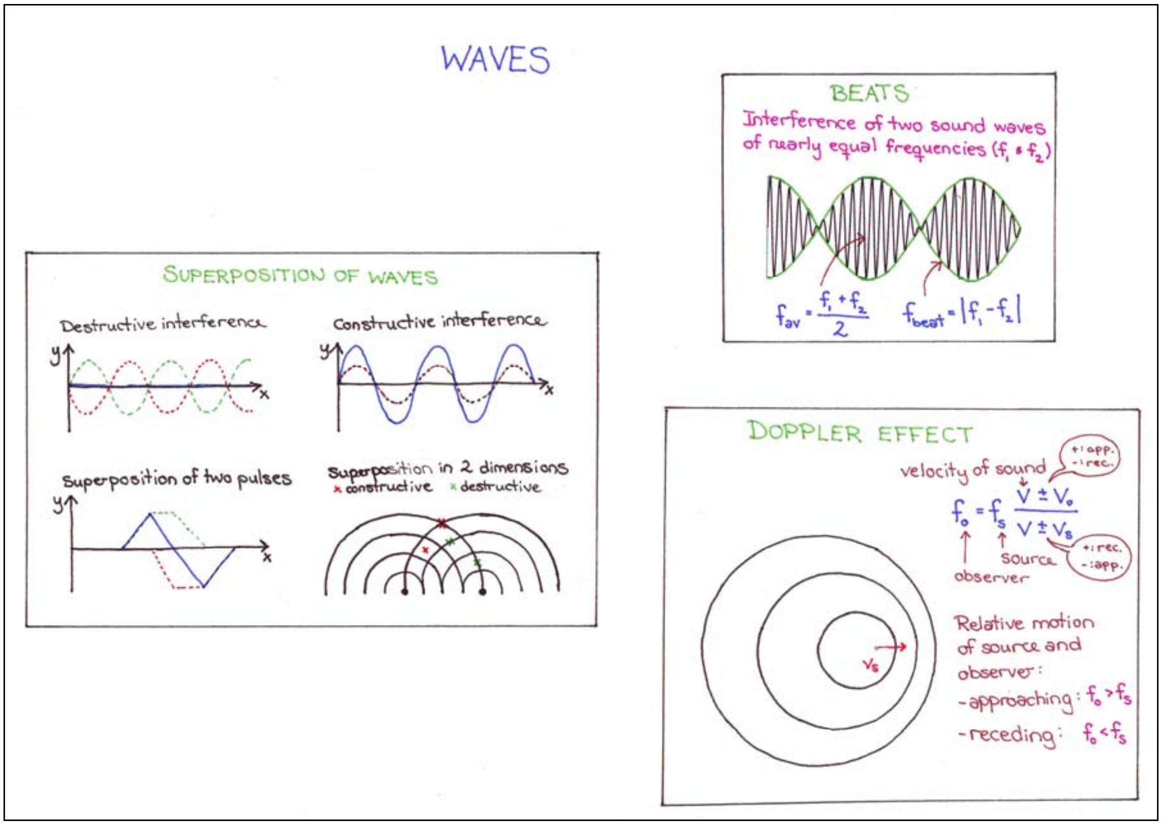
INTENSITY

$$I = \frac{P}{A}$$

A is surface of constant phase

$A = 4\pi r^2$ for a sphere (3D)

$A = 2\pi r$ for a circle (2D)



WAVES

SUPERPOSITION OF WAVES

Destructive interference

Constructive interference

Superposition of two pulses

Superposition in 2 dimensions
× constructive × destructive

BEATS

Interference of two sound waves of nearly equal frequencies ($f_1 \approx f_2$)

$f_{av} = \frac{f_1 + f_2}{2}$ $f_{beat} = |f_1 - f_2|$

DOPPLER EFFECT

velocity of sound

+: app.
-: rec.

$$f_o = f_s \frac{V \pm V_o}{V \pm V_s}$$

+: rec.
-: app.

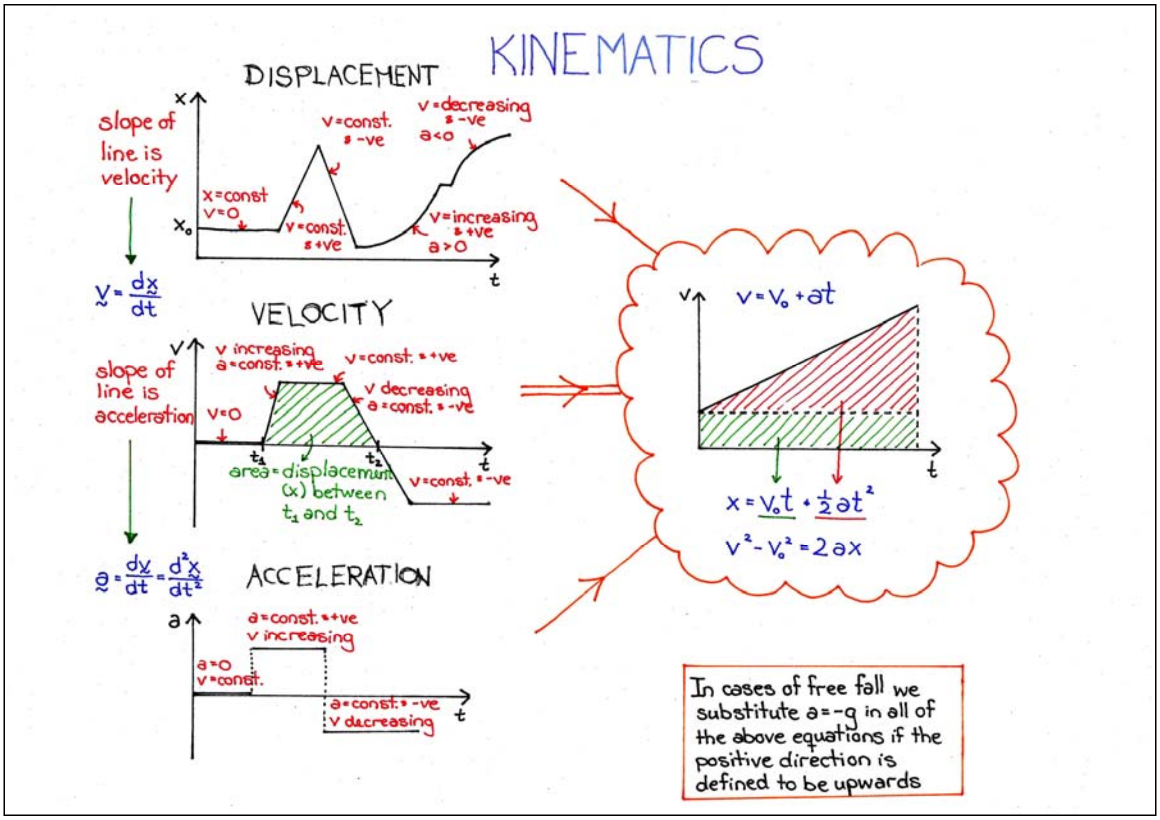
observer

source

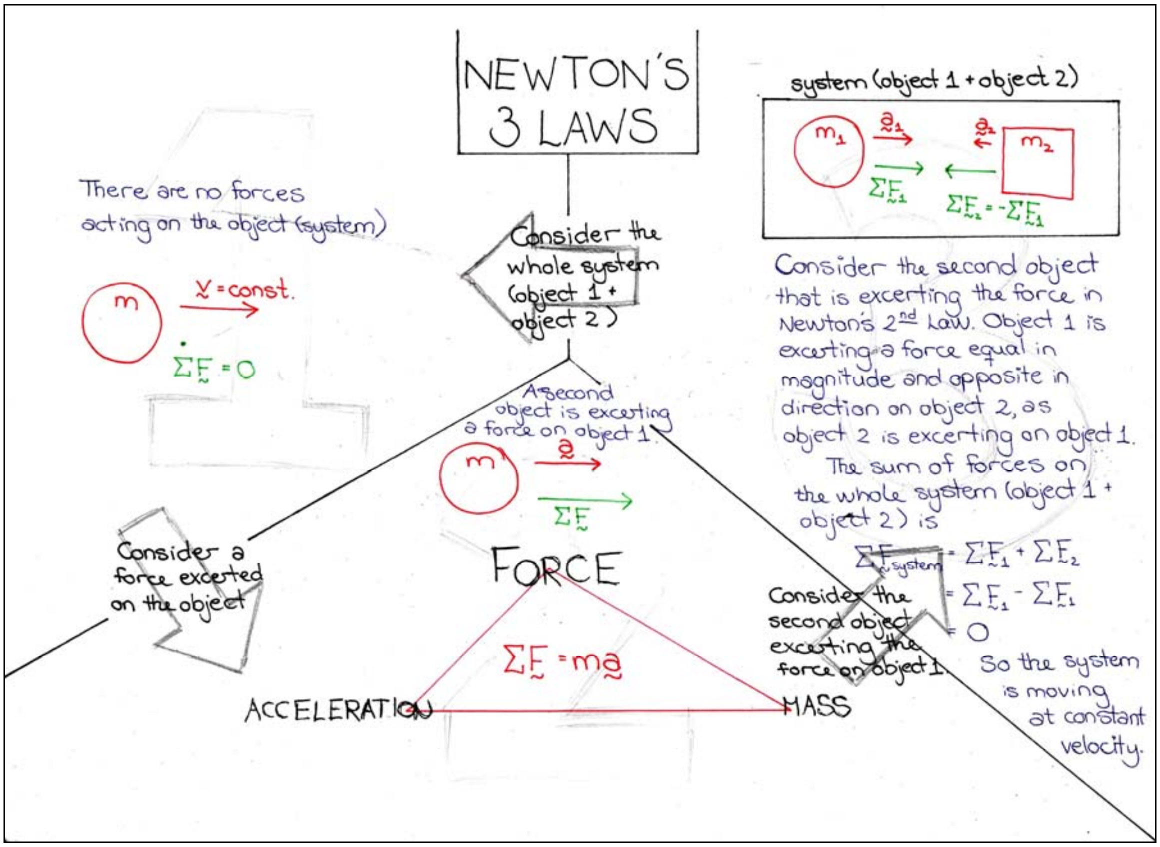
Relative motion of source and observer:

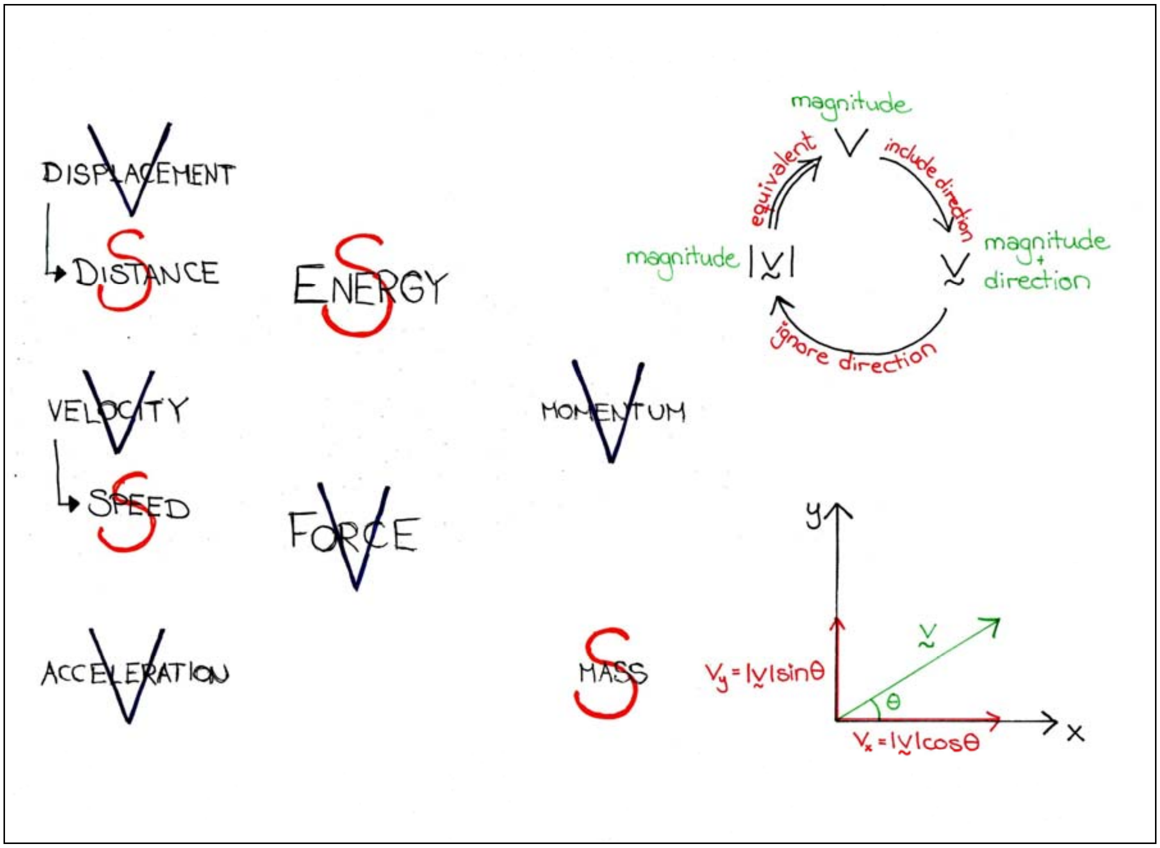
- approaching: $f_o > f_s$
- receding: $f_o < f_s$

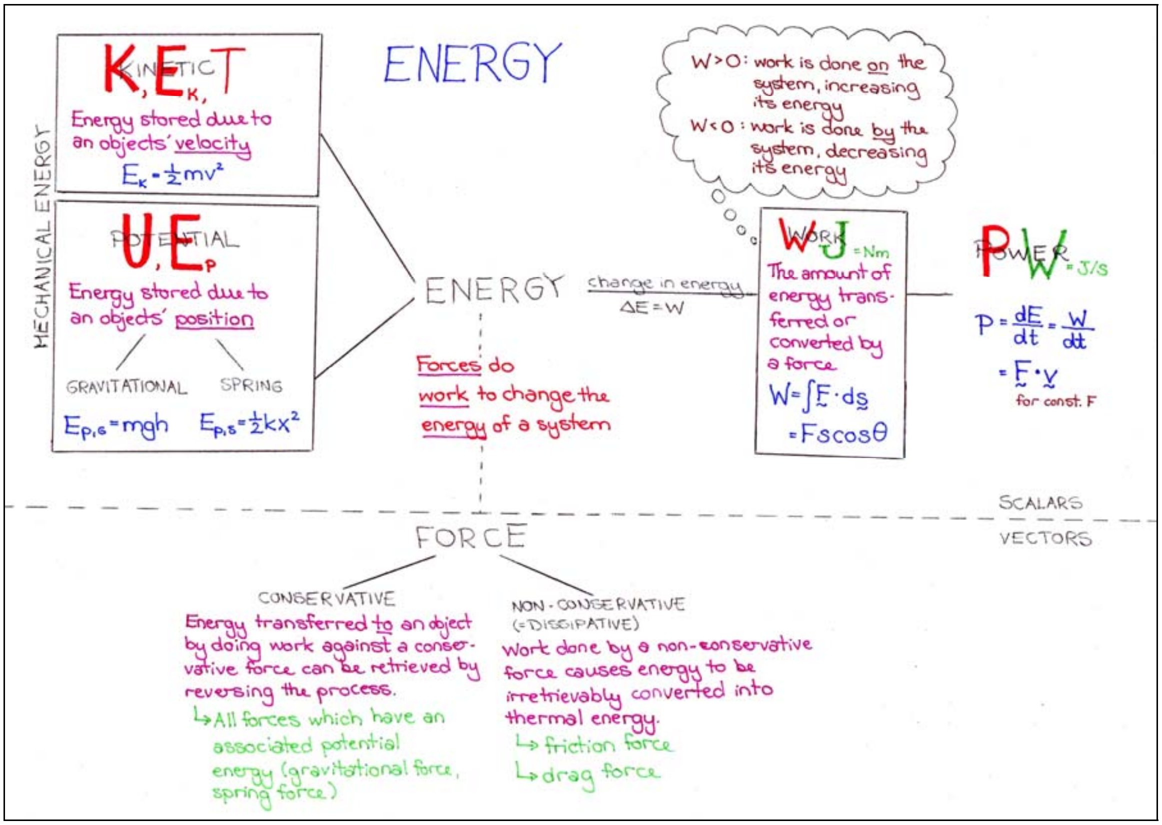
D.2 The Regular course



In cases of free fall we substitute $a = -g$ in all of the above equations if the positive direction is defined to be upwards


NEWTON'S 3 LAWS
There are no forces acting on the object (system)
m
$\underset{\sim}{v}$ = const.
$\Sigma \underset{\sim}{F} = 0$
Consider the whole system (object 1 + object 2)
A second object is excerting a force on object 1.
m
$\underset{\sim}{a}$
$\Sigma \underset{\sim}{F}$
FORCE
$\Sigma \underset{\sim}{F} = m\underset{\sim}{a}$
ACCELERATION
MASS
Consider a force excerted on the object
Consider the second object excerting the force on object 1.
system (object 1 + object 2)
m_1
$\underset{\sim}{a}_1$
$\underset{\sim}{a}_2$
m_2
$\Sigma \underset{\sim}{F}_1$
$\Sigma \underset{\sim}{F}_2 = -\Sigma \underset{\sim}{F}_1$
Consider the second object that is excerting the force in Newton's 2nd Law. Object 1 is excerting a force equal in magnitude and opposite in direction on object 2, as object 2 is excerting on object 1.
The sum of forces on the whole system (object 1 + object 2) is
$\Sigma \underset{\sim}{F}_{system} = \Sigma \underset{\sim}{F}_1 + \Sigma \underset{\sim}{F}_2$
$= \Sigma \underset{\sim}{F}_1 - \Sigma \underset{\sim}{F}_1$
$= 0$
So the system is moving at constant velocity.


DISPLACEMENT
DISTANCE
ENERGY
VELOCITY
SPEED
MOMENTUM
FORCE
ACCELERATION
MASS
V
S
magnitude
V
include direction
magnitude + direction
$\underset{\sim}{v}$
ignore direction
magnitude
$|\underset{\sim}{v}|$
equivalent
y
x
$\underset{\sim}{v}$
θ
$V_y = |\underset{\sim}{v}| \sin\theta$
$V_x = |\underset{\sim}{v}| \cos\theta$



Energy stored due to an objects' velocity

$E_K = \frac{1}{2}mv^2$

Energy stored due to an objects' position

$E_{P,G} = mgh$ $E_{P,S} = \frac{1}{2}kx^2$

$\Delta E = W$

Forces do work to change the energy of a system

W>0: work is done on the system, increasing its energy

W<0: work is done by the system, decreasing its energy

The amount of energy transferred or converted by a force

$W = \int \underset{\sim}{F} \cdot d\underset{\sim}{s} = Fs\cos\theta$

$P = \frac{dE}{dt} = \frac{W}{dt} = \underset{\sim}{F} \cdot \underset{\sim}{v}$ for const. F

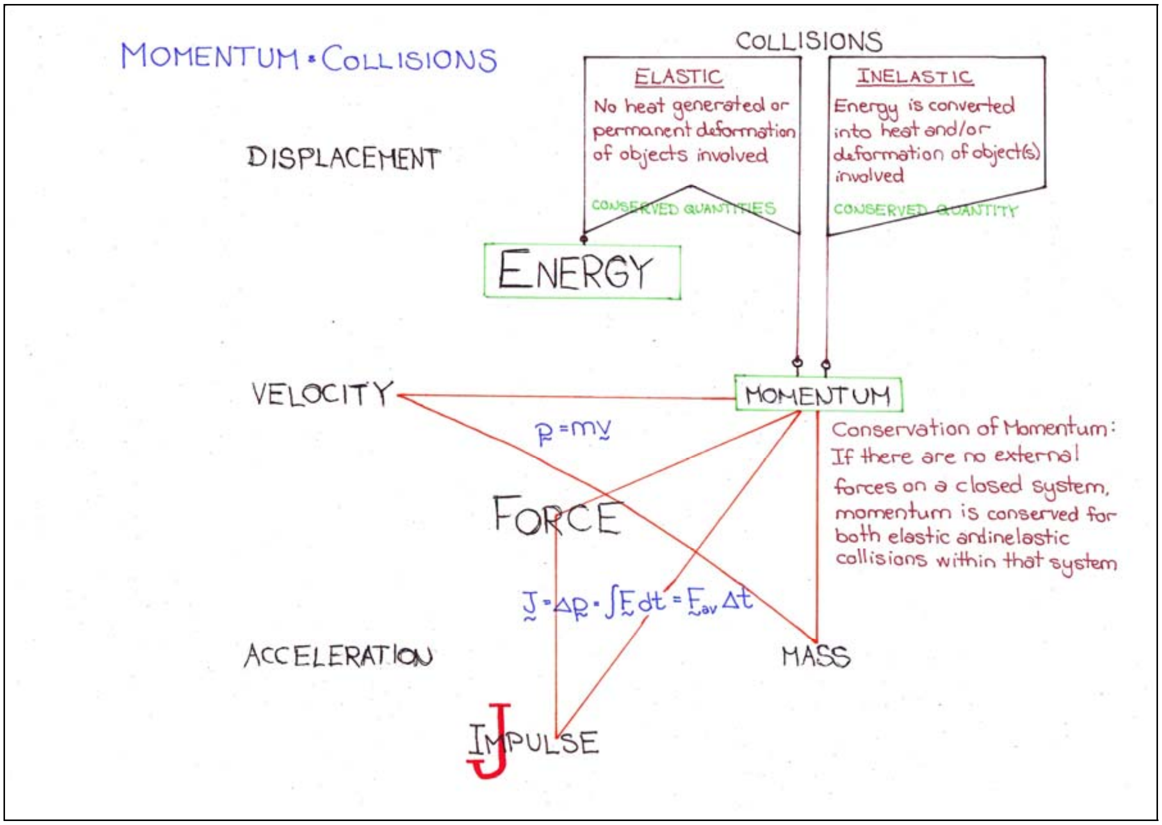
Energy transferred to an object by doing work against a conservative force can be retrieved by reversing the process.

↳ All forces which have an associated potential energy (gravitational force, spring force)

Work done by a non-conservative force causes energy to be irretrievably converted into thermal energy.

↳ friction force

↳ drag force



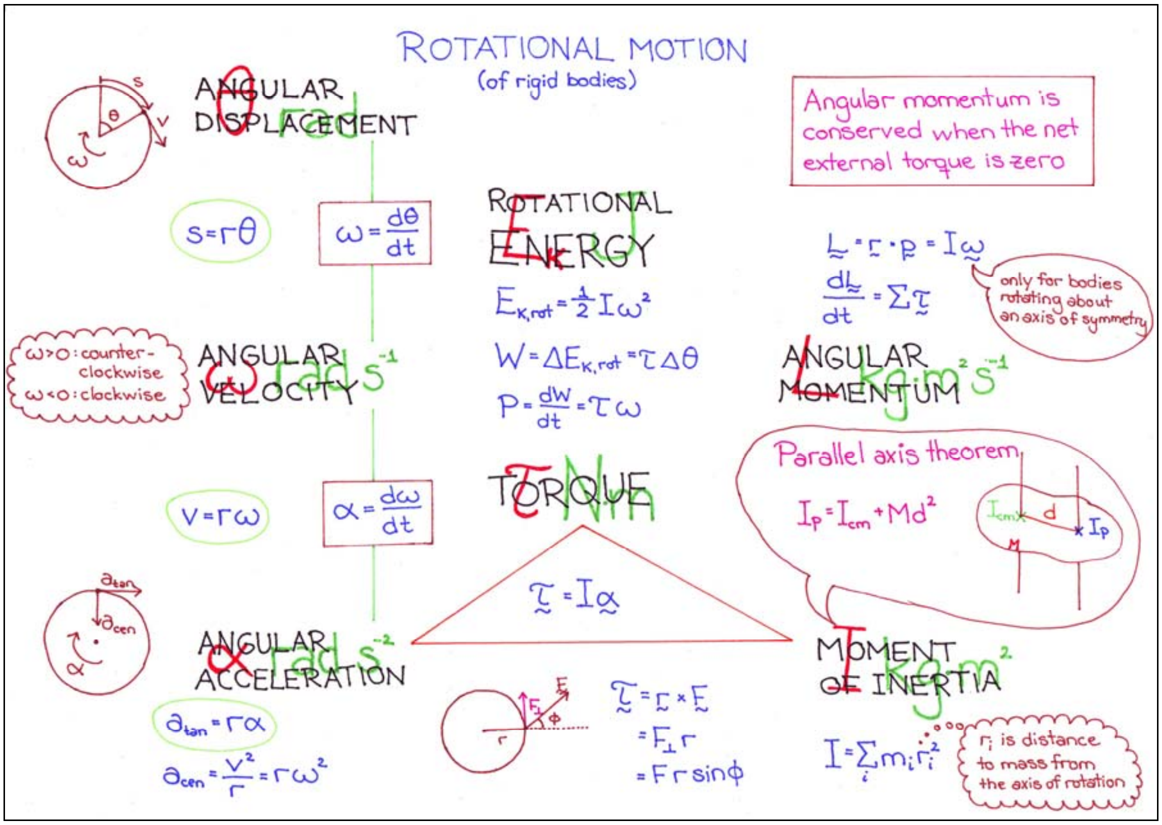
No heat generated or permanent deformation of objects involved

Energy is converted into heat and/or deformation of object(s) involved

$\underset{\sim}{p} = m\underset{\sim}{v}$

Conservation of Momentum: If there are no external forces on a closed system, momentum is conserved for both elastic and inelastic collisions within that system

$\underset{\sim}{J} = \Delta\underset{\sim}{p} = \int \underset{\sim}{F}\,dt = \underset{\sim}{F}_{av}\Delta t$



ROTATIONAL MOTION
(of rigid bodies)

Angular momentum is conserved when the net external torque is zero

$s = r\theta$

$\omega = \frac{d\theta}{dt}$

$v = r\omega$

$\alpha = \frac{d\omega}{dt}$

ω>0: counter-clockwise
ω<0: clockwise

$a_{tan} = r\alpha$

$a_{cen} = \frac{v^2}{r} = r\omega^2$

$E_{K,rot} = \frac{1}{2} I\omega^2$

$W = \Delta E_{K,rot} = \tau\Delta\theta$

$P = \frac{dW}{dt} = \tau\omega$

$\underset{\sim}{\tau} = I\underset{\sim}{\alpha}$

$\underset{\sim}{\tau} = \underset{\sim}{r} \times \underset{\sim}{F}$
$= F_\perp r$
$= F r \sin\phi$

$\underset{\sim}{L} = \underset{\sim}{r} \cdot \underset{\sim}{p} = I\underset{\sim}{\omega}$

$\frac{d\underset{\sim}{L}}{dt} = \Sigma\underset{\sim}{\tau}$

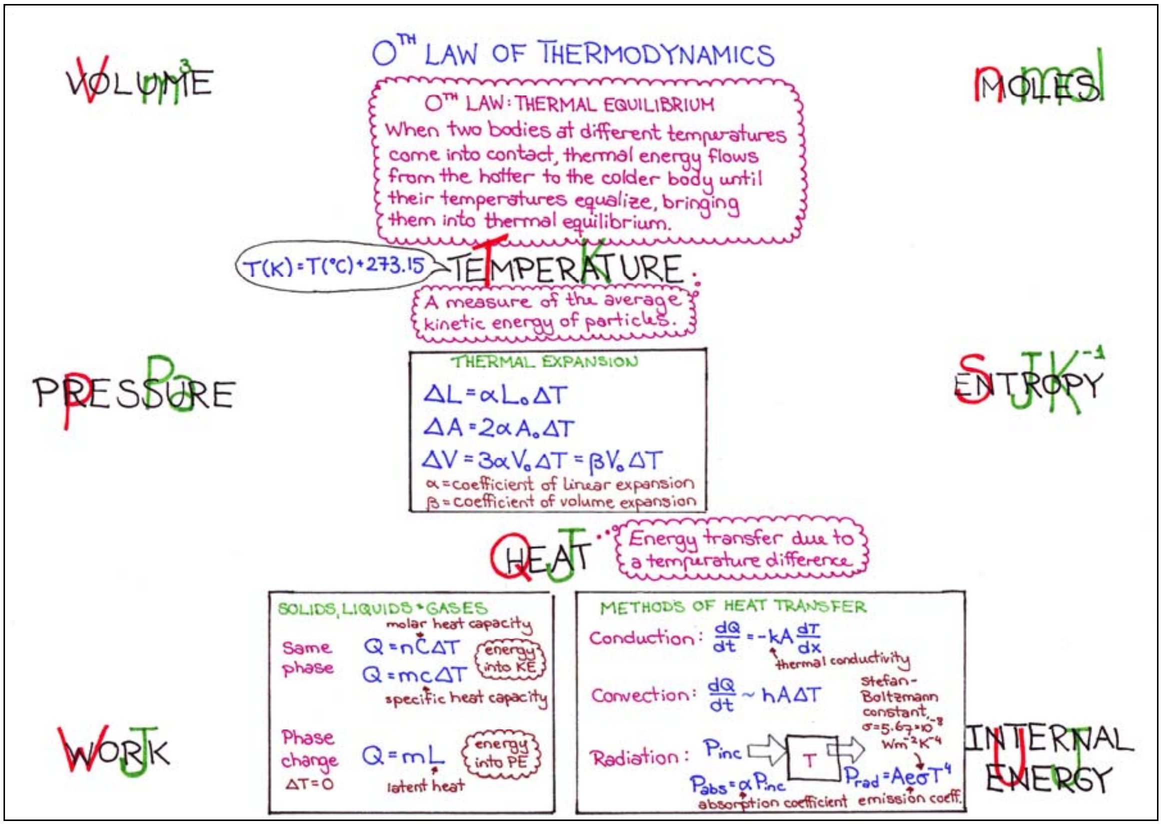
only for bodies rotating about an axis of symmetry

Parallel axis theorem

$I_p = I_{cm} + Md^2$

$I = \sum_i m_i r_i^2$

r_i is distance to mass from the axis of rotation



0TH LAW OF THERMODYNAMICS

0TH LAW: THERMAL EQUILIBRIUM

When two bodies at different temperatures come into contact, thermal energy flows from the hotter to the colder body until their temperatures equalize, bringing them into thermal equilibrium.

$T(K) = T(°C) + 273.15$

TEMPERATURE: A measure of the average kinetic energy of particles.

THERMAL EXPANSION

$\Delta L = \alpha L_0 \Delta T$

$\Delta A = 2\alpha A_0 \Delta T$

$\Delta V = 3\alpha V_0 \Delta T = \beta V_0 \Delta T$

α = coefficient of linear expansion
β = coefficient of volume expansion

HEAT: Energy transfer due to a temperature difference

SOLIDS, LIQUIDS + GASES

Same phase: $Q = n\overset{\text{molar heat capacity}}{C}\Delta T$, $Q = m\underset{\text{specific heat capacity}}{c}\Delta T$ (energy into KE)

Phase change, $\Delta T = 0$: $Q = m\underset{\text{latent heat}}{L}$ (energy into PE)

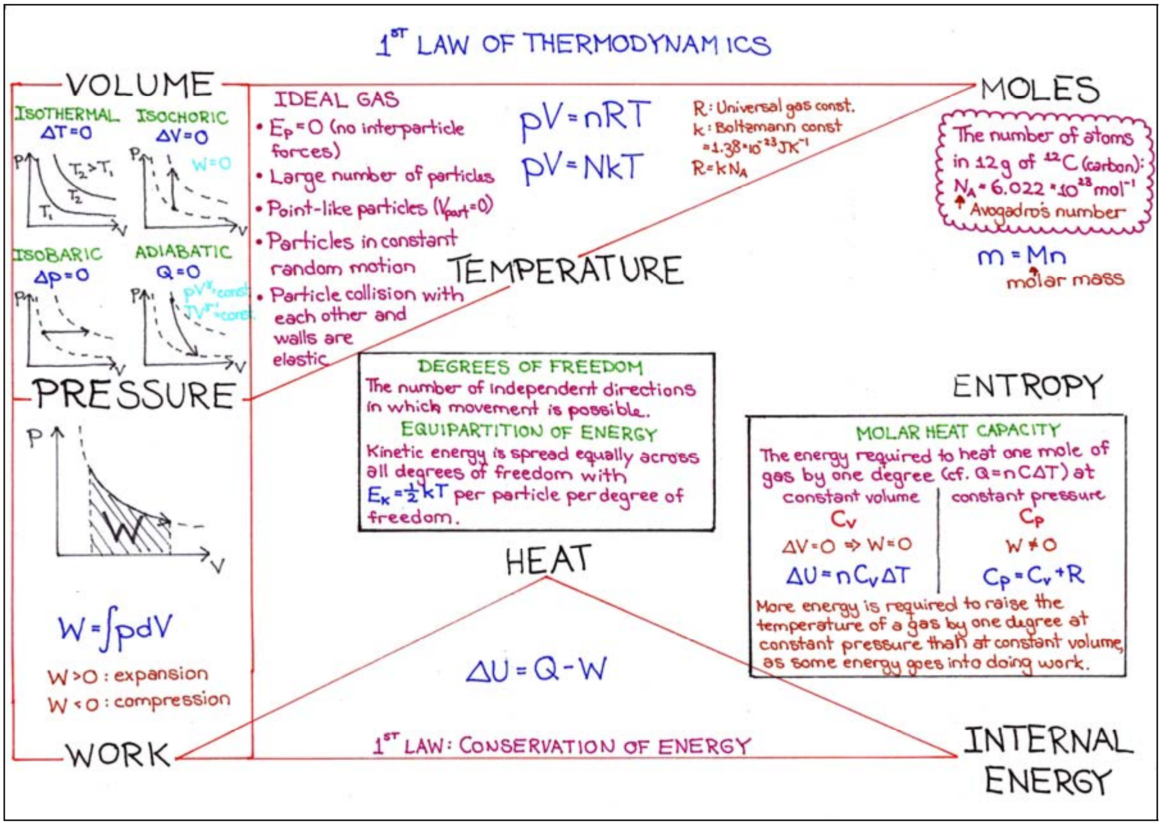
METHODS OF HEAT TRANSFER

Conduction: $\frac{dQ}{dt} = -\underset{\text{thermal conductivity}}{k}A\frac{dT}{dx}$

Convection: $\frac{dQ}{dt} \sim hA\Delta T$

Radiation: $P_{abs} = \underset{\text{absorption coefficient}}{\alpha} P_{inc}$, $P_{rad} = A\underset{\text{emission coeff.}}{e}\sigma T^4$

Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$



1ST LAW OF THERMODYNAMICS

VOLUME

ISOTHERMAL $\Delta T = 0$

ISOCHORIC $\Delta V = 0$

ISOBARIC $\Delta p = 0$

ADIABATIC $Q = 0$

PRESSURE

$W = \int p dV$

$W > 0$: expansion

$W < 0$: compression

WORK

IDEAL GAS

- $E_P = 0$ (no interparticle forces)
- Large number of particles
- Point-like particles ($V_{part} = 0$)
- Particles in constant random motion
- Particle collision with each other and walls are elastic

$pV = nRT$

$pV = NkT$

R: Universal gas const.

k: Boltzmann const $= 1.38 \cdot 10^{-23} JK^{-1}$

$R = kN_A$

TEMPERATURE

MOLES

The number of atoms in 12 g of ^{12}C (carbon): $N_A = 6.022 \cdot 10^{23} mol^{-1}$

Avogadro's number

$m = Mn$

molar mass

DEGREES OF FREEDOM

The number of independent directions in which movement is possible.

EQUIPARTITION OF ENERGY

Kinetic energy is spread equally across all degrees of freedom with $E_K = \frac{1}{2}kT$ per particle per degree of freedom.

ENTROPY

MOLAR HEAT CAPACITY

The energy required to heat one mole of gas by one degree (cf. $Q = nC\Delta T$) at

constant volume	constant pressure
C_V	C_P
$\Delta V = 0 \Rightarrow W = 0$	$W \neq 0$
$\Delta U = nC_V\Delta T$	$C_P = C_V + R$

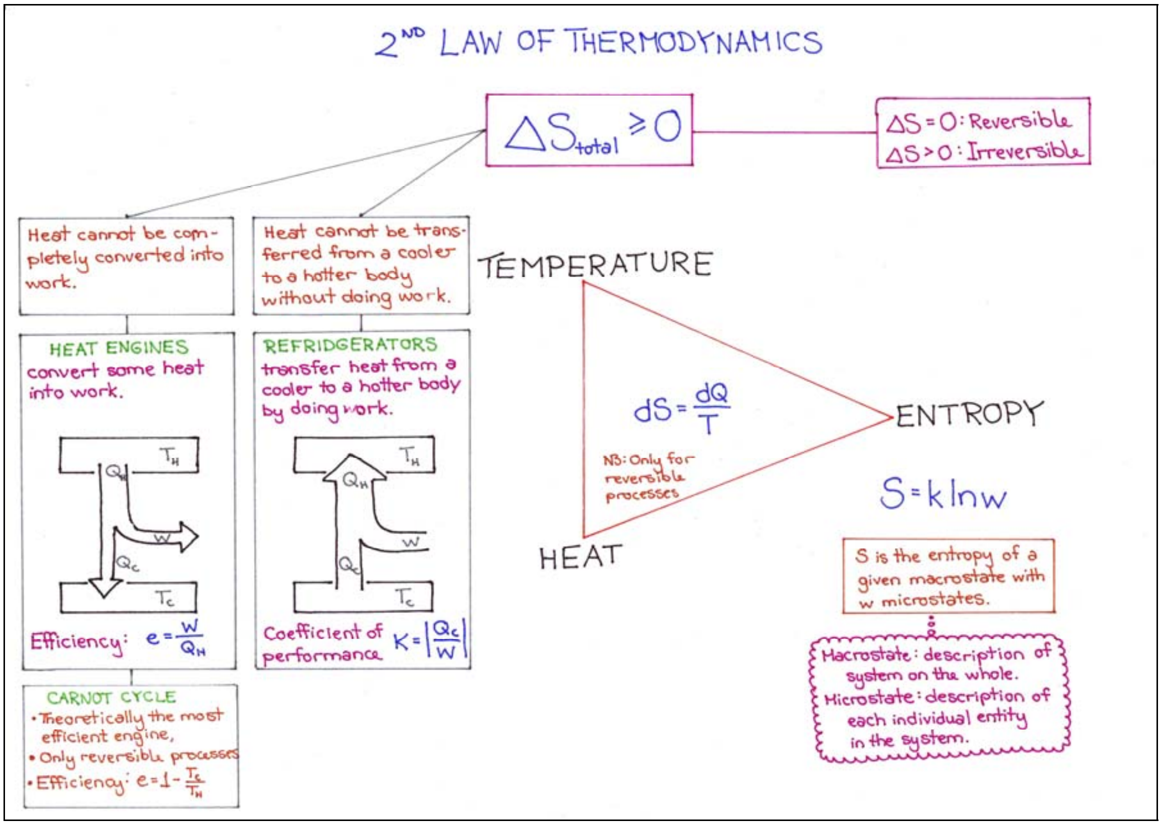
More energy is required to raise the temperature of a gas by one degree at constant pressure than at constant volume, as some energy goes into doing work.

HEAT

$\Delta U = Q - W$

1ST LAW: CONSERVATION OF ENERGY

INTERNAL ENERGY



2ND LAW OF THERMODYNAMICS

$\Delta S_{total} \geq 0$

$\Delta S = 0$: Reversible

$\Delta S > 0$: Irreversible

Heat cannot be completely converted into work.

Heat cannot be transferred from a cooler to a hotter body without doing work.

HEAT ENGINES

convert some heat into work.

Efficiency: $e = \frac{W}{Q_H}$

REFRIDGERATORS

transfer heat from a cooler to a hotter body by doing work.

Coefficient of performance $K = \left|\frac{Q_C}{W}\right|$

CARNOT CYCLE

- Theoretically the most efficient engine,
- Only reversible processes
- Efficiency: $e = 1 - \frac{T_C}{T_H}$

TEMPERATURE

$dS = \frac{dQ}{T}$

NB: Only for reversible processes

HEAT

ENTROPY

$S = k \ln w$

S is the entropy of a given macrostate with w microstates.

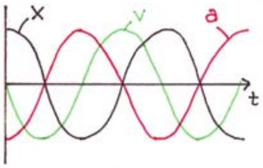
Macrostate: description of system on the whole.

Microstate: description of each individual entity in the system.

OSCILLATIONS

DISPLACEMENT

$x = x_{max} \cos(\omega t + \varepsilon)$



VELOCITY

$v = \frac{dx}{dt} = \overbrace{-x_{max}\,\omega}^{v_{max}} \sin(\omega t + \varepsilon)$

$[m]\,[s^{-1}] \quad [s^{-1}][s]$

$= [m/s]$

ACCELERATION

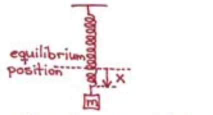
$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = \overbrace{-x_{max}\,\omega^2}^{a_{max}} \cos(\omega t + \varepsilon)$

In an oscillating system without damping, energy is conserved

$E = E_K + E_P$

ENERGY

$E_P = \frac{1}{2}kx^2$



$F = -kx$ ← Hooke's Law

FORCE

ω ANGULAR FREQUENCY rad s^{-1} — #radians per second

$\omega = 2\pi f, \ \omega = \sqrt{\frac{k}{m}}$

f FREQUENCY Hz $= s^{-1}$ — #cycles (=2π rad) per second

$f = \frac{1}{T}$

T PERIOD s — the time it takes to complete one cycle

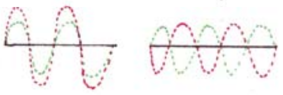
↑

TIME

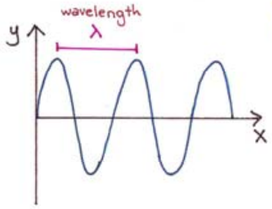
A number between 0 and 2π

Initial phase, ε, indicates at which point of the cycle the system starts

Φ PHASE rad



WAVES



DISPLACEMENT

- For longitudinal waves y is parallel to x
- For transverse waves y is perpendicular to x

$y(x,t) = A\sin(kx \pm \omega t)$

wavenumber
unit: rad m^{-1}
$k = \frac{2\pi}{\lambda}$

− : wave travels in +x-direction
+ : wave travels in −x-direction

VELOCITY

Phase velocity

$v = f\lambda$

Velocity of transverse waves on a string

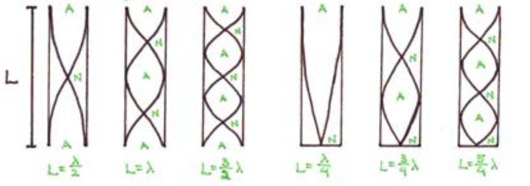
$v = \sqrt{\frac{F_T}{\mu}}$ ← string tension

linear density $\mu = \frac{\Delta m}{\Delta \ell}$

Standing waves in air columns

Both ends open or closed — One end open, the other closed

A = antinode, N = node



$L = N\left(\frac{\lambda}{2}\right), N = 1, 2, 3, \ldots$

$L = N\left(\frac{\lambda}{4}\right), N = 1, 3, 5, \ldots$

RESONANCE

Oscillations increase in amplitude when the driving frequency corresponds to the natural frequency.

INTENSITY

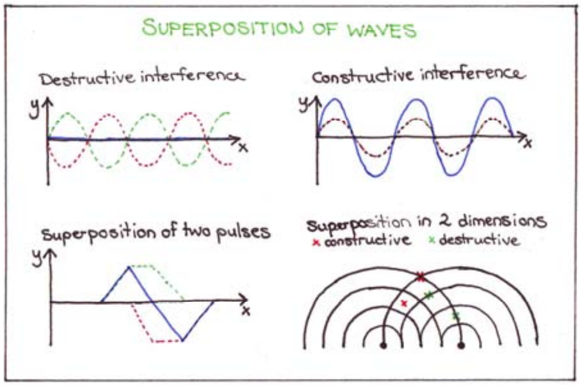
$I = \frac{P}{A}$

A is surface of constant phase

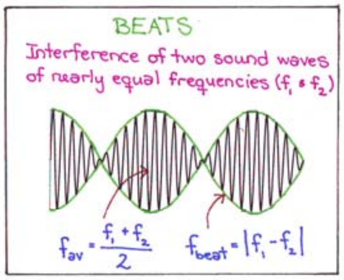
$A = 4\pi r^2$ for a sphere (3D)

$A = 2\pi r$ for a circle (2D)

WAVES



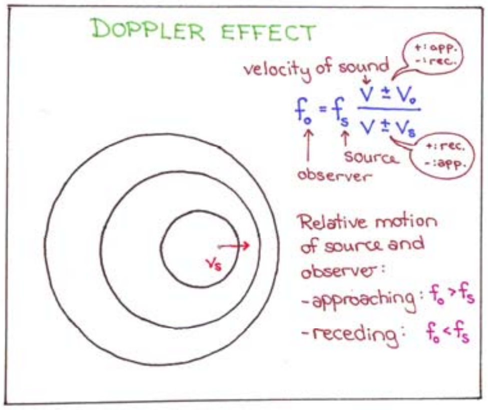
SUPERPOSITION OF WAVES



BEATS

Interference of two sound waves of nearly equal frequencies $(f_1 \approx f_2)$

$$f_{av} = \frac{f_1 + f_2}{2} \qquad f_{beat} = |f_1 - f_2|$$



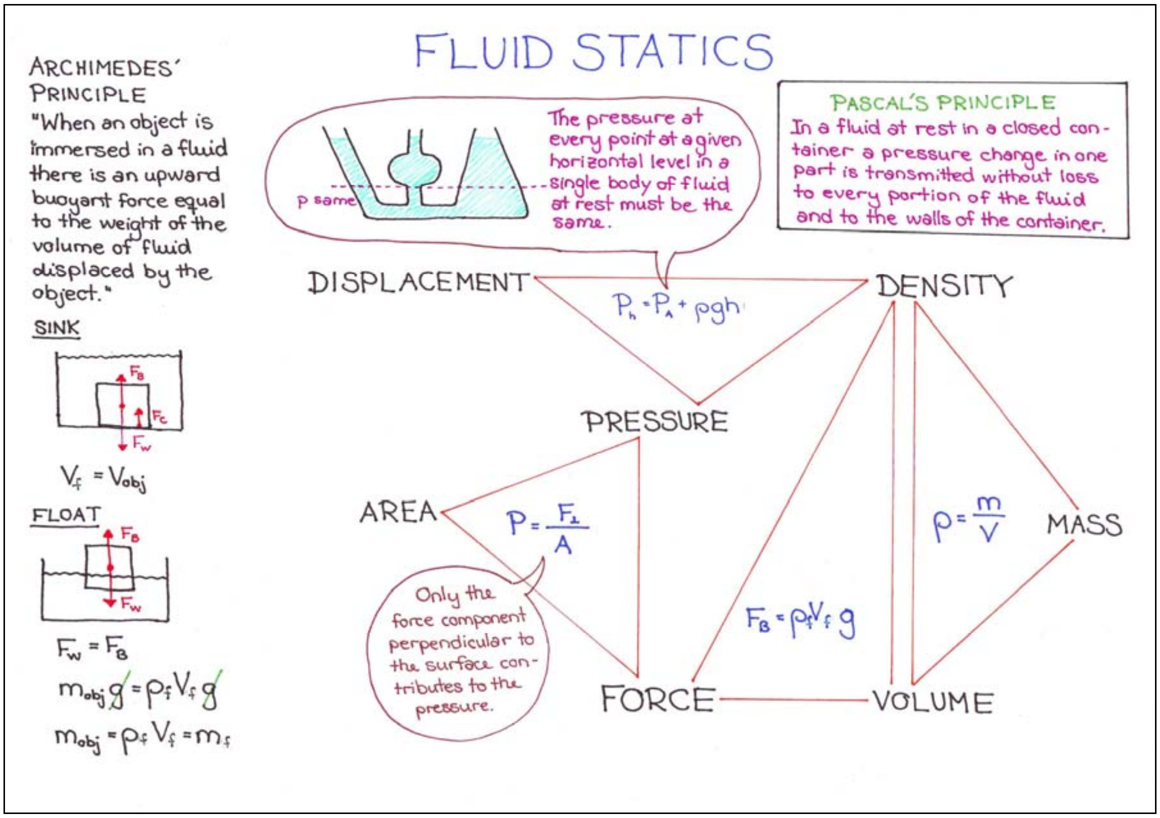
DOPPLER EFFECT

$$f_o = f_s \frac{V \pm V_o}{V \pm V_s}$$

Relative motion of source and observer:

- approaching: $f_o > f_s$
- receding: $f_o < f_s$

D.3 The Environmental course



FLUID STATICS

ARCHIMEDES' PRINCIPLE

"When an object is immersed in a fluid there is an upward buoyant force equal to the weight of the volume of fluid displaced by the object."

SINK

$V_f = V_{obj}$

FLOAT

$F_w = F_B$

$m_{obj}\cancel{g} = \rho_f V_f \cancel{g}$

$m_{obj} = \rho_f V_f = m_f$

The pressure at every point at a given horizontal level in a single body of fluid at rest must be the same.

PASCAL'S PRINCIPLE

In a fluid at rest in a closed container a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container.

$P_h = P_A + \rho g h$

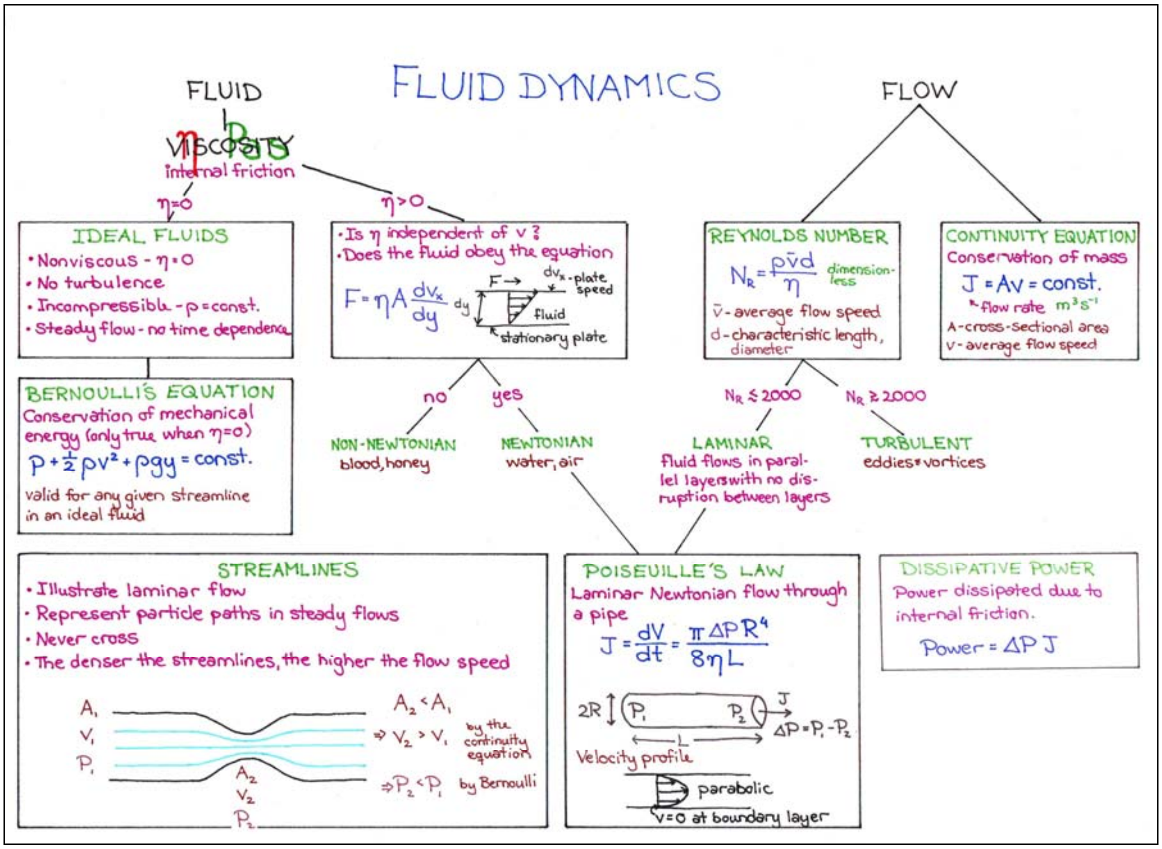
$P = \frac{F_\perp}{A}$

Only the force component perpendicular to the surface contributes to the pressure.

$F_B = \rho_f V_f g$

$\rho = \frac{m}{V}$

FLUID DYNAMICS



FLUID

VISCOSITY η Pa s

internal friction

$\eta = 0$

IDEAL FLUIDS

- Nonviscous - $\eta = 0$
- No turbulence
- Incompressible - $\rho = \text{const.}$
- Steady flow - no time dependence

BERNOULLI'S EQUATION

Conservation of mechanical energy (only true when $\eta = 0$)

$$P + \frac{1}{2}\rho v^2 + \rho g y = \text{const.}$$

valid for any given streamline in an ideal fluid

$\eta > 0$

- Is η independent of v?
- Does the fluid obey the equation

$$F = \eta A \frac{dv_x}{dy}$$

no — **NON-NEWTONIAN** blood, honey

yes — **NEWTONIAN** water, air

FLOW

REYNOLDS NUMBER

$$N_R = \frac{\rho \bar{v} d}{\eta}$$ dimensionless

$\bar{v}$ - average flow speed

d - characteristic length, diameter

$N_R \lesssim 2000$ — **LAMINAR** fluid flows in parallel layers with no disruption between layers

$N_R \gtrsim 2000$ — **TURBULENT** eddies + vortices

CONTINUITY EQUATION

Conservation of mass

$$J = Av = \text{const.}$$

J - flow rate $m^3 s^{-1}$

A - cross-sectional area

v - average flow speed

STREAMLINES

- Illustrate laminar flow
- Represent particle paths in steady flows
- Never cross
- The denser the streamlines, the higher the flow speed

$A_2 < A_1$

$\Rightarrow v_2 > v_1$ by the continuity equation

$\Rightarrow P_2 < P_1$ by Bernoulli

POISEUILLE'S LAW

Laminar Newtonian flow through a pipe

$$J = \frac{dV}{dt} = \frac{\pi \Delta P R^4}{8 \eta L}$$

$\Delta P = P_1 - P_2$

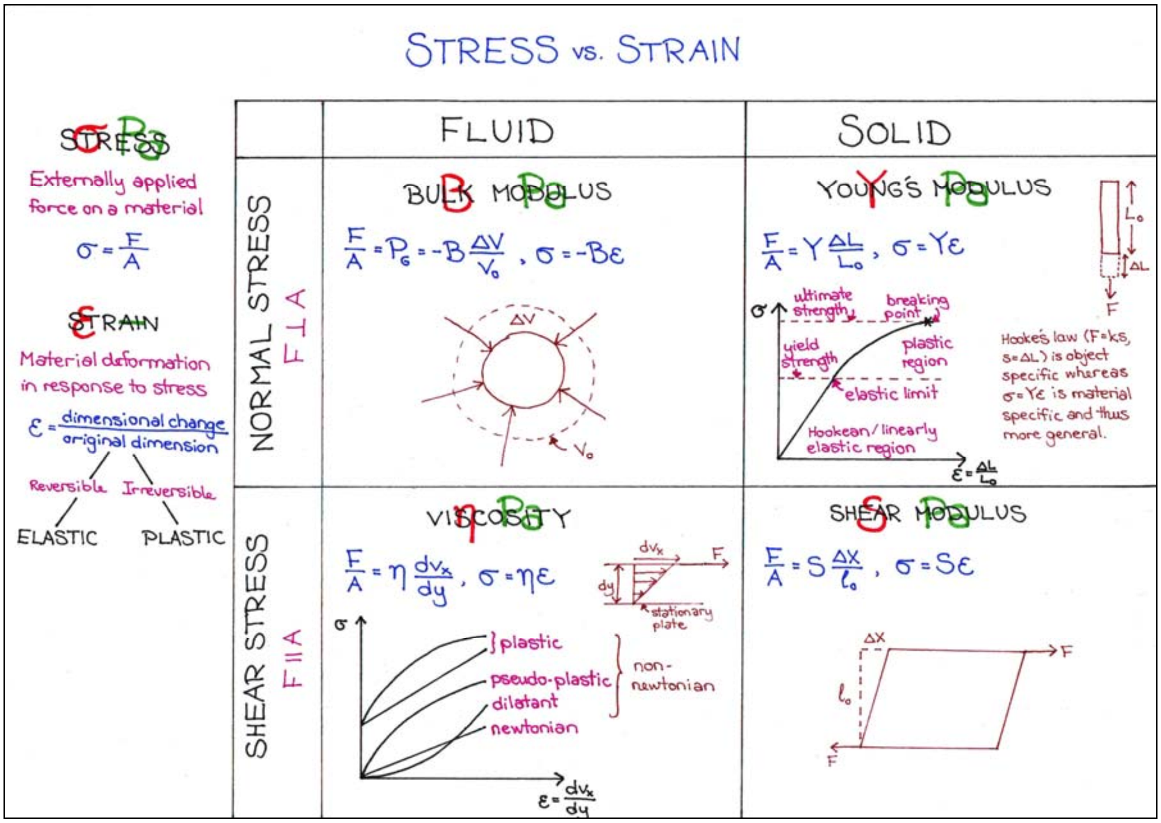
Velocity profile

DISSIPATIVE POWER

Power dissipated due to internal friction.

$$\text{Power} = \Delta P\, J$$

STRESS vs. STRAIN



STRESS σ Pa

Externally applied force on a material

$$\sigma = \frac{F}{A}$$

STRAIN ε

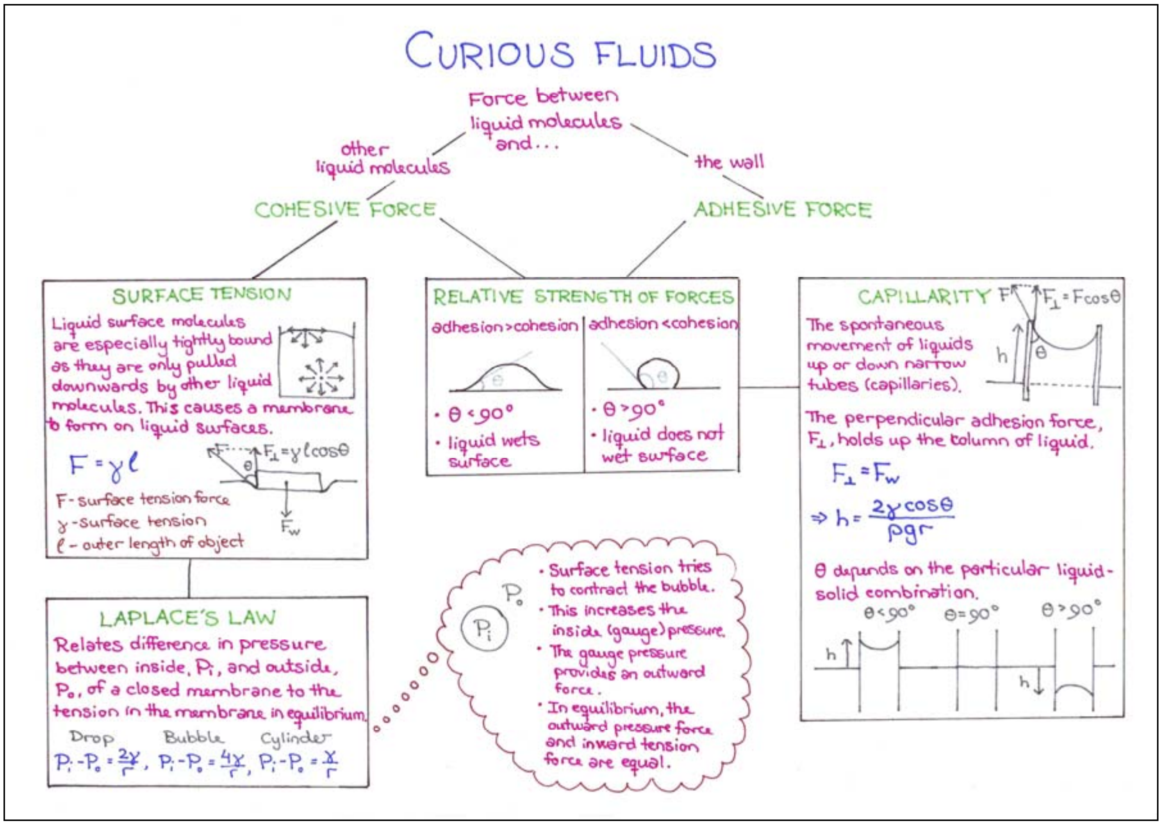
Material deformation in response to stress

$$\varepsilon = \frac{\text{dimensional change}}{\text{original dimension}}$$

Reversible — ELASTIC

Irreversible — PLASTIC

	FLUID	SOLID
NORMAL STRESS $F \perp A$	BULK MODULUS B Pa $\frac{F}{A} = P_G = -B\frac{\Delta V}{V_0}$, $\sigma = -B\varepsilon$	YOUNG'S MODULUS Y Pa $\frac{F}{A} = Y\frac{\Delta L}{L_0}$, $\sigma = Y\varepsilon$ Hooke's law ($F = ks$, $s = \Delta L$) is object specific whereas $\sigma = Y\varepsilon$ is material specific and thus more general.
SHEAR STRESS $F \parallel A$	VISCOSITY η Pa s $\frac{F}{A} = \eta\frac{dv_x}{dy}$, $\sigma = \eta\varepsilon$	SHEAR MODULUS S Pa $\frac{F}{A} = S\frac{\Delta x}{l_0}$, $\sigma = S\varepsilon$



CURIOUS FLUIDS

Force between liquid molecules and...

other liquid molecules — COHESIVE FORCE

the wall — ADHESIVE FORCE

SURFACE TENSION

Liquid surface molecules are especially tightly bound as they are only pulled downwards by other liquid molecules. This causes a membrane to form on liquid surfaces.

$$F = \gamma \ell$$

F - surface tension force

γ - surface tension

ℓ - outer length of object

RELATIVE STRENGTH OF FORCES

adhesion > cohesion	adhesion < cohesion
• θ < 90° • liquid wets surface	• θ > 90° • liquid does not wet surface

CAPILLARITY

The spontaneous movement of liquids up or down narrow tubes (capillaries).

The perpendicular adhesion force, $F_\perp$, holds up the column of liquid.

$$F_\perp = F_w$$

$$\Rightarrow h = \frac{2\gamma\cos\theta}{\rho g r}$$

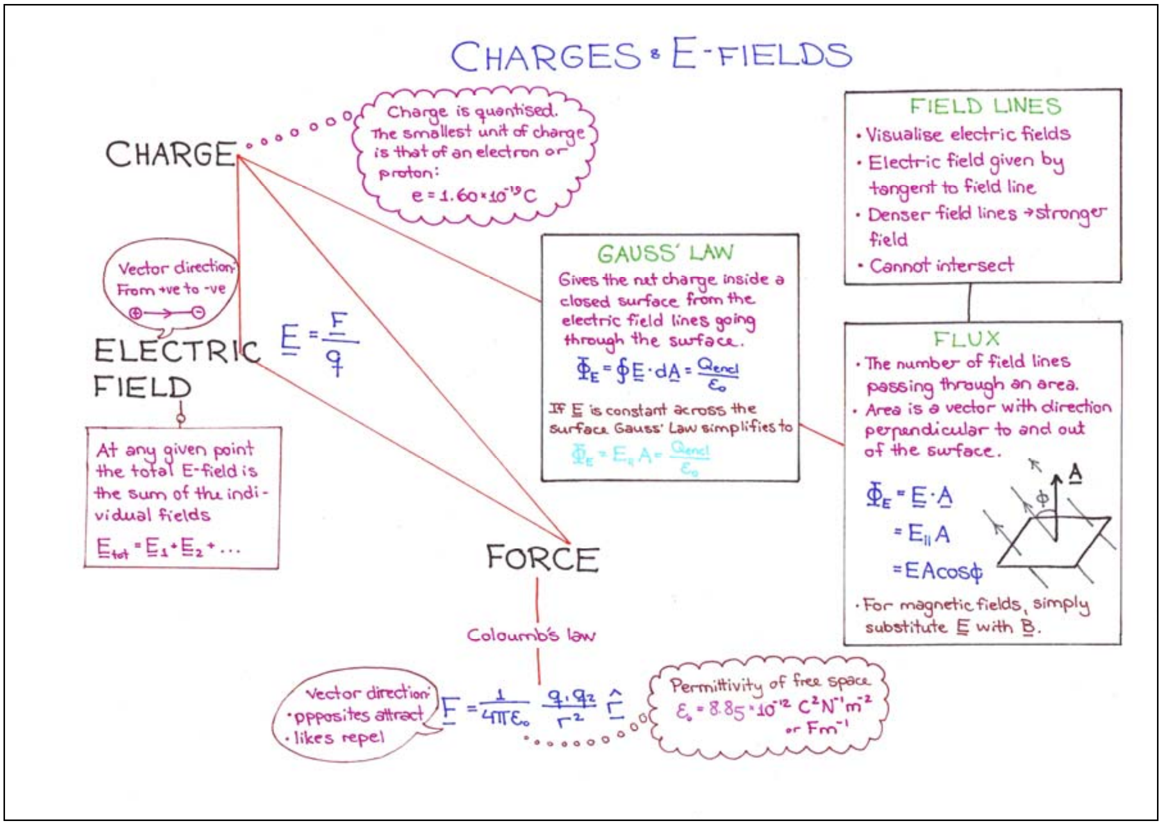
θ depends on the particular liquid-solid combination.

LAPLACE'S LAW

Relates difference in pressure between inside, P_i, and outside, P_o, of a closed membrane to the tension in the membrane in equilibrium.

Drop	Bubble	Cylinder
$P_i - P_o = \frac{2\gamma}{r}$	$P_i - P_o = \frac{4\gamma}{r}$	$P_i - P_o = \frac{\gamma}{r}$

- Surface tension tries to contract the bubble.
- This increases the inside (gauge) pressure.
- The gauge pressure provides an outward force.
- In equilibrium, the outward pressure force and inward tension force are equal.



CHARGES & E-FIELDS

CHARGE

Charge is quantised. The smallest unit of charge is that of an electron or proton:

$$e = 1.60 \times 10^{-19} C$$

Vector direction: From +ve to -ve

ELECTRIC FIELD

$$\underline{E} = \frac{\underline{F}}{q}$$

At any given point the total E-field is the sum of the individual fields

$$\underline{E}_{tot} = \underline{E}_1 + \underline{E}_2 + \ldots$$

FORCE

Coloumb's law

$$\underline{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\underline{r}}$$

Vector direction:
- opposites attract
- likes repel

Permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$ or Fm^{-1}

GAUSS' LAW

Gives the net charge inside a closed surface from the electric field lines going through the surface.

$$\Phi_E = \oint \underline{E} \cdot d\underline{A} = \frac{Q_{encl}}{\varepsilon_0}$$

If $\underline{E}$ is constant across the surface Gauss' Law simplifies to

$$\Phi_E = E_\parallel A = \frac{Q_{encl}}{\varepsilon_0}$$

FIELD LINES

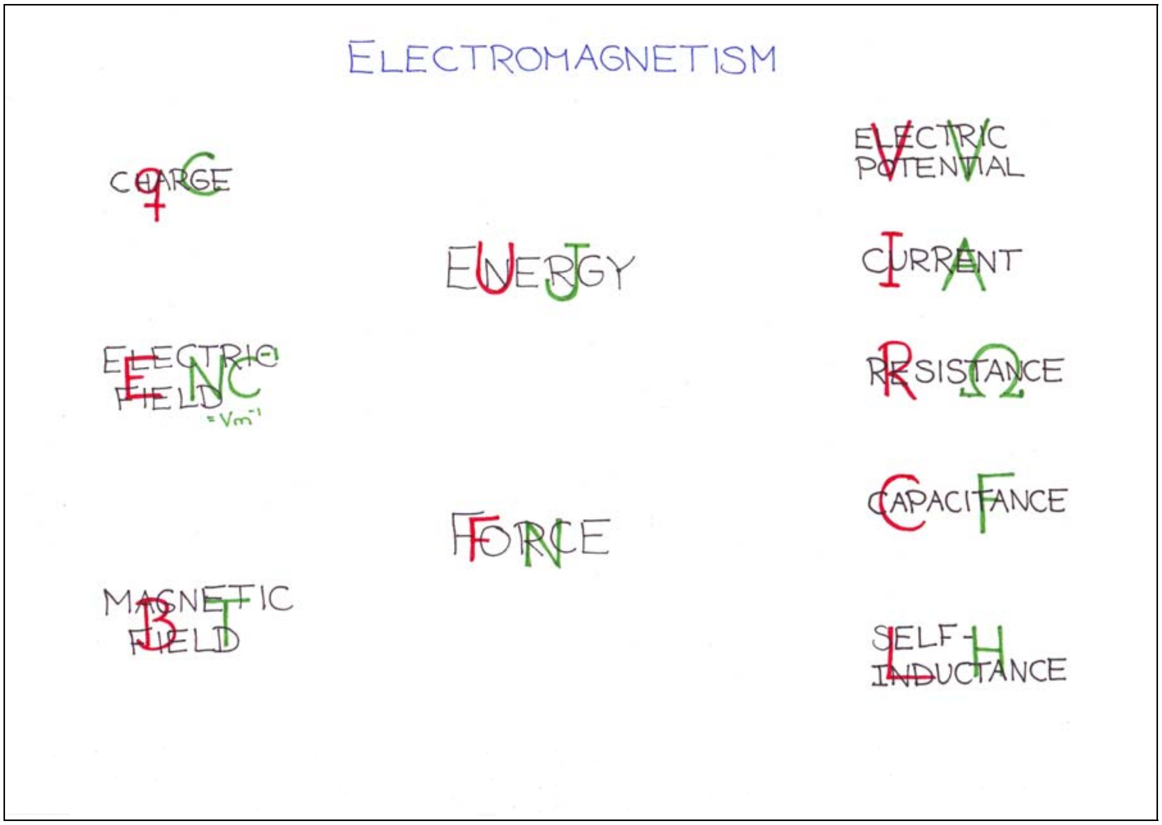
- Visualise electric fields
- Electric field given by tangent to field line
- Denser field lines → stronger field
- Cannot intersect

FLUX

- The number of field lines passing through an area.
- Area is a vector with direction perpendicular to and out of the surface.

$$\Phi_E = \underline{E} \cdot \underline{A}$$
$$= E_\parallel A$$
$$= EA\cos\phi$$

- For magnetic fields, simply substitute $\underline{E}$ with $\underline{B}$.



ELECTROMAGNETISM

CHARGE q C

ENERGY U J

ELECTRIC FIELD E NC $=\mathrm{Vm^{-1}}$

FORCE F N

MAGNETIC FIELD B T

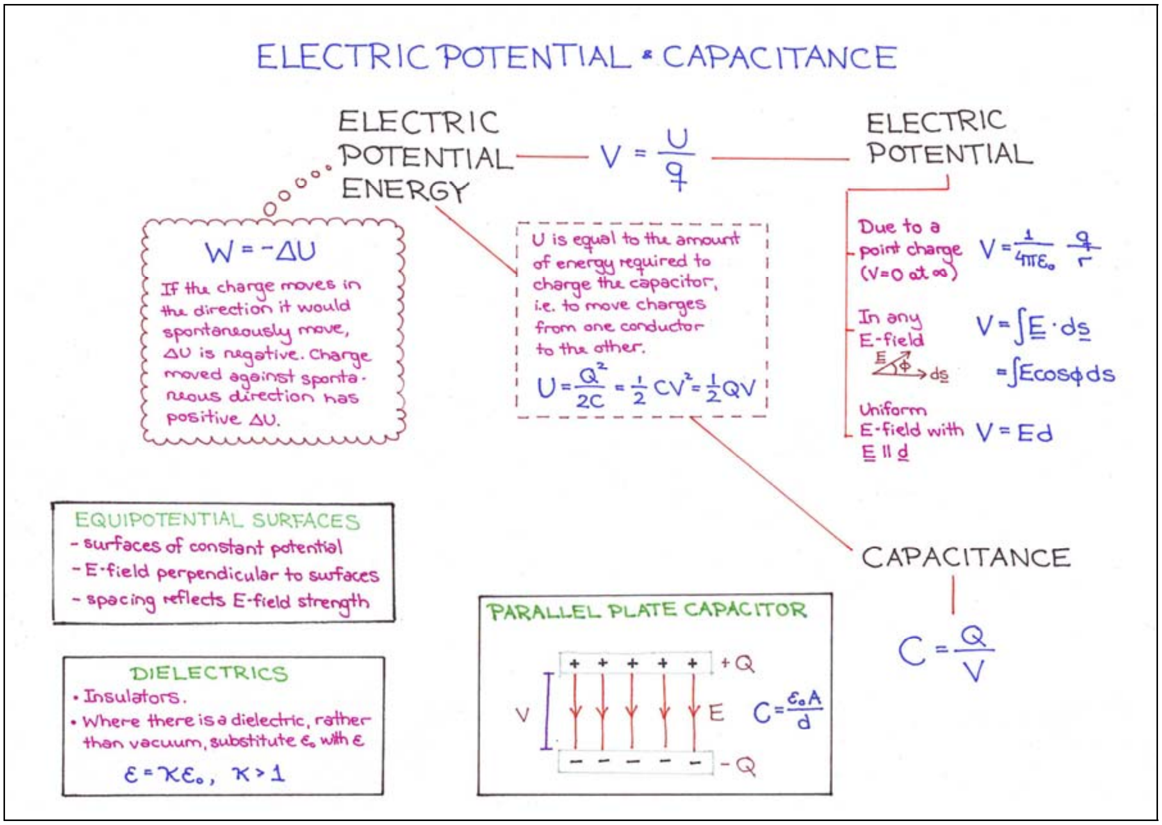
ELECTRIC POTENTIAL V V

CURRENT I A

RESISTANCE R Ω

CAPACITANCE C F

SELF-INDUCTANCE L H



ELECTRIC POTENTIAL & CAPACITANCE

ELECTRIC POTENTIAL ENERGY — $V = \frac{U}{q}$ — ELECTRIC POTENTIAL

$W = -\Delta U$

If the charge moves in the direction it would spontaneously move, ΔU is negative. Charge moved against spontaneous direction has positive ΔU.

U is equal to the amount of energy required to charge the capacitor, i.e. to move charges from one conductor to the other.

$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$

Due to a point charge ($V=0$ at ∞) $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

In any E-field $V = \int \underline{E} \cdot d\underline{s}$

$\underline{E}$ ϕ $d\underline{s}$ $= \int E\cos\phi \, ds$

Uniform E-field with $\underline{E} \parallel \underline{d}$ $V = Ed$

CAPACITANCE

$C = \frac{Q}{V}$

EQUIPOTENTIAL SURFACES
- surfaces of constant potential
- E-field perpendicular to surfaces
- spacing reflects E-field strength

DIELECTRICS
- Insulators.
- Where there is a dielectric, rather than vacuum, substitute ε_0 with ε

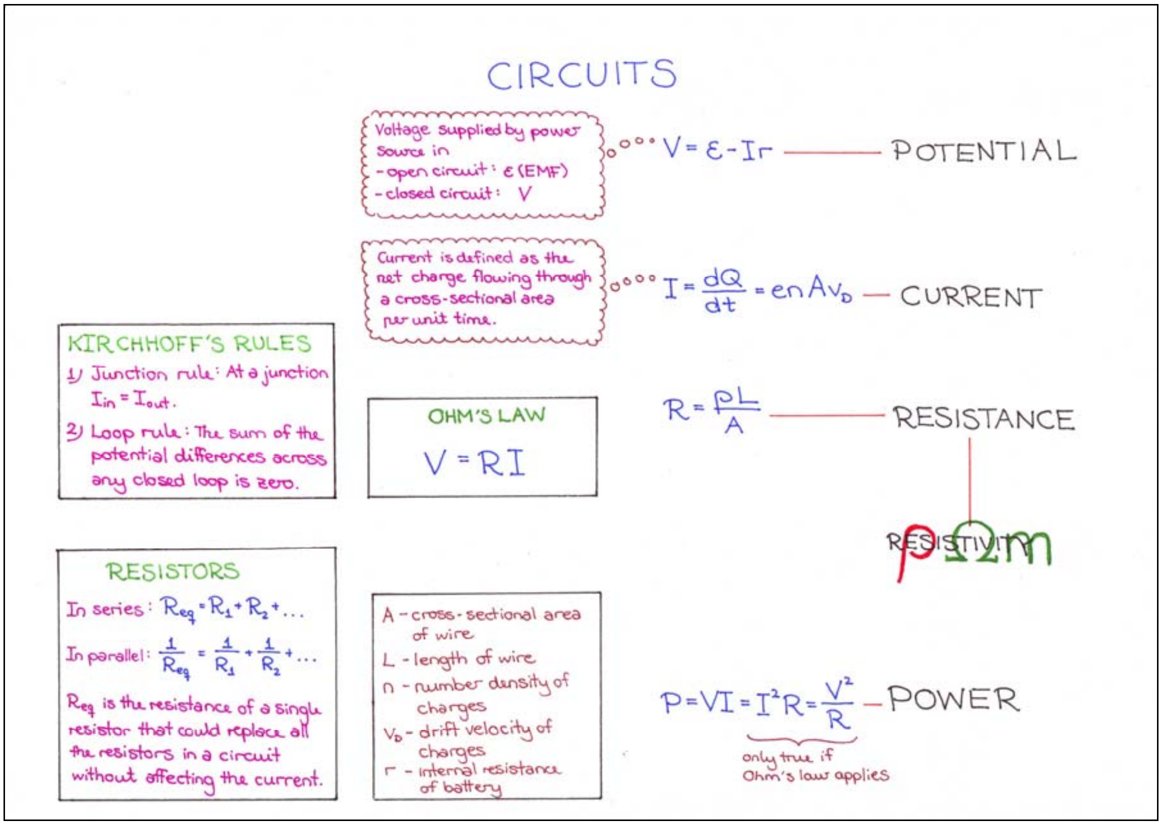
$\varepsilon = \kappa\varepsilon_0, \quad \kappa > 1$

PARALLEL PLATE CAPACITOR

+ + + + + $+Q$

V E $C = \frac{\varepsilon_0 A}{d}$

− − − − − $-Q$



CIRCUITS

Voltage supplied by power source in
- open circuit: ε (EMF)
- closed circuit: V

$V = \varepsilon - Ir$ — POTENTIAL

Current is defined as the net charge flowing through a cross-sectional area per unit time.

$I = \frac{dQ}{dt} = enAv_D$ — CURRENT

$R = \frac{\rho L}{A}$ — RESISTANCE

RESISTIVITY ρ Ωm

KIRCHHOFF'S RULES

1) Junction rule: At a junction $I_{in} = I_{out}$.

2) Loop rule: The sum of the potential differences across any closed loop is zero.

OHM'S LAW

$V = RI$

RESISTORS

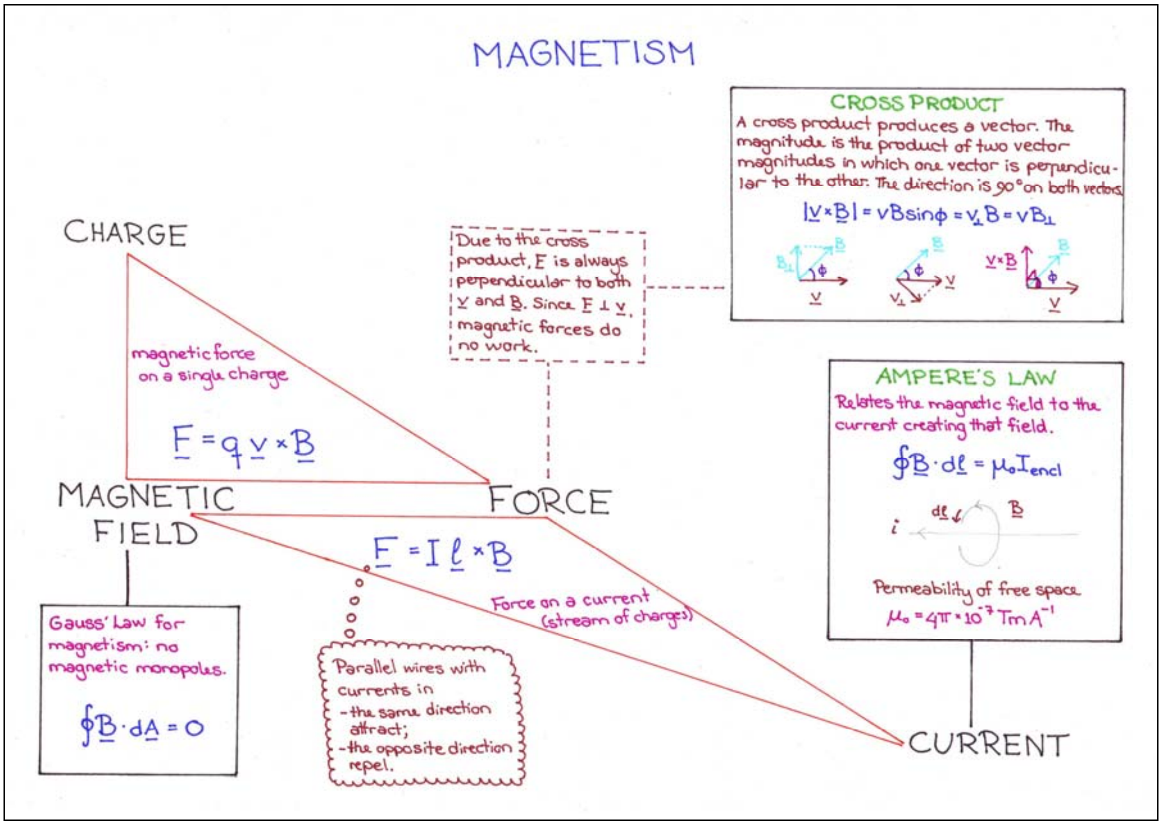
In series: $R_{eq} = R_1 + R_2 + \dots$

In parallel: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

R_{eq} is the resistance of a single resistor that could replace all the resistors in a circuit without affecting the current.

A - cross-sectional area of wire
L - length of wire
n - number density of charges
V_D - drift velocity of charges
r - internal resistance of battery

$P = VI = \underbrace{I^2R = \frac{V^2}{R}}_{\text{only true if Ohm's law applies}}$ — POWER



MAGNETISM

CHARGE

magnetic force on a single charge

$\underline{F} = q\,\underline{v} \times \underline{B}$

MAGNETIC FIELD

FORCE

$\underline{F} = I\,\underline{\ell} \times \underline{B}$

Force on a current (stream of charges)

CURRENT

Due to the cross product, $\underline{F}$ is always perpendicular to both $\underline{v}$ and $\underline{B}$. Since $\underline{F} \perp \underline{v}$, magnetic forces do no work.

CROSS PRODUCT

A cross product produces a vector. The magnitude is the product of two vector magnitudes in which one vector is perpendicular to the other. The direction is 90° on both vectors.

$|\underline{v} \times \underline{B}| = vB\sin\phi = v_\perp B = vB_\perp$

AMPERE'S LAW

Relates the magnetic field to the current creating that field.

$\oint \underline{B} \cdot d\underline{\ell} = \mu_0 I_{encl}$

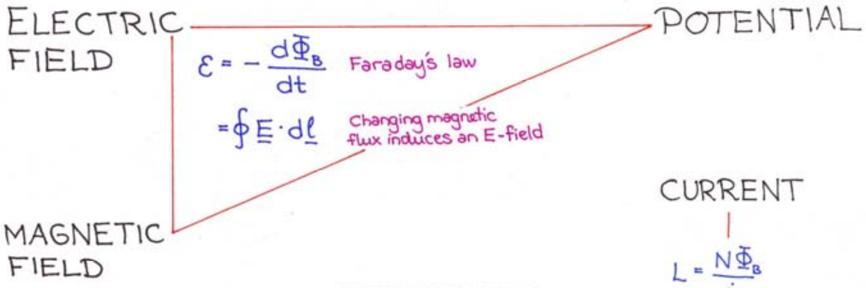
Permeability of free space
$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{TmA^{-1}}$

Gauss' Law for magnetism: no magnetic monopoles.

$\oint \underline{B} \cdot d\underline{A} = 0$

Parallel wires with currents in
- the same direction attract;
- the opposite direction repel.

INDUCTION



$\mathcal{E} = -\frac{d\Phi_B}{dt}$ Faraday's law

$= \oint \underline{E} \cdot d\underline{\ell}$ Changing magnetic flux induces an E-field

CURRENT

$L = \frac{N\Phi_B}{i}$

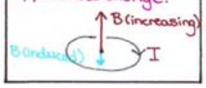
$= \frac{\mu_0 N^2 A}{\ell}$ for a solenoid

SELF-INDUCTANCE

When the current in a circuit changes, the flux through the circuit changes. This induces an emf, called self-induced emf, which oppose the change in current that caused the emf.

LENZ'S LAW

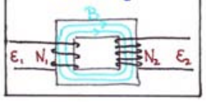
The direction of any magnetic induction effect is such as to oppose the change.



TRANSFORMERS

A core of high permeability keeps the field lines almost entirely within the core such that Φ_B is the same in both windings.

$$\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{N_2}{N_1}$$



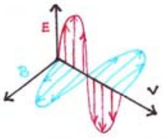
EDDY CURRENTS

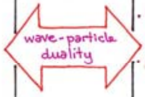
Induced circulating currents in metal bodies that experience changing magnetic fields.

ELECTROMAGNETIC RADIATION

WAVE REPRESENTATION

- Used to describe propagation in space and time.
- Speed constant in vacuum $c = 3.00 \times 10^8\ ms^{-1}$
- $c = f\lambda$





PARTICLE REPRESENTATION

- Used to describe interaction with matter.
- Photons : indivisible 'packets' of EM radiation.
- Energy of photon $E = hf$

  Planck's constant : $h = 6.63 \times 10^{-34}$ Js
- Momentum of photon $p = \frac{E}{c}$

BLACKBODY RADIATION

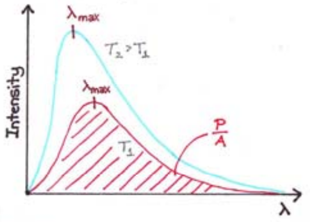
- A blackbody is an object that absorbs all EM radiation that falls onto it. These objects emit only thermal radiation, called blackbody radiation, which spectrum depends solely on the temperature of the object.
- Stefan-Boltzmann law

  Power radiated by a blackbody (P/A is reflected by area below the curve).

  $P = \sigma A T^4$

  Stefan-Boltzmann constant : $\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$
- Wien's displacement law

  $\lambda_{max} = \frac{2.9 \times 10^{-3}\ mK}{T}$



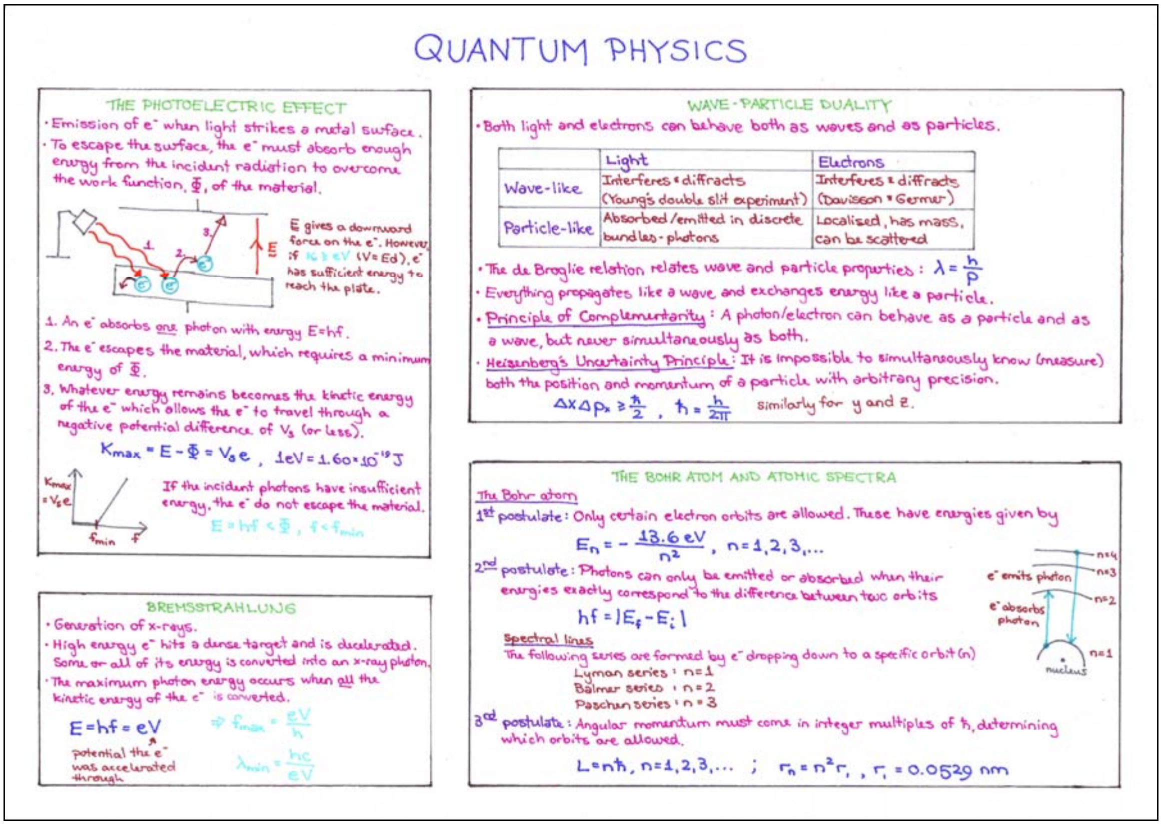
THE ELECTROMAGNETIC SPECTRUM

- The spectrum classifies all possible types of electromagnetic radiation.

Radio waves	Microwaves	Infrared	Visible	Ultraviolet	X-rays	γ-rays
accelerating charges	accelerating charges	blackbody radiation, molecular vibration and rotation	blackbody radiation, atomic transitions	blackbody radiation, atomic transitions	atomic transitions (to lowest energy level), bremsstrahlung	nuclear reactions, matter + antimatter

λ ← ~0.3m | ~1mm | 780nm | 390nm | ~10nm | ~10pm | 0

NB! Intervals not drawn to scale.



QUANTUM PHYSICS

THE PHOTOELECTRIC EFFECT

- Emission of e^- when light strikes a metal surface.
- To escape the surface, the e^- must absorb enough energy from the incident radiation to overcome the work function, Φ, of the material.

E gives a downward force on the e^-. However, if $K \geq eV$ ($V = Ed$), e^- has sufficient energy to reach the plate.

1. An e^- absorbs one photon with energy $E = hf$.
2. The e^- escapes the material, which requires a minimum energy of Φ.
3. Whatever energy remains becomes the kinetic energy of the e^- which allows the e^- to travel through a negative potential difference of V_s (or less).

$$K_{max} = E - \Phi = V_s e \ , \quad 1\,eV = 1.60 \times 10^{-19}\,J$$

If the incident photons have insufficient energy, the e^- do not escape the material.

$$E = hf < \Phi \ , \quad f < f_{min}$$

BREMSSTRAHLUNG

- Generation of x-rays.
- High energy e^- hits a dense target and is decelerated. Some or all of its energy is converted into an x-ray photon.
- The maximum photon energy occurs when all the kinetic energy of the e^- is converted.

$$E = hf = eV \quad \Rightarrow f_{max} = \frac{eV}{h}$$

potential the e^- was accelerated through

$$\lambda_{min} = \frac{hc}{eV}$$

WAVE-PARTICLE DUALITY

- Both light and electrons can behave both as waves and as particles.

	Light	Electrons
Wave-like	Interferes & diffracts (Young's double slit experiment)	Interferes & diffracts (Davisson & Germer)
Particle-like	Absorbed/emitted in discrete bundles - photons	Localised, has mass, can be scattered

- The de Broglie relation relates wave and particle properties: $\lambda = \frac{h}{p}$
- Everything propagates like a wave and exchanges energy like a particle.
- Principle of Complementarity: A photon/electron can behave as a particle and as a wave, but never simultaneously as both.
- Heisenberg's Uncertainty Principle: It is impossible to simultaneously know (measure) both the position and momentum of a particle with arbitrary precision.

$$\Delta x \Delta p_x \geq \frac{\hbar}{2} \ , \quad \hbar = \frac{h}{2\pi}$$ similarly for y and z.

THE BOHR ATOM AND ATOMIC SPECTRA

The Bohr atom

1st postulate: Only certain electron orbits are allowed. These have energies given by

$$E_n = -\frac{13.6\,eV}{n^2} \ , \quad n = 1, 2, 3, \ldots$$

2nd postulate: Photons can only be emitted or absorbed when their energies exactly correspond to the difference between two orbits

$$hf = |E_f - E_i|$$

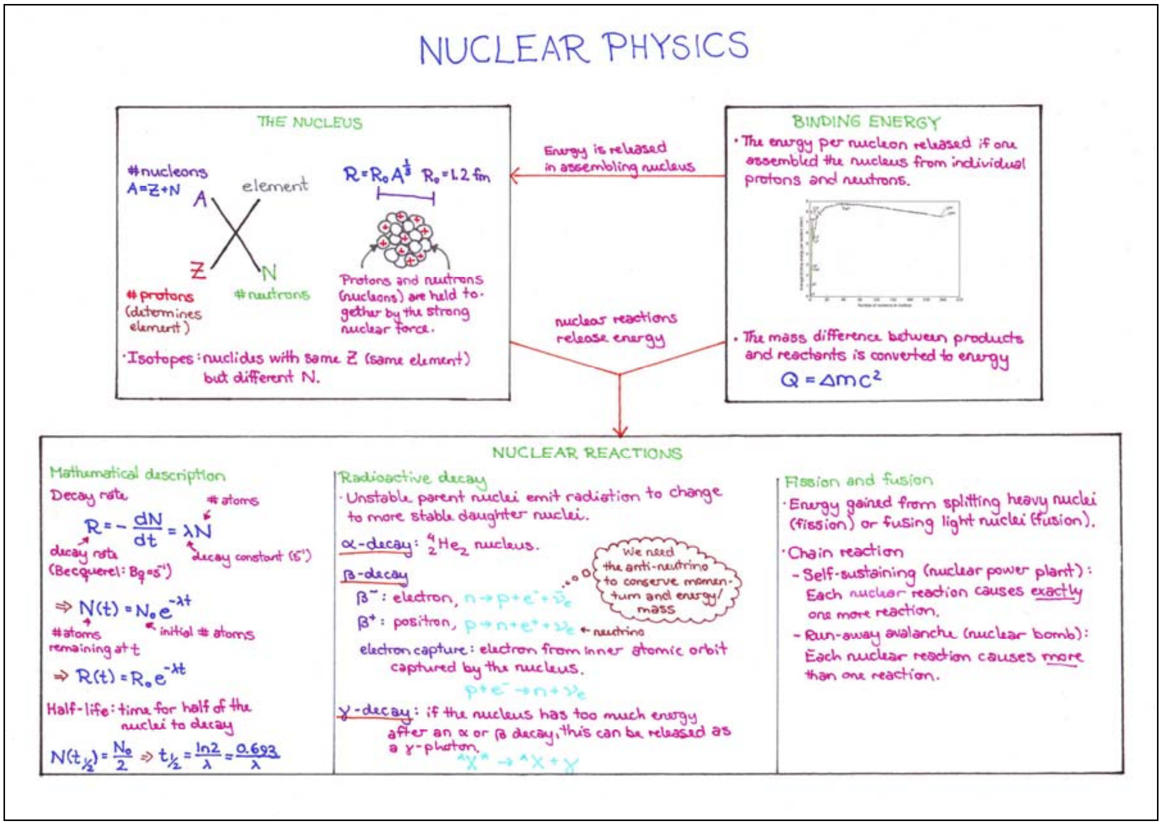
Spectral lines

The following series are formed by e^- dropping down to a specific orbit (n)

Lyman series : n = 1
Balmer series : n = 2
Paschen series : n = 3

3rd postulate: Angular momentum must come in integer multiples of $\hbar$, determining which orbits are allowed.

$$L = n\hbar, \ n = 1, 2, 3, \ldots \ ; \quad r_n = n^2 r_1 \ , \ r_1 = 0.0529\,nm$$



NUCLEAR PHYSICS

THE NUCLEUS

#nucleons
$A = Z + N$

protons (determines element)

neutrons

$$R = R_0 A^{\frac{1}{3}} \quad R_0 = 1.2\,fm$$

Protons and neutrons (nucleons) are held together by the strong nuclear force.

- Isotopes: nuclides with same Z (same element) but different N.

BINDING ENERGY

- The energy per nucleon released if one assembled the nucleus from individual protons and neutrons.
- The mass difference between products and reactants is converted to energy

$$Q = \Delta m c^2$$

NUCLEAR REACTIONS

Mathematical description

Decay rate

$$R = -\frac{dN}{dt} = \lambda N$$

decay rate (Becquerel: $Bq = s^{-1}$)

atoms

decay constant (s^{-1})

$$\Rightarrow N(t) = N_0 e^{-\lambda t}$$

atoms remaining at t

initial # atoms

$$\Rightarrow R(t) = R_0 e^{-\lambda t}$$

Half-life: time for half of the nuclei to decay

$$N(t_{1/2}) = \frac{N_0}{2} \Rightarrow t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

Radioactive decay

- Unstable parent nuclei emit radiation to change to more stable daughter nuclei.

α-decay: $^4_2He_2$ nucleus.

β-decay

β^-: electron, $n \rightarrow p + e^- + \bar{\nu}_e$

We need the anti-neutrino to conserve momentum and energy/mass

β^+: positron, $p \rightarrow n + e^+ + \nu_e$ ← neutrino

electron capture: electron from inner atomic orbit captured by the nucleus.

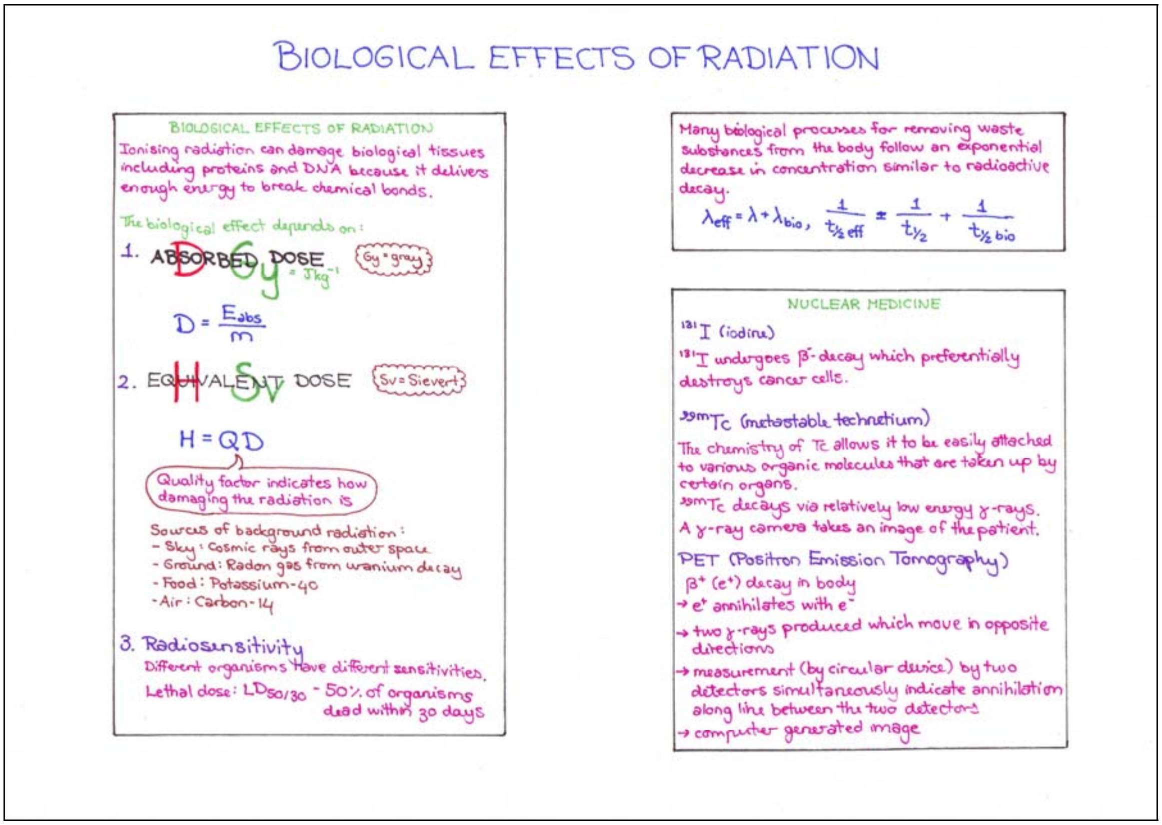
$$p + e^- \rightarrow n + \nu_e$$

γ-decay: if the nucleus has too much energy after an α or β decay, this can be released as a γ-photon.

$$^AX^* \rightarrow {}^AX + \gamma$$

Fission and fusion

- Energy gained from splitting heavy nuclei (fission) or fusing light nuclei (fusion).
- Chain reaction
  - Self-sustaining (nuclear power plant): Each nuclear reaction causes exactly one more reaction.
  - Run-away avalanche (nuclear bomb): Each nuclear reaction causes more than one reaction.



BIOLOGICAL EFFECTS OF RADIATION

BIOLOGICAL EFFECTS OF RADIATION

Ionising radiation can damage biological tissues including proteins and DNA because it delivers enough energy to break chemical bonds.

The biological effect depends on:

1. ABSORBED DOSE D Gy $= Jkg^{-1}$ (Gy = gray)

$$D = \frac{E_{abs}}{m}$$

2. EQUIVALENT DOSE H Sv (Sv = Sievert)

$$H = QD$$

Quality factor indicates how damaging the radiation is

Sources of background radiation:
- Sky: Cosmic rays from outer space
- Ground: Radon gas from uranium decay
- Food: Potassium-40
- Air: Carbon-14

3. Radiosensitivity

Different organisms have different sensitivities.

Lethal dose: $LD_{50/30}$ - 50% of organisms dead within 30 days

Many biological processes for removing waste substances from the body follow an exponential decrease in concentration similar to radioactive decay.

$$\lambda_{eff} = \lambda + \lambda_{bio}, \quad \frac{1}{t_{1/2\,eff}} = \frac{1}{t_{1/2}} + \frac{1}{t_{1/2\,bio}}$$

NUCLEAR MEDICINE

^{131}I (iodine)

^{131}I undergoes β^--decay which preferentially destroys cancer cells.

^{99m}Tc (metastable technetium)

The chemistry of Tc allows it to be easily attached to various organic molecules that are taken up by certain organs.

^{99m}Tc decays via relatively low energy γ-rays.

A γ-ray camera takes an image of the patient.

PET (Positron Emission Tomography)

β^+ (e^+) decay in body

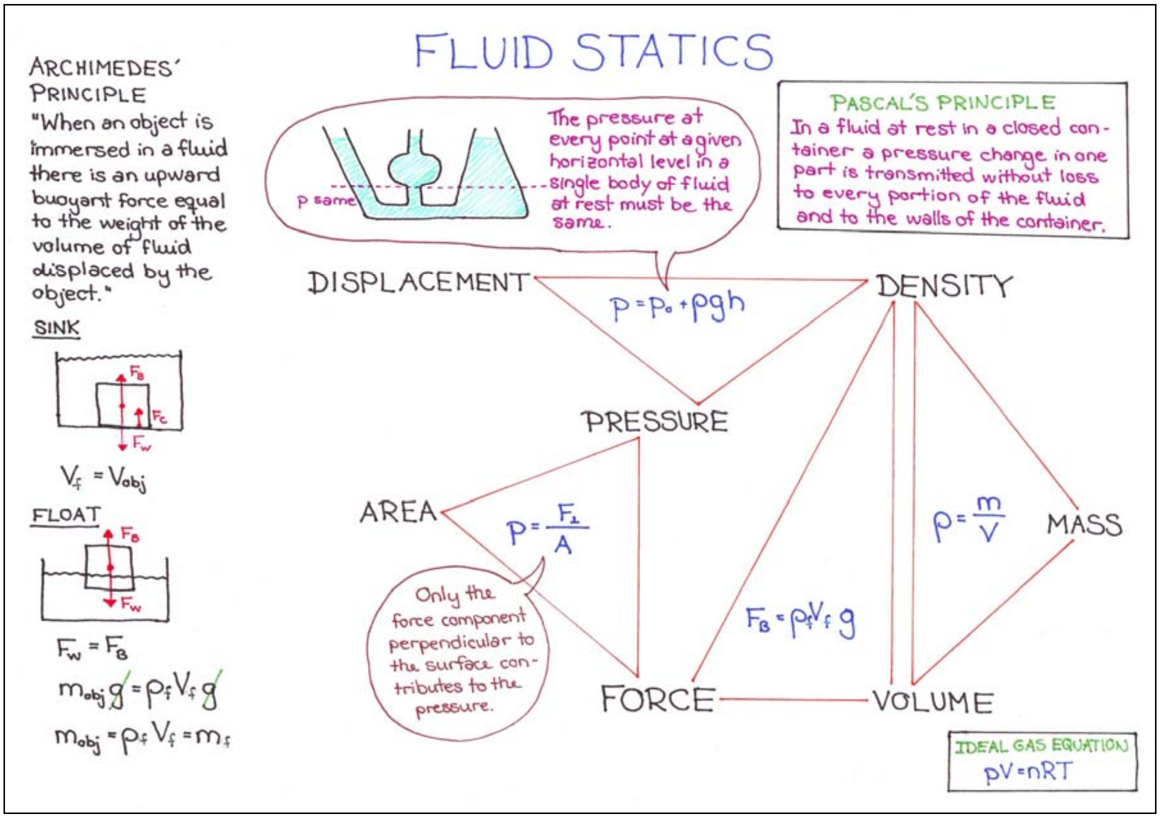
→ e^+ annihilates with e^-

→ two γ-rays produced which move in opposite directions

→ measurement (by circular device) by two detectors simultaneously indicate annihilation along line between the two detectors

→ computer generated image

D.4 The Technological course



FLUID STATICS

ARCHIMEDES' PRINCIPLE

"When an object is immersed in a fluid there is an upward buoyant force equal to the weight of the volume of fluid displaced by the object."

The pressure at every point at a given horizontal level in a single body of fluid at rest must be the same.

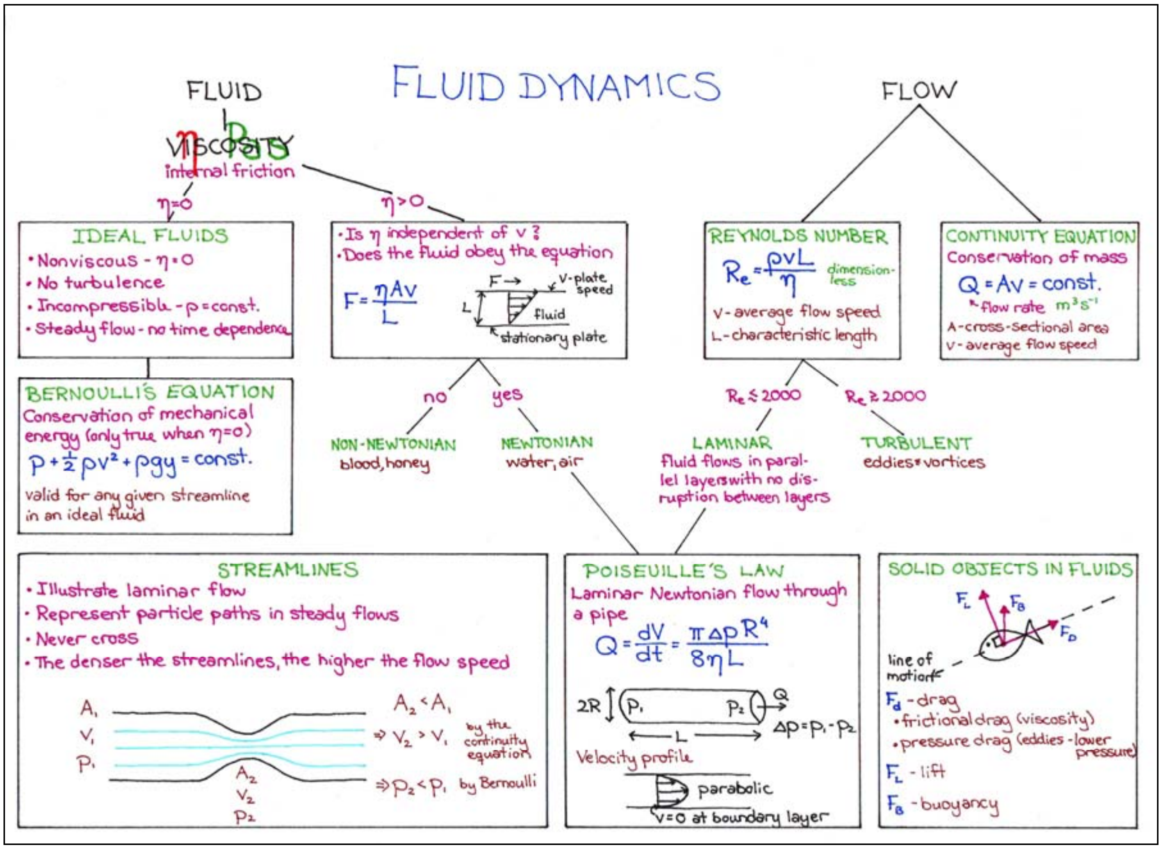
PASCAL'S PRINCIPLE

In a fluid at rest in a closed container a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container.

Only the force component perpendicular to the surface contributes to the pressure.

IDEAL GAS EQUATION

$pV = nRT$



FLUID DYNAMICS

FLUID

VISCOSITY η Pa s

internal friction

$\eta = 0$

IDEAL FLUIDS

- Nonviscous - $\eta = 0$
- No turbulence
- Incompressible - ρ = const.
- Steady flow - no time dependence

BERNOULLI'S EQUATION

Conservation of mechanical energy (only true when $\eta = 0$)

$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{const.}$$

valid for any given streamline in an ideal fluid

$\eta > 0$

- Is η independent of v ?
- Does the fluid obey the equation

$$F = \frac{\eta A v}{L}$$

no: **NON-NEWTONIAN** blood, honey

yes: **NEWTONIAN** water, air

FLOW

REYNOLDS NUMBER

$$R_e = \frac{\rho v L}{\eta}$$ dimensionless

v - average flow speed
L - characteristic length

$R_e \lesssim 2000$: **LAMINAR** fluid flows in parallel layers with no disruption between layers

$R_e \gtrsim 2000$: **TURBULENT** eddies & vortices

CONTINUITY EQUATION

Conservation of mass

$$Q = Av = \text{const.}$$

flow rate $m^3 s^{-1}$
A - cross-sectional area
v - average flow speed

STREAMLINES

- Illustrate laminar flow
- Represent particle paths in steady flows
- Never cross
- The denser the streamlines, the higher the flow speed

$A_2 < A_1$

$\Rightarrow v_2 > v_1$ by the continuity equation

$\Rightarrow p_2 < p_1$ by Bernoulli

POISEUILLE'S LAW

Laminar Newtonian flow through a pipe

$$Q = \frac{dV}{dt} = \frac{\pi \Delta p R^4}{8 \eta L}$$

$\Delta p = p_1 - p_2$

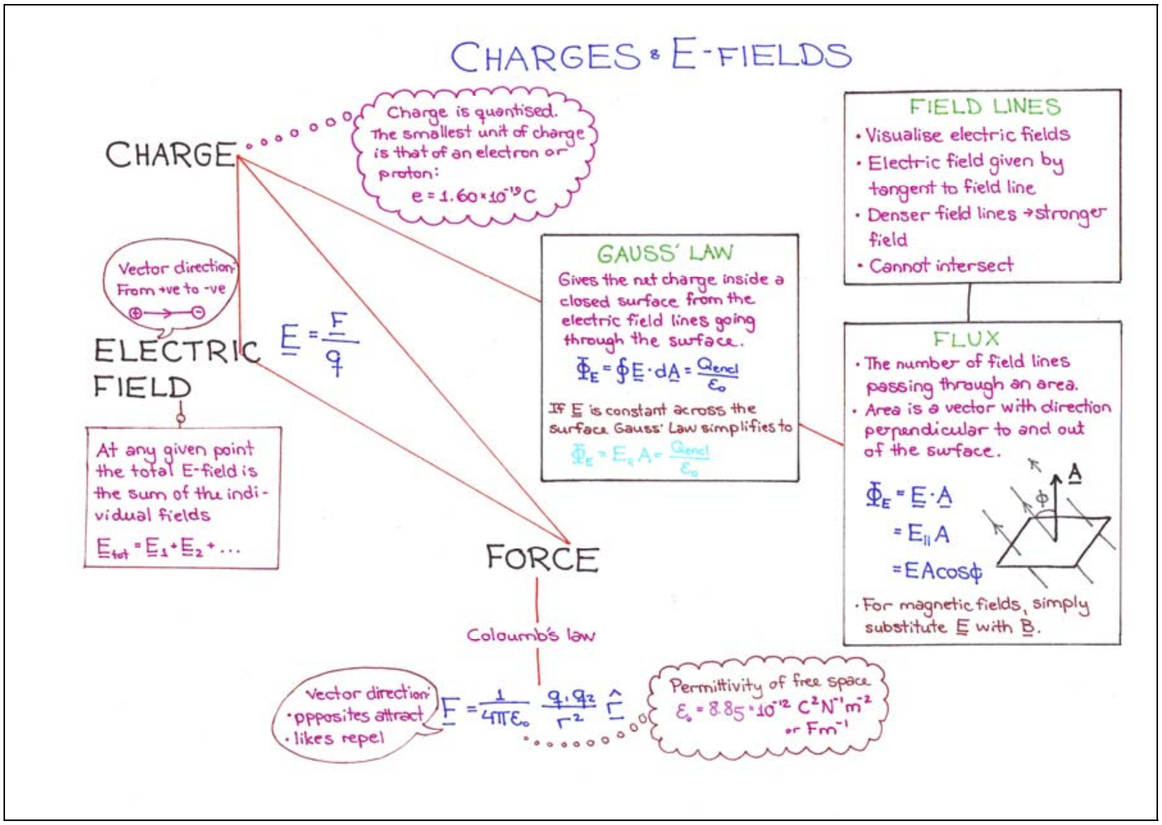
Velocity profile

SOLID OBJECTS IN FLUIDS

F_d - drag
- frictional drag (viscosity)
- pressure drag (eddies - lower pressure)

F_L - lift

F_B - buoyancy



CHARGES & E-FIELDS

CHARGE

Charge is quantised. The smallest unit of charge is that of an electron or proton:

$$e = 1.60 \times 10^{-19} C$$

Vector direction: From +ve to -ve

ELECTRIC FIELD

$$\underline{E} = \frac{\underline{F}}{q}$$

At any given point the total E-field is the sum of the individual fields

$$\underline{E}_{tot} = \underline{E}_1 + \underline{E}_2 + \ldots$$

GAUSS' LAW

Gives the net charge inside a closed surface from the electric field lines going through the surface.

$$\Phi_E = \oint \underline{E} \cdot d\underline{A} = \frac{Q_{encl}}{\varepsilon_0}$$

If $\underline{E}$ is constant across the surface Gauss' Law simplifies to

$$\Phi_E = E_{\parallel} A = \frac{Q_{encl}}{\varepsilon_0}$$

FIELD LINES

- Visualise electric fields
- Electric field given by tangent to field line
- Denser field lines → stronger field
- Cannot intersect

FLUX

- The number of field lines passing through an area.
- Area is a vector with direction perpendicular to and out of the surface.

$$\Phi_E = \underline{E} \cdot \underline{A} = E_{\parallel} A = EA\cos\phi$$

- For magnetic fields, simply substitute $\underline{E}$ with $\underline{B}$.

FORCE

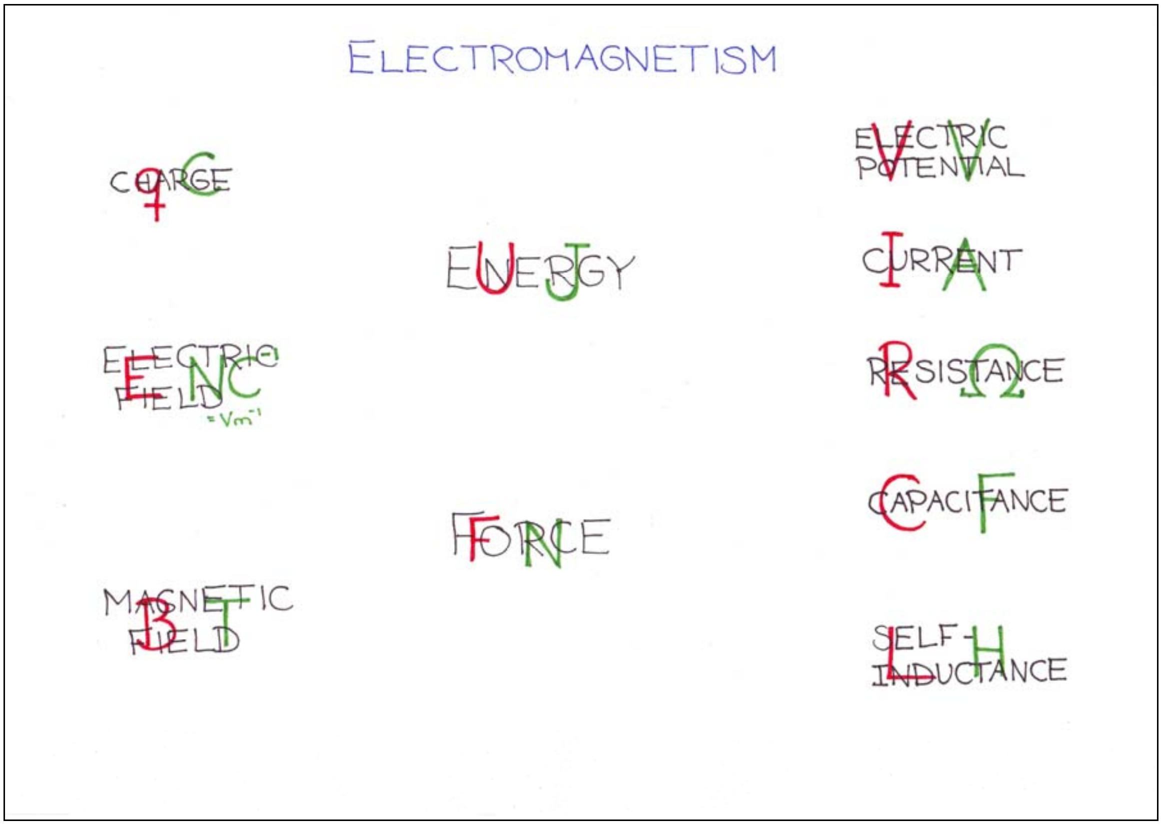
Coloumb's law

$$\underline{F} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \hat{\underline{r}}$$

Vector direction:
- opposites attract
- likes repel

Permittivity of free space

$$\varepsilon_0 = 8.85 \times 10^{-12} C^2 N^{-1} m^{-2} \text{ or } F m^{-1}$$



ELECTROMAGNETISM

CHARGE q C

ENERGY U J

ELECTRIC FIELD E NC^{-1} $= Vm^{-1}$

FORCE F N

MAGNETIC FIELD B T

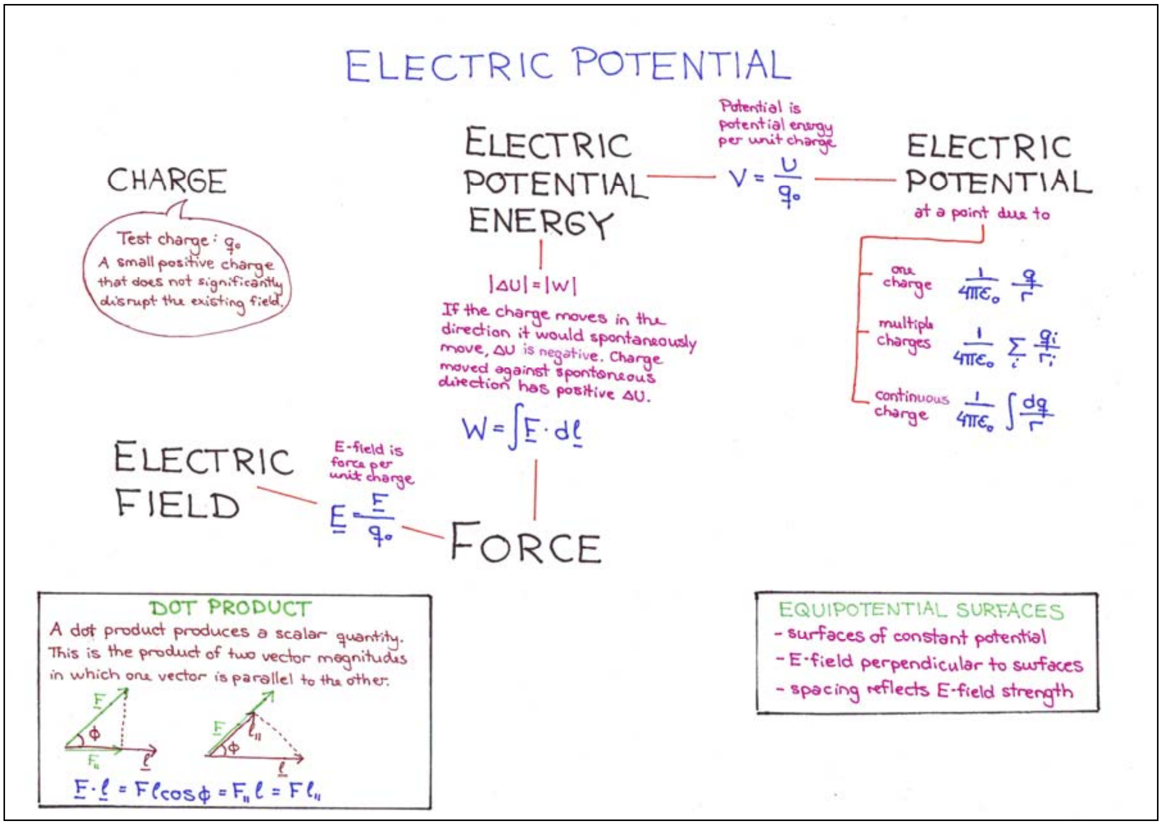
ELECTRIC POTENTIAL V V

CURRENT I A

RESISTANCE R Ω

CAPACITANCE C F

SELF-INDUCTANCE L H



ELECTRIC POTENTIAL

CHARGE

Test charge : q_0
A small positive charge that does not significantly disrupt the existing field.

ELECTRIC POTENTIAL ENERGY

Potential is potential energy per unit charge

$$V = \frac{U}{q_0}$$

ELECTRIC POTENTIAL

at a point due to

one charge $\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

multiple charges $\frac{1}{4\pi\varepsilon_0}\sum_i\frac{q_i}{r_i}$

continuous charge $\frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$

$$|\Delta U| = |W|$$

If the charge moves in the direction it would spontaneously move, ΔU is negative. Charge moved against spontoneous direction has positive ΔU.

$$W = \int \underline{F} \cdot d\underline{\ell}$$

ELECTRIC FIELD

E-field is force per unit charge

$$\underline{E} = \frac{\underline{F}}{q_0}$$

FORCE

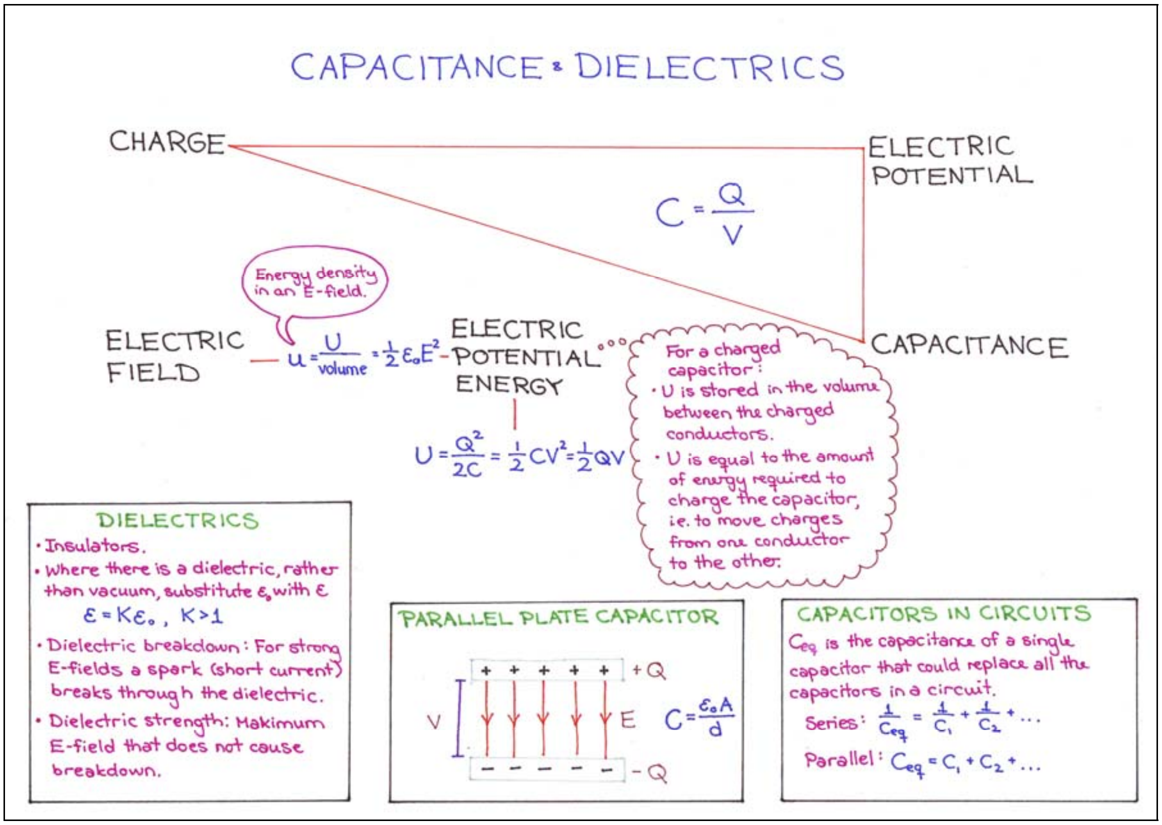
DOT PRODUCT

A dot product produces a scalar quantity. This is the product of two vector magnitudes in which one vector is parallel to the other.

$$\underline{F} \cdot \underline{\ell} = F\ell\cos\phi = F_{\parallel}\ell = F\ell_{\parallel}$$

EQUIPOTENTIAL SURFACES

- surfaces of constant potential
- E-field perpendicular to surfaces
- spacing reflects E-field strength



CAPACITANCE & DIELECTRICS

CHARGE — ELECTRIC POTENTIAL — CAPACITANCE

$$C = \frac{Q}{V}$$

Energy density in an E-field.

ELECTRIC FIELD — $u = \frac{U}{\text{volume}} = \frac{1}{2}\varepsilon_0 E^2$ — ELECTRIC POTENTIAL ENERGY

$$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

For a charged capacitor:
- U is stored in the volume between the charged conductors.
- U is equal to the amount of energy required to charge the capacitor, i.e. to move charges from one conductor to the other.

DIELECTRICS

- Insulators.
- Where there is a dielectric, rather than vacuum, substitute ε_0 with ε: $\varepsilon = K\varepsilon_0$, $K > 1$
- Dielectric breakdown: For strong E-fields a spark (short current) breaks through the dielectric.
- Dielectric strength: Maximum E-field that does not cause breakdown.

PARALLEL PLATE CAPACITOR

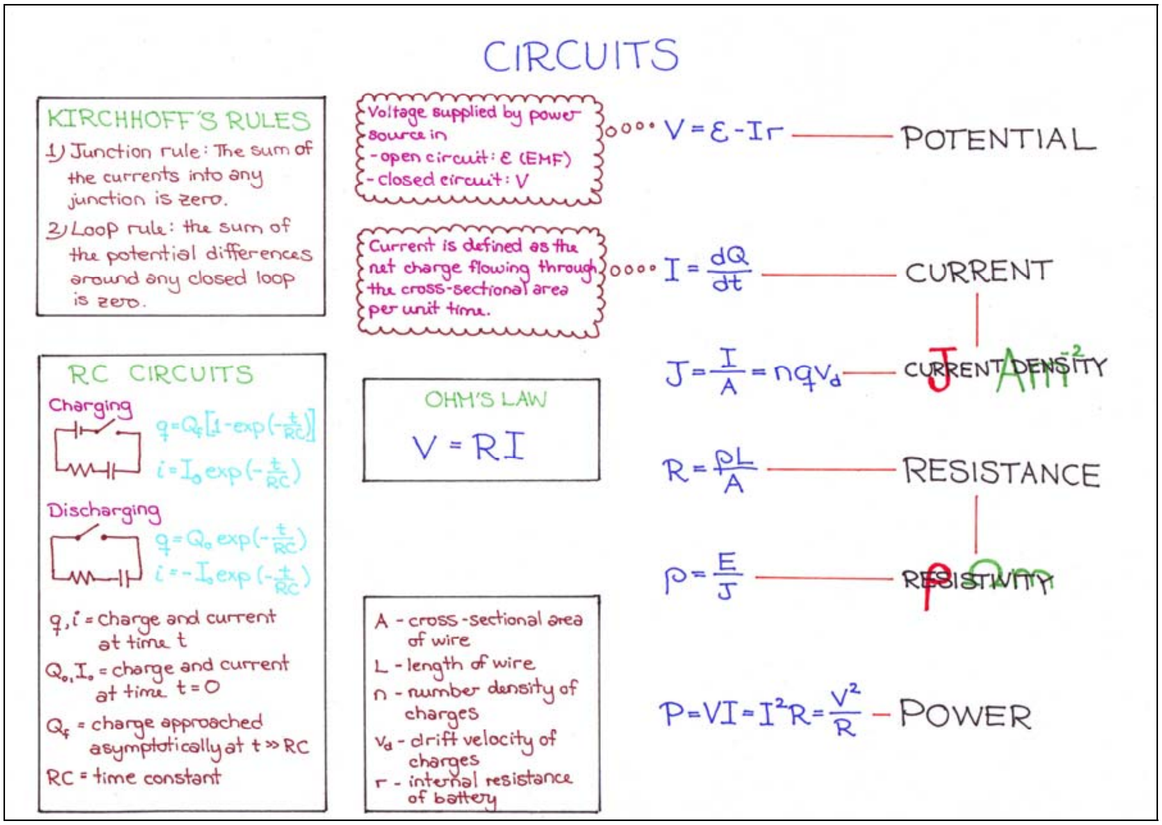
$$C = \frac{\varepsilon_0 A}{d}$$

CAPACITORS IN CIRCUITS

C_{eq} is the capacitance of a single capacitor that could replace all the capacitors in a circuit.

Series: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$

Parallel: $C_{eq} = C_1 + C_2 + \dots$



CIRCUITS

KIRCHHOFF'S RULES

1) Junction rule: The sum of the currents into any junction is zero.

2) Loop rule: the sum of the potential differences around any closed loop is zero.

Voltage supplied by power source in
- open circuit: ε (EMF)
- closed circuit: V

$V = \varepsilon - Ir$ — POTENTIAL

Current is defined as the net charge flowing through the cross-sectional area per unit time.

$I = \frac{dQ}{dt}$ — CURRENT

$J = \frac{I}{A} = nqv_d$ — CURRENT DENSITY

$R = \frac{\rho L}{A}$ — RESISTANCE

$\rho = \frac{E}{J}$ — RESISTIVITY

$P = VI = I^2R = \frac{V^2}{R}$ — POWER

OHM'S LAW

$$V = RI$$

RC CIRCUITS

Charging

$q = Q_f\left[1 - \exp\left(-\frac{t}{RC}\right)\right]$

$i = I_0 \exp\left(-\frac{t}{RC}\right)$

Discharging

$q = Q_0 \exp\left(-\frac{t}{RC}\right)$

$i = -I_0 \exp\left(-\frac{t}{RC}\right)$

q, i = charge and current at time t

Q_0, I_0 = charge and current at time $t = 0$

Q_f = charge approached asymptotically at $t \gg RC$

RC = time constant

A - cross-sectional area of wire

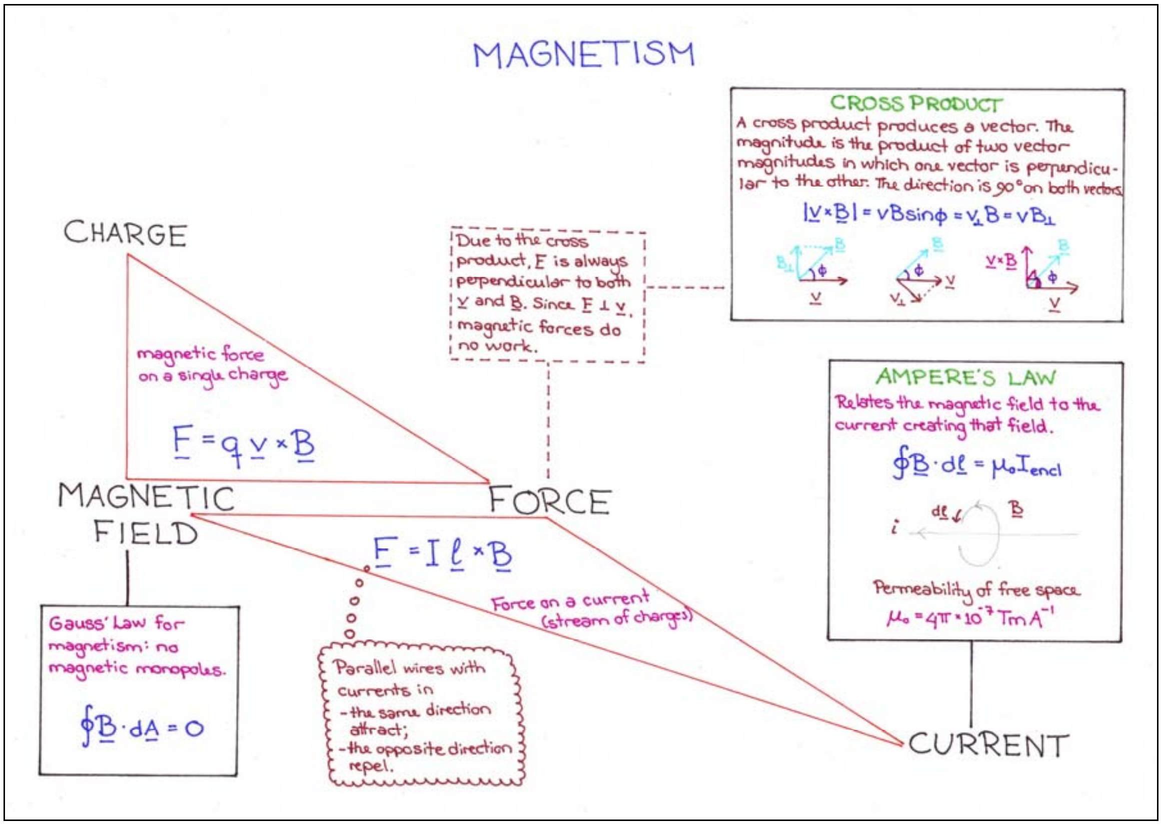
L - length of wire

n - number density of charges

v_d - drift velocity of charges

r - internal resistance of battery

MAGNETISM



$\underline{F} = q\,\underline{v} \times \underline{B}$

$\underline{F} = I\,\underline{\ell} \times \underline{B}$

Due to the cross product, $\underline{F}$ is always perpendicular to both $\underline{v}$ and $\underline{B}$. Since $\underline{F} \perp \underline{v}$, magnetic forces do no work.

CROSS PRODUCT

A cross product produces a vector. The magnitude is the product of two vector magnitudes in which one vector is perpendicular to the other. The direction is 90° on both vectors

$|\underline{v} \times \underline{B}| = vB\sin\phi = v_\perp B = vB_\perp$

AMPERE'S LAW

Relates the magnetic field to the current creating that field.

$\oint \underline{B} \cdot d\underline{\ell} = \mu_0 I_{encl}$

Permeability of free space

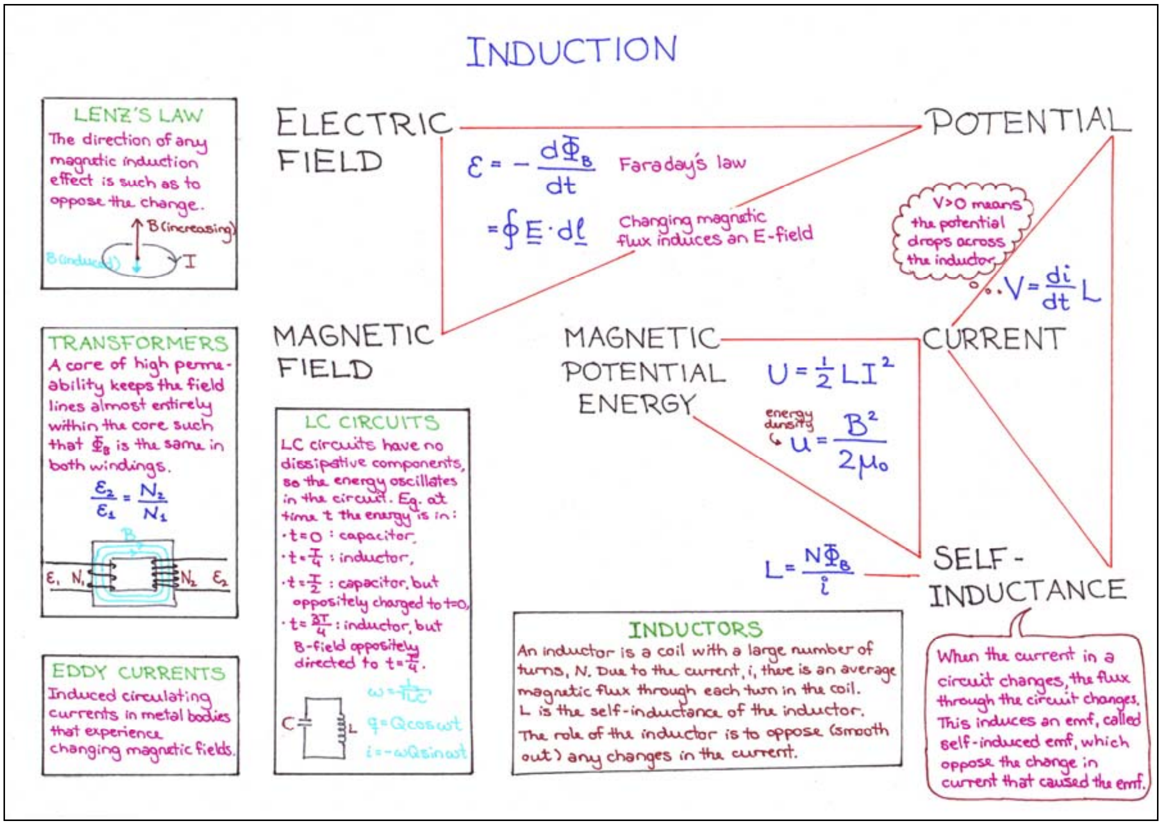
$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{Tm\,A^{-1}}$

Gauss' Law for magnetism: no magnetic monopoles.

$\oint \underline{B} \cdot d\underline{A} = 0$

Parallel wires with currents in
- the same direction attract;
- the opposite direction repel.

INDUCTION



$\mathcal{E} = -\dfrac{d\Phi_B}{dt}$

$= \oint \underline{E} \cdot d\underline{\ell}$

V>0 means the potential drops across the inductor.

$V = \dfrac{di}{dt} L$

$U = \frac{1}{2} L I^2$

$u = \dfrac{B^2}{2\mu_0}$

$L = \dfrac{N \Phi_B}{i}$

LENZ'S LAW

The direction of any magnetic induction effect is such as to oppose the change.

TRANSFORMERS

A core of high permeability keeps the field lines almost entirely within the core such that Φ_B is the same in both windings.

$\dfrac{\mathcal{E}_2}{\mathcal{E}_1} = \dfrac{N_2}{N_1}$

EDDY CURRENTS

Induced circulating currents in metal bodies that experience changing magnetic fields.

LC CIRCUITS

LC circuits have no dissipative components, so the energy oscillates in the circuit. Eg. at time t the energy is in:
- $t=0$: capacitor,
- $t=\frac{T}{4}$: inductor,
- $t=\frac{T}{2}$: capacitor, but oppositely charged to $t=0$,
- $t=\frac{3T}{4}$: inductor, but B-field oppositely directed to $t=\frac{T}{4}$.

$\omega = \frac{1}{\sqrt{LC}}$

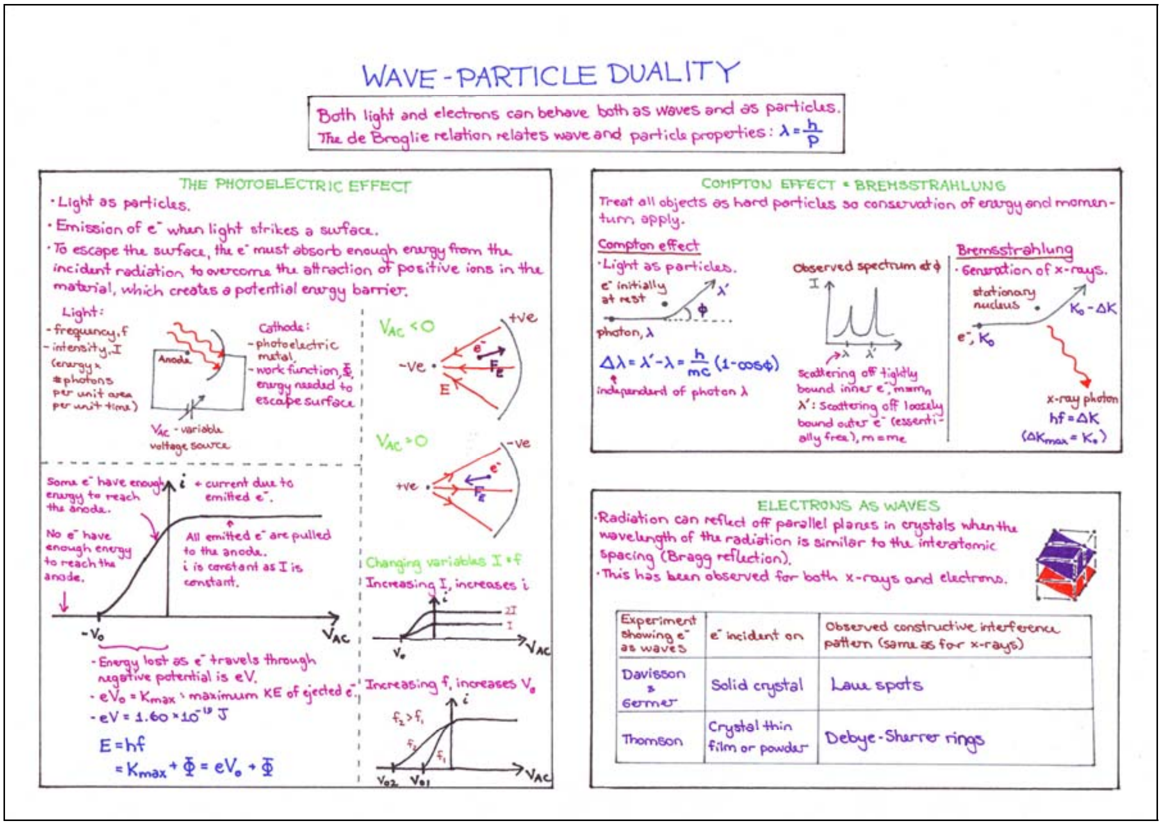
$q = Q\cos\omega t$

$i = -\omega Q\sin\omega t$

INDUCTORS

An inductor is a coil with a large number of turns, N. Due to the current, i, there is an average magnetic flux through each turn in the coil. L is the self-inductance of the inductor. The role of the inductor is to oppose (smooth out) any changes in the current.

When the current in a circuit changes, the flux through the circuit changes. This induces an emf, called self-induced emf, which oppose the change in current that caused the emf.



WAVE - PARTICLE DUALITY

Both light and electrons can behave both as waves and as particles.
The de Broglie relation relates wave and particle properties: $\lambda = \frac{h}{p}$

THE PHOTOELECTRIC EFFECT

- Light as particles.
- Emission of e^- when light strikes a surface.
- To escape the surface, the e^- must absorb enough energy from the incident radiation to overcome the attraction of positive ions in the material, which creates a potential energy barrier.

Light:
- frequency, f
- intensity, I (energy ∝ # photons per unit area per unit time)

Cathode:
- photoelectric metal,
- work function, Φ, energy needed to escape surface

- Energy lost as e^- travels through negative potential is eV.
- $eV_0 = K_{max}$: maximum KE of ejected e^-.
- $eV = 1.60 \times 10^{-19}$ J

$$E = hf = K_{max} + \Phi = eV_0 + \Phi$$

Changing variables I + f

Increasing I, increases i

Increasing f, increases V_0

COMPTON EFFECT + BREMSSTRAHLUNG

Treat all objects as hard particles so conservation of energy and momentum apply.

Compton effect

- Light as particles.

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{mc}(1 - \cos\phi)$$

independent of photon λ

Observed spectrum at ϕ

λ: Scattering off tightly bound inner e^-, $m = m_n$

λ': Scattering off loosely bound outer e^- (essentially free), $m = m_e$

Bremsstrahlung

- Generation of x-rays.

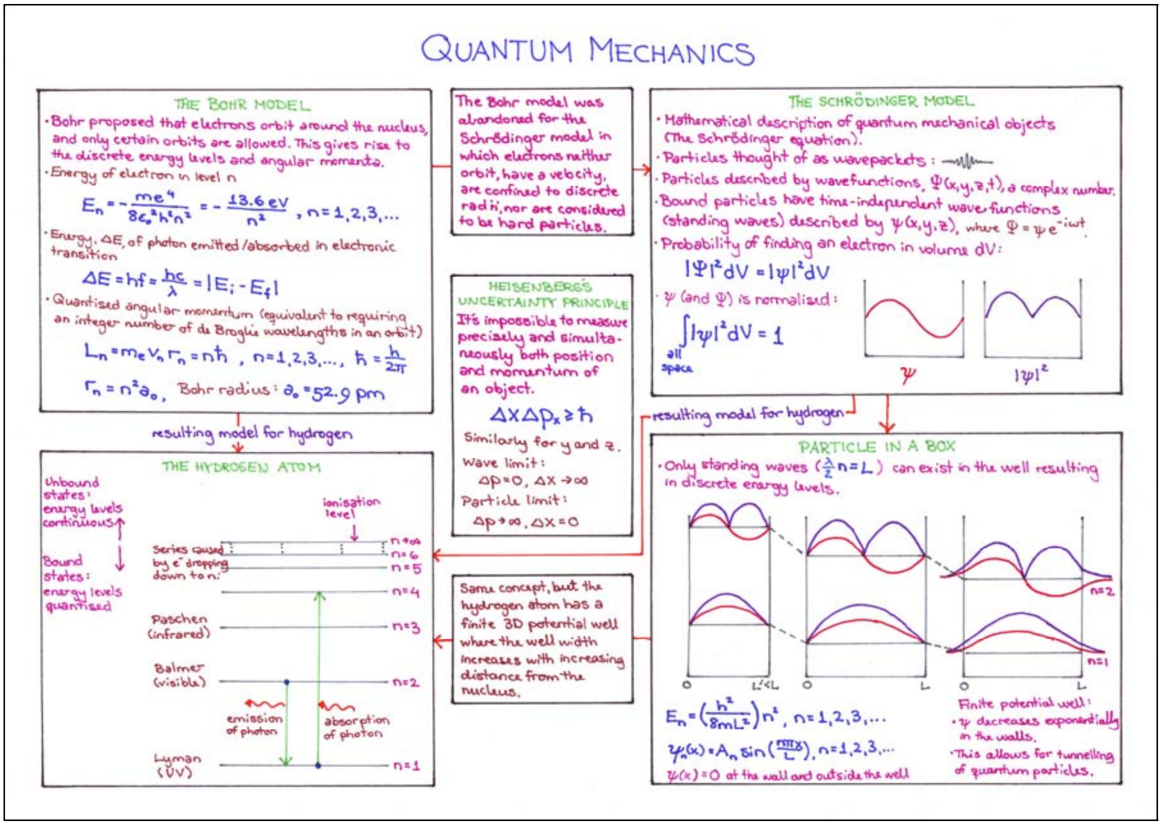
$hf = \Delta K$

$(\Delta K_{max} = K_0)$

ELECTRONS AS WAVES

- Radiation can reflect off parallel planes in crystals when the wavelength of the radiation is similar to the interatomic spacing (Bragg reflection).
- This has been observed for both x-rays and electrons.

Experiment showing e^- as waves	e^- incident on	Observed constructive interference pattern (same as for x-rays)
Davisson + Germer	Solid crystal	Laue spots
Thomson	Crystal thin film or powder	Debye-Sherrer rings



QUANTUM MECHANICS

THE BOHR MODEL

- Bohr proposed that electrons orbit around the nucleus, and only certain orbits are allowed. This gives rise to the discrete energy levels and angular momenta.
- Energy of electron in level n

$$E_n = -\frac{me^4}{8\epsilon_0^2 h^2 n^2} = -\frac{13.6\text{ eV}}{n^2}, \quad n = 1, 2, 3, \ldots$$

- Energy, ΔE, of photon emitted/absorbed in electronic transition

$$\Delta E = hf = \frac{hc}{\lambda} = |E_i - E_f|$$

- Quantised angular momentum (equivalent to requiring an integer number of de Broglie wavelengths in an orbit)

$$L_n = m_e v_n r_n = n\hbar, \quad n = 1, 2, 3, \ldots, \quad \hbar = \frac{h}{2\pi}$$

$$r_n = n^2 a_0, \quad \text{Bohr radius: } a_0 = 52.9 \text{ pm}$$

The Bohr model was abandoned for the Schrödinger model in which electrons neither orbit, have a velocity, are confined to discrete radii, nor are considered to be hard particles.

HEISENBERG'S UNCERTAINTY PRINCIPLE

It's impossible to measure precisely and simultaneously both position and momentum of an object.

$$\Delta x \Delta p_x \geq \hbar$$

Similarly for y and z.

Wave limit:
$\Delta p = 0$, $\Delta x \to \infty$

Particle limit:
$\Delta p \to \infty$, $\Delta x = 0$

THE SCHRÖDINGER MODEL

- Mathematical description of quantum mechanical objects (The Schrödinger equation).
- Particles thought of as wavepackets:
- Particles described by wavefunctions, $\Psi(x,y,z,t)$, a complex number.
- Bound particles have time-independent wave functions (standing waves) described by $\psi(x,y,z)$, where $\Psi = \psi e^{-i\omega t}$.
- Probability of finding an electron in volume dV:

$$|\Psi|^2 dV = |\psi|^2 dV$$

- ψ (and Ψ) is normalised:

$$\int_{\text{all space}} |\psi|^2 dV = 1$$

resulting model for hydrogen

THE HYDROGEN ATOM

Same concept, but the hydrogen atom has a finite 3D potential well where the well width increases with increasing distance from the nucleus.

resulting model for hydrogen

PARTICLE IN A BOX

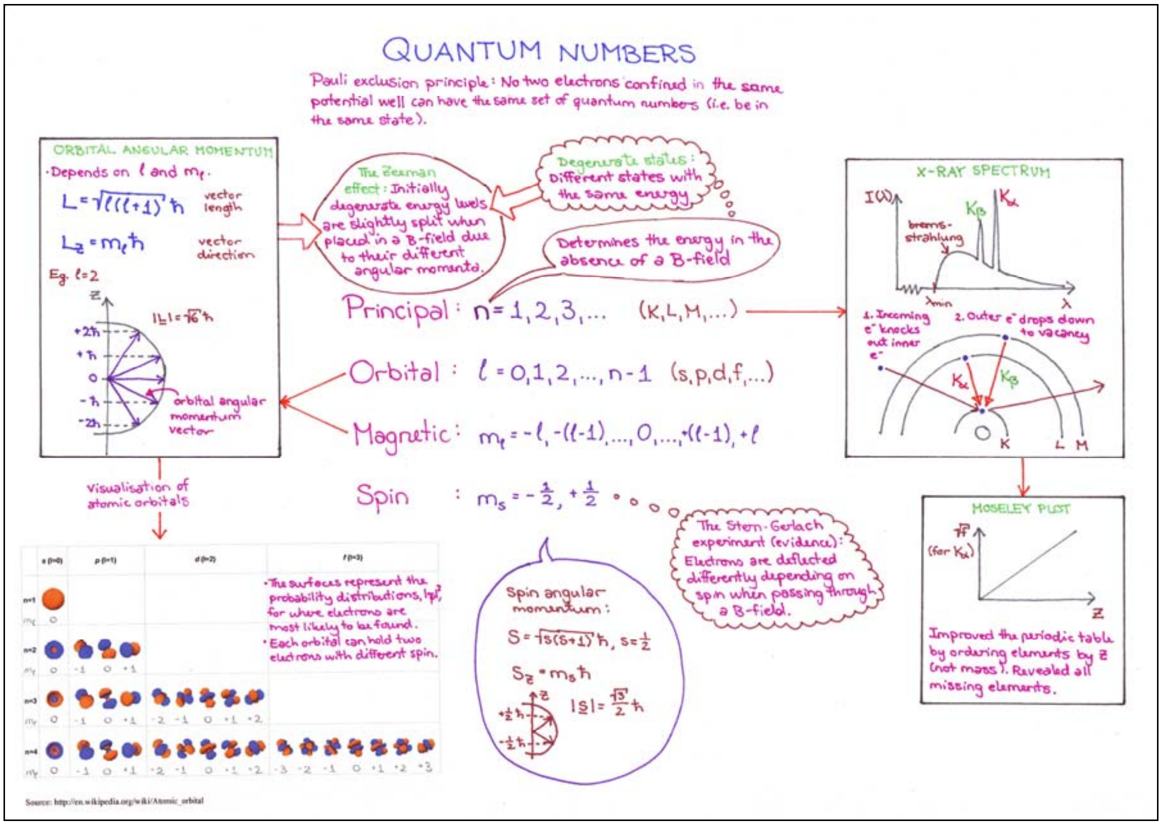
- Only standing waves ($\frac{\lambda}{2} n = L$) can exist in the well resulting in discrete energy levels.

$$E_n = \left(\frac{h^2}{8mL^2}\right) n^2, \quad n = 1, 2, 3, \ldots$$

$$\psi_n(x) = A_n \sin\left(\frac{n\pi x}{L}\right), \quad n = 1, 2, 3, \ldots$$

$\psi(x) = 0$ at the wall and outside the well

Finite potential well:
- ψ decreases exponentially in the walls.
- This allows for tunnelling of quantum particles.



QUANTUM NUMBERS

Pauli exclusion principle: No two electrons confined in the same potential well can have the same set of quantum numbers (i.e. be in the same state).

ORBITAL ANGULAR MOMENTUM

- Depends on ℓ and m_ℓ.

$L = \sqrt{\ell(\ell+1)}\,\hbar$ vector length

$L_z = m_\ell \hbar$ vector direction

Eg. $\ell = 2$

The Zeeman effect: Initially degenerate energy levels are slightly split when placed in a B-field due to their different angular momenta.

Degenerate states: Different states with the same energy

Determines the energy in the absence of a B-field

Principal: $n = 1, 2, 3, \ldots$ (K, L, M, …)

Orbital: $\ell = 0, 1, 2, \ldots, n-1$ (s, p, d, f, …)

Magnetic: $m_\ell = -\ell, -(\ell-1), \ldots, 0, \ldots, +(\ell-1), +\ell$

Spin: $m_s = -\frac{1}{2}, +\frac{1}{2}$

X-RAY SPECTRUM

1. Incoming e^- knocks out inner e^-
2. Outer e^- drops down to vacancy

MOSELEY PLOT

Improved the periodic table by ordering elements by Z (not mass). Revealed all missing elements.

Visualisation of atomic orbitals

- The surfaces represent the probability distributions, $|\psi|^2$, for where electrons are most likely to be found.
- Each orbital can hold two electrons with different spin.

Source: http://en.wikipedia.org/wiki/Atomic_orbital

Spin angular momentum:

$S = \sqrt{s(s+1)}\,\hbar$, $s = \frac{1}{2}$

$S_z = m_s \hbar$

$|\underline{S}| = \frac{\sqrt{3}}{2}\hbar$

The Stern-Gerlach experiment (evidence): Electrons are deflected differently depending on spin when passing through a B-field.

E Instruments

E.1 Interviews – invitation and schedule

Interviews were conducted with students in second semester, 2007. Students were invited via class announcements and emails. The following invitation was sent to the Technological students; a similar invitation was sent to the Environmental students. Semi-structured interviews were subsequently conducted using the interview schedule on the next page.

Dear 1st year TEC students,

In the survey you completed in week 3 you expressed interest in attending a lunch time group discussion about your physics tutorials to help evaluate and improve them. Well, the time has come, and I would like to invite you all to pizza in week 9. Please choose from one of the following days, and reply to this email to let me know which day you intend to come:

1pm Tuesday 18th September

1pm Thursday 20th September

1pm Friday 21st September

The group discussion will go for an hour in a room to be advised, and it would be helpful if you've had a think about what you like and dislike about the tutorials.

Enjoy your long weekend, and I hope to see you for lunch in week 9!

Regards,

Christine Lindstrøm

Topic	*Questions*	*Duration*	*Start time*
Introduction	Settle down Introduce students to purpose of the interview	10	:00
Motivation	Why do they come to tutorials? Do they work during tutes? Why/why not? Do the tutors motivate them to work? Suggested improvements.	10	:10
Tutorial: beginning	MM: Does the summary lecture help give an overview, or is it just more boring lecture stuff? Would it be better to just start solving problems right away?	3	:20
Tutorial: problem solving	All: Do you feel the problems make you learn? Are the problems too hard or easy? Are the demonstrators helpful in making you learn physics? Are the solutions handed out at the end helpful?	10	:23
Tutorial: end	MM: Does going through a problem at the end help?	3	:33
Overall	Do the tutorials help you get more out of lectures (eg. -flashback to map and links between concepts, -don't worry too much about things you don't get as it will be done in tutes, -problems make you understand things more clearly. What do you see as the primary advantage of tutorials?	7	:36
MMs vs. WTs and other tutes	Comment on comparison between the two. Next year we'll only run one type of tutorial, which do you think it should be?	5	:42
Tutorial improvement	Comparing with tutorials in other subjects, do you have any suggestions as to how the Map Meetings can be improved?	4	:47
Conclusion	Thank you!		:51

E.2 Questionnaires

Questionnaires were administered four times in 2007: in weeks 3 and 13 of first semester and again in week 3 and 13 of second semester. For logistic reasons, the week 3 administrations were in lectures while those in week 13 were in tutorials. The questionnaires differ slightly. In particular, questions regarding how useful the students found the tutorials for learning physics could only be asked at the end of each semester.

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PHYSICS QUESTIONNAIRE NO. 1

This questionnaire is part of Christine Lindstrøm's PhD project in which students' attitudes towards their physics studies will be investigated, especially with relation to participation in physics tutorials. Please note that:

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- No information about individual answers or your identity will be given to people teaching or assessing the course.

For the following questions, think about the statement in each box and respond by marking your level of agreement with the statement according to the following scale:

SD	D	N	A	SA
Strongly Disagree with the statement	**Disagree** with the statement (possibly with some reservations or qualifications)	**Neutral** In-between agreeing and disagreeing	**Agree** with the statement (possibly with some reservations or qualifications)	**Strongly Agree** with the statement

SID ____________________________

Please circle one only

1. I generally manage to solve difficult physics problems if I try hard enough SD D N A SA
2. I know I can stick to my aims and accomplish my goals in physics SD D N A SA
3. I will remain calm in my physics exam because I know I will have the knowledge to solve the problems SD D N A SA
4. I know I can pass the physics exam if I put in enough work during the semester SD D N A SA
5. The motto 'If other people can, I can too' applies to me when it comes to physics SD D N A SA
6. Physics is about linking a few fundamental ideas in several different ways SD D N A SA
7. Physics is one of the most complicated subjects I have ever studied (including high school subjects) SD D N A SA
8. Physics is about remembering a lot of facts and equations SD D N A SA
9. The Fundamentals physics course has been harder than I expected SD D N A SA
10. Studying physics is interesting SD D N A SA

Please turn over

I feel really successful when…

11.	I know more physics than other people	SD	D	N	A	SA
12.	What I learn in physics makes sense	SD	D	N	A	SA
13.	The other students in my tutorial group and I manage to solve a tutorial problem together	SD	D	N	A	SA
14.	I don't have to try hard to do well in physics	SD	D	N	A	SA
15.	I get a high exam mark	SD	D	N	A	SA
16.	I solve a problem by working hard	SD	D	N	A	SA
17.	I do my very best	SD	D	N	A	SA
18.	I work in a group on physics problems	SD	D	N	A	SA
19.	I can complete an assignment without really having understood the answers	SD	D	N	A	SA
20.	Others get physics problems wrong and I don't	SD	D	N	A	SA
21.	I can answer more physics questions than other students	SD	D	N	A	SA
22.	A group of us help each other	SD	D	N	A	SA
23.	I learn something interesting	SD	D	N	A	SA
24.	I can copy an assignment off somebody else	SD	D	N	A	SA
25.	I am in a group and we help each other figure something in physics out	SD	D	N	A	SA
26.	Others know more than me so they can answer the questions	SD	D	N	A	SA
27.	Something I learn makes me want to find out more	SD	D	N	A	SA
28.	I do better than others in physics	SD	D	N	A	SA
29.	I have somebody else to discuss physics problems with	SD	D	N	A	SA
30.	I know I can pass the exam without studying too hard	SD	D	N	A	SA

Thank you very much ;o)

The End

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PHYSICS QUESTIONNAIRE NO. 2

This questionnaire is part of Christine Lindstrøm's PhD project in which students' attitudes towards their physics studies will be investigated, especially with relation to participation in physics tutorials. Please note that:

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- No information about individual answers or your identity will be given to people teaching or assessing the course.

For the following questions, think about the statement in each box and respond by marking your level of agreement with the statement according to the following scale:

SD	D	N	A	SA
Strongly Disagree with the statement	**Disagree** with the statement (possibly with some reservations or qualifications)	**Neutral** In-between agreeing and disagreeing	**Agree** with the statement (possibly with some reservations or qualifications)	**Strongly Agree** with the statement

SID ______________________

Please circle one only

1.	I generally manage to solve difficult physics problems if I try hard enough	SD	D	N	A	SA
2.	I know I can stick to my aims and accomplish my goals in physics	SD	D	N	A	SA
3.	I will remain calm in my physics exam because I know I will have the knowledge to solve the problems	SD	D	N	A	SA
4.	I know I can pass the physics exam if I put in enough work during the semester	SD	D	N	A	SA
5.	The motto 'If other people can, I can too' applies to me when it comes to physics	SD	D	N	A	SA
6.	Physics is about linking a few fundamental ideas in several different ways	SD	D	N	A	SA
7.	Physics is one of the most complicated subjects I have ever studied (including high school subjects)	SD	D	N	A	SA
8.	Physics is about remembering a lot of facts and equations	SD	D	N	A	SA
9.	The Fundamentals physics course has been harder than I expected	SD	D	N	A	SA
10.	Studying physics is interesting	SD	D	N	A	SA
The following were useful for learning physics						
11.	Lectures	SD	D	N	A	SA
12.	Labs	SD	D	N	A	SA
13.	Tutorials	SD	D	N	A	SA

Please turn over

I feel really successful when…

14.	I know more physics than other people	SD	D	N	A	SA
15.	What I learn in physics makes sense	SD	D	N	A	SA
16.	The other students in my tutorial group and I manage to solve a tutorial problem together	SD	D	N	A	SA
17.	I don't have to try hard to do well in physics	SD	D	N	A	SA
18.	I get a high exam mark	SD	D	N	A	SA
19.	I solve a problem by working hard	SD	D	N	A	SA
20.	I do my very best	SD	D	N	A	SA
21.	I work in a group on physics problems	SD	D	N	A	SA
22.	I can complete an assignment without really having understood the answers	SD	D	N	A	SA
23.	Others get physics problems wrong and I don't	SD	D	N	A	SA
24.	I can answer more physics questions than other students	SD	D	N	A	SA
25.	A group of us help each other	SD	D	N	A	SA
26.	I learn something interesting	SD	D	N	A	SA
27.	I can copy an assignment off somebody else	SD	D	N	A	SA
28.	I am in a group and we help each other figure something in physics out	SD	D	N	A	SA
29.	Others know more than me so they can answer the questions	SD	D	N	A	SA
30.	Something I learn makes me want to find out more	SD	D	N	A	SA
31.	I do better than others in physics	SD	D	N	A	SA
32.	I have somebody else to discuss physics problems with	SD	D	N	A	SA
33.	I know I can pass the exam without studying too hard	SD	D	N	A	SA

The following parts of the tutorial helped me learn

34.	The summary 'lecture' at the beginning of the tutorial	SD	D	N	A	SA
35.	Talking to the tutors	SD	D	N	A	SA
36.	Working on problems	SD	D	N	A	SA
37.	Trying out the demonstrations	SD	D	N	A	SA
38.	Seeing problems worked through on the board	SD	D	N	A	SA

39. If you attended at least one of *each* type of tutorial offered this semester (Map Meeting and Workshop tutorial), which style did you prefer, and why?

40. What have you liked/disliked about the type of tutorial you are attending today?

Thank you very much ;o)

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PHYSICS QUESTIONNAIRE NO. 3

This questionnaire is part of Christine Lindstrøm's PhD project in which students' attitudes towards their physics studies will be investigated, especially with relation to participation in physics tutorials. Please note that:

- Participation in this project by completing this survey is completely voluntary, and
- No information about individual answers or your identity will be given to people teaching or assessing the course.

For the following questions, think about the statement in each box and respond by marking your level of agreement with the statement according to the following scale:

SD	D	N	A	SA
Strongly Disagree with the statement	**Disagree** with the statement (possibly with some reservations or qualifications)	**Neutral** In-between agreeing and disagreeing	**Agree** with the statement (possibly with some reservations or qualifications)	**Strongly Agree** with the statement

SID ______________________

Please circle one only

1. I generally manage to solve difficult physics problems if I try hard enough SD D N A SA
2. I know I can stick to my aims and accomplish my goals in physics SD D N A SA
3. I will remain calm in my physics exam because I know I will have the knowledge to solve the problems SD D N A SA
4. I know I can pass the physics exam if I put in enough work during the semester SD D N A SA
5. The motto 'If other people can, I can too' applies to me when it comes to physics SD D N A SA
6. Physics is about linking a few fundamental ideas in several different ways SD D N A SA
7. The physics course was a good preparation for the final exam last semester SD D N A SA
8. Studying physics is interesting SD D N A SA
9. I find that at times studying physics gives me a feeling of deep personal satisfaction SD D N A SA
10. I am discouraged by a poor mark on a physics test and worry about how I will do on the next test SD D N A SA
11. Physics is about remembering a lot of facts and equations SD D N A SA
12. I have been looking forward to doing physics again this semester SD D N A SA

Please turn over

13. I felt well prepared for the exam last semester SD D N A SA

14. When studying physics, I learn some things by rote, going over them again and again until I know them by heart SD D N A SA

15. While I realize that ideas are always changing as knowledge is increasing, I feel a need to discover for myself what is understood about the physical world at this time SD D N A SA

16. The more physics I learn, the more interesting it becomes SD D N A SA

17. The exam last semester was as I had expected it to be SD D N A SA

18. I feel I have a good overview of what I learnt last semester SD D N A SA

19. In reading new material in physics I often find that I am continually reminded of material I already know, and see the latter in a new light SD D N A SA

20. I worry that, even if I have studied hard for a physics test, I may not get a good mark SD D N A SA

21. I knew what was expected of me in last semester's exam SD D N A SA

22. I feel that virtually any topic in physics can become interesting once I get into it SD D N A SA

23. I am prepared to work hard in my physics course because I feel it will contribute to my employment prospects SD D N A SA

24. I felt that I knew how to approach the exam questions last semester SD D N A SA

25. When studying physics, I become increasingly absorbed in my work the more I do SD D N A SA

26. The way physics is taught makes the subject interesting SD D N A SA

27. I am very aware that teachers know a lot more than I do, so I concentrate on what they say is important rather than rely on my own judgement SD D N A SA

28. I strongly believe that my main aim in studying physics is to understand it for my own satisfaction SD D N A SA

29. I can see how different topics we cover in physics are related to one another SD D N A SA

I learn physics by…

30. reading the textbook SD D N A SA

31. studying worked examples SD D N A SA

32. reading the lecture notes SD D N A SA

33. summarizing the lecture notes SD D N A SA

34. solving problems SD D N A SA

35. discussing physics with other students SD D N A SA

36. searching for answers to problems I think of myself SD D N A SA

37. doing past exam papers SD D N A SA

38. using tutorial sheets SD D N A SA

39. talking to lecturers or tutors SD D N A SA

If you attended/attend Map Meeting tutorials with Christine or Mud either last semester or this semester and would be interested in receiving a free lunch while giving feedback on these tutorials, please write down your email address, and you will be contacted in a few weeks

Thank you very much ;o)

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PHYSICS QUESTIONNAIRE NO. 4

This questionnaire is part of Christine Lindstrøm's PhD project in which students' attitudes towards their physics studies will be investigated, especially with relation to participation in physics tutorials. Please note that:

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- No information about individual answers or your identity will be given to people teaching or assessing the course.

For the following questions, think about the statement in each box and respond by marking your level of agreement with the statement according to the following scale:

SD	D	N	A	SA
Strongly Disagree with the statement	**Disagree** with the statement (possibly with some reservations or qualifications)	**Neutral** In-between agreeing and disagreeing	**Agree** with the statement (possibly with some reservations or qualifications)	**Strongly Agree** with the statement

SID ________________________

Please circle one only

1.	I generally manage to solve difficult physics problems if I try hard enough	SD	D	N	A	SA
2.	I know I can stick to my aims and accomplish my goals in physics	SD	D	N	A	SA
3.	I will remain calm in my physics exam because I know I will have the knowledge to solve the problems	SD	D	N	A	SA
4.	I know I can pass the physics exam if I put in enough work during the semester	SD	D	N	A	SA
5.	The motto 'If other people can, I can too' applies to me when it comes to physics	SD	D	N	A	SA
6.	Physics is about linking a few fundamental ideas in several different ways	SD	D	N	A	SA
7.	Studying physics is interesting	SD	D	N	A	SA
8.	Physics is about remembering a lot of facts and equations	SD	D	N	A	SA
9.	Physics is one of the most complicated subjects I have ever studied (including high school subjects)	SD	D	N	A	SA
10.	Studying physics this year was harder than I had expected	SD	D	N	A	SA
11.	I find that at times studying physics gives me a feeling of deep personal satisfaction	SD	D	N	A	SA
12.	I have enjoyed studying physics this semester	SD	D	N	A	SA
13.	When studying physics, I learn some things by rote, going over them again and again until I know them by heart	SD	D	N	A	SA
14.	While I realize that ideas are always changing as knowledge is increasing, I feel a need to discover for myself what is understood about the physical world at this time	SD	D	N	A	SA
15.	The more physics I learn, the more interesting it becomes	SD	D	N	A	SA
16.	I feel I have a good overview of what I have learnt this semester	SD	D	N	A	SA

Please turn over

17. In reading new material in physics I often find that I am continually reminded of material I already know, and see the latter in a new light SD D N A SA

18. I worry that, even if I have studied hard for a physics test, I may not get a good mark SD D N A SA

19. I feel that virtually any topic in physics can become interesting once I get into it SD D N A SA

20. I have worked hard in my physics course because I feel it will contribute to my employment prospects and further studies SD D N A SA

21. I feel that I know how to approach the exam questions this semester SD D N A SA

22. When studying physics, I become increasingly absorbed in my work the more I do SD D N A SA

23. The way physics is taught makes the subject interesting SD D N A SA

24. I am very aware that teachers know a lot more than I do, so I concentrate on what they say is important rather than rely on my own judgement SD D N A SA

25. I strongly believe that my main aim in studying physics is to understand it for my own satisfaction SD D N A SA

26. I can see how different topics we cover in physics are related to one another SD D N A SA

Answer the following questions with respect to the type of tutorial you are attending today

27. I work well in tutorials SD D N A SA

28. For how many minutes (out of the 50 minute tutorial) do you estimate that you are focusing on physics? _____ min

29. The tutors motivate me to do work SD D N A SA

30. [Workshop tutorial students only] I have been getting the maps this semester Yes No

31. It is worth my time coming to tutorials SD D N A SA

32. The main reason for coming to tutorials is so that I can get the attendance mark SD D N A SA

33. I would not come to tutorials if they were voluntary SD D N A SA

34. Overall, I am satisfied with the type of tutorial I am attending today SD D N A SA

35. Please indicate the difficulty level of the tutorial problems Too hard Just right Too easy

36. If you have attended (at least once) both a Workshop tutorial (no map) and a Map Meeting tutorial (maps given out), which tutorial type did you prefer? Workshop Map Meeting

The following were useful for learning physics

37. Lectures SD D N A SA

38. Labs SD D N A SA

39. Tutorials (referring to the type you are attending today) SD D N A SA

The following aspects of the type of tutorial *I am attending today* **were useful for learning physics (if you are attending a workshop tutorial today, do not answer questions 45-47)**

40. Solving the tutorial questions SD D N A SA

41. Studying the tutorial solutions SD D N A SA

42. Working in groups SD D N A SA

43. Doing the demonstrations SD D N A SA

44. Talking to the tutors SD D N A SA

45. Listening to the summary lecture at the start of the tutorial SD D N A SA

46. The map SD D N A SA

47. Seeing a questions gone through on the board at the end of the tutorial SD D N A SA

Thank you very much ;o)

F Degree course enrollments

Category	*Degree*
Bachelor of Science	Bachelor of Science
Medical science	Bachelor of Medical Science
Engineering	Bachelor of Engineering
Combined science	Bachelor of Arts and Sciences Bachelor of Science, Bachelor of Law Bachelor of Science, Bachelor of Arts Bachelor of Science, Bachelor of Commerce
Science/Engineering	Bachelor of Engineering, Bachelor of Science
Combined engineering	Bachelor of Engineering, Bachelor of Arts Bachelor of Engineering, Bachelor of Commerce Bachelor of Engineering, Bachelor of Medical Science
Life sciences	Bachelor of Science, Bachelor of Medicine Bachelor of Science (Marine Science) Bachelor of Science (Molecular Biology & Genetics) Bachelor of Science (Molecular Biotechnology) Bachelor of Science (Nutrition) Bachelor of Science, Master of Nursing
Technological science	Bachelor of Computer Science and Technology Bachelor of Information Technology Bachelor of Science and Technology
Science Education	Bachelor of Education, Bachelor of Science Bachelor of Education, Bachelor of Science Bachelor of Education, Bachelor of Science Bachelor of Teaching
Non-science	Bachelor of Arts Bachelor of Commerce (Liberal studies) Bachelor of Economic and Social Sciences Bachelor of Liberal Studies Bachelor of Psychology Exchange/study abroad

G Papers

G.1 *Factor analysis paper*

This paper was published in the proceedings from the UniServe Science symposium, 2008. The main focus of the paper is to carefully explain the mathematics of exploratory factor analysis (known as principal components analysis in mathematics), a widely used but generally not well understood procedure to identify clusters of correlating items in questionnaires. I had not found any literature that explained exploratory factor analysis in a relatively simple way – most accounts are found in mathematics textbooks, which are generally overly complicated for the science education community; I therefore wrote this paper to provide such a reference.

G.2 *Physics goal orientation paper*

This paper reports on the development of a questionnaire to evaluate students' physics goal orientations. Achievement goal theory forms a large and important part of the motivation literature, but a specific instrument for measuring goal orientations in physics had not been developed. I therefore developed a physics goal orientation survey, but because this was not finished until the end of 2008, it could not be used for my thesis. The development and preliminary findings were therefore published separately in the *International Journal of Innovation in Science and Mathematics Education* in 2010.

G.3 *Self-efficacy paper*

This paper reports on the validation of the physics self-efficacy instrument used in this thesis. No similar instrument was found in literature prior to its development. The paper also contains an extensive analysis of trends in first year physics students' self-efficacy in 2007 that were not included in the thesis because it does not consider the tutorials. The paper was submitted to *Physical Review – Special Topics Physics Education Research* and is currently at the stage of revision prior to resubmission.

Initial development of a Physics Goal Orientation survey using factor analysis

Christine Lindstrøm and **Manjula D. Sharma**, School of Physics, University of Sydney, Australia
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Abstract: *This paper presents the first stage in the development of a Physics Goal Orientation survey - a survey identifying students' beliefs about how to be successful in physics studies. The analysis method used is exploratory factor analysis, a powerful statistical method requiring subjective decision making. Instead of taking a 'black box' approach, which can easily lead researchers to draw incorrect conclusions, we have provided the mathematical basis for principal components analysis, the most common type of exploratory factor analysis.*

Introduction

Goal orientation theory forms part of the motivation literature, and is perhaps the most prominent theory today (Urdan, Kneisel, and Mason, 1999). It focuses on students' *reasons* for engaging in academic tasks, as these affect important educational outcomes such as types of cognitive strategies used, and how well newly learnt material is retained (Anderman, Austin, and Johnson, 2002). Studies of high school students' motivation in the general settings of 'classroom' and 'sports' have identified four different goal orientations, each associated with a certain belief in how success is achieved (Duda and Nicholls, 1992; Skaalvik, 1997). Task orientation is associated with the belief that success is a product of effort, understanding and collaboration. Ego orientation describes the belief that success relies on greater ability and attempting to outperform others. Cooperation oriented students value interaction with their peers in the learning process; and lastly, work avoidance describes the goal of minimum effort – maximum gain. A similar study in physics, however, has not been found, so the first aim of the paper is to develop a Physics Goal Orientation survey.

Factor analysis has become an increasingly popular statistical method over the past few decades, primarily due to the ease of use with statistical packages such as the *Statistical Package for the Social Sciences (SPSS)*. Whereas the availability of such analysis has the potential to improve work in science education, it is a double edged sword if a solid understanding of the underlying statistics does not accompany its use, as shown by Preacher and MacCallum (2003). Unfortunately, however, the literature on factor analysis is seemingly divided into the thoroughly mathematical and the purely practical. Therefore, the second aim of this paper is to provide adequate mathematical insight to support decision making in the process of using the most common statistical approach to exploratory factor analysis, principal components analysis. The mathematics requires familiarity with vectors or linear algebra.

Research method

In developing a new survey, statements are written or adapted from previous surveys and accompanied by a Likert scale. Each underlying construct has statements, each measuring a different aspect of the construct. Some statements will need to be removed, and a minimum of four statements must be retained for each factor. The requirement on sample size is not clear. In general, the conceptual basis of the statements (theory driven) and results from factor analysis (data driven) are useful guides.

In 2006, 125 first year physics students at the University of Sydney completed the Physics Goal Orientation survey. For each of the 20 statements students responded on a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). All statements were adapted from Duda and Nicholls'

(1992) surveys to suit tertiary physics education (see Table 1).

I feel really successful when…

Item 1	I know more physics than other people
Item 2	what I learn in physics makes sense
Item 3	the other students in my tutorial group and I manage to solve a tutorial problem together
Item 4	I don't have to try hard to do well in physics
Item 5	I get a high exam mark
Item 6	I solve a problem by working hard
Item 7	I do my very best
Item 8	I work in a group on physics problems
Item 9	I can complete an assignment without really having understood the answers
Item 10	others get physics problems wrong and I don't
Item 11	I can answer more physics questions than other students
Item 12	a group of us help each other
Item 13	I learn something interesting
Item 14	I can copy an assignment off somebody else
Item 15	I am in a group and we help each other figure something in physics out
Item 16	others know more than me so they can answer the questions
Item 17	something I learn makes me want to find out more
Item 18	I do better than others in physics
Item 19	I have somebody else to discuss physics problems with
Item 20	I know I can pass the exam without studying too hard

Table 1: Statements on the Physics Goals Orientations Survey.

Theory of factor analysis

Factor analysis is a data reduction method, allowing a reduction in the number of variables in a data set, while retaining a large fraction of the information. In science education factor analysis is commonly used with surveys that measure some psychometric construct, which cannot be measured directly (such as self-efficacy or students' study strategies). Respondents indicate on a Likert scale their level of agreement with several statements that focus on different aspects of the construct. Factor analysis is then used to evaluate whether the statements indeed measure aspects of the same underlying construct, and finally give each individual respondent to the survey an overall score on the construct.

Two different types of factor analysis exist. Exploratory factor analysis is used to identify underlying structure in the data. Confirmatory factor analysis is used in hypothesis testing, and is the only method for confirming whether modeled factor structures are compatible with the data. Only exploratory factor analysis is discussed in this paper. Please note that normally distributed variables are only required if the data are used to generalise findings (Field, 2000). The novice user will find Field (2000) helpful, whereas Gorsuch (1983) and Floyd and Widaman (1995) provide fine detail. The brief discussion below bridges the gap.

The correlation matrix

The basis of factor analysis is that people show a pattern in their responses to groups of statements or variables. From Table 1, respondents would be expected to indicate a similar level of agreement with Items 1 and 18 . A scatter plot of responses should therefore produce a strong, linear correlation. The Pearson's r correlation coefficients between each pair of variables are presented in the Correlation matrix or R-matrix in the *SPSS* output of a factor analysis; a $k \times k$ matrix for k variables. All further analysis of the data is based on this matrix; individual responses are no longer considered. However, before the analysis can proceed, several assumptions on the Correlation matrix must be met.

Firstly, no two variables must correlate too strongly. Since the purpose of a factor analysis is to identify underlying concepts using statements that target *different* aspects of a concept, two almost identical statements do not satisfy this requirement. Therefore, the determinant of the Correlation matrix is required to be greater than 10^{-5}. If this condition is violated, correlations with $r > 0.8$ should be eliminated by removing one item at the time until the determinant is satisfactory.

The second test is Bartlett's test of sphericity, which reports how similar the Correlation matrix is to an identity matrix. The statistical significance of the similarity is quoted, and since the Correlation matrix is required to be considerably dissimilar to an identity matrix, which has no intervariable correlation, the p-value must be less than 0.05.

The last test is the Kaiser-Mayer-Olkin measure of sampling adequacy, or KMO. This measure predicts whether the data is expected to factor well. Its value should be greater than 0.5 for an adequate sample, but the greater the value, the better. In the Anti-image matrix, the diagonal elements are individual KMOs, whose average is the sample KMO. Variables with individual KMOs lower than 0.5 should be considered removed as they show an unacceptably high level of multicollinearity. (See Hutcheson and Sofroniou, 1999, for more detail.)

Constructing the vector space

The remaining factor analysis will be explained invoking multi-dimensional vector spaces, where each variable is considered a unit vector. The correlation, r, between two variables is represented in vector space according to $r_{12} = x_1 x_2 \cos\theta_{12}$, where θ is the angle between the two vectors. However, since each variable is a unit vector, this simplifies to $r = \cos\theta$. In this representation r is the fractional length of one vector projected onto the other. Note that r^2 represents the variance shared between the two vectors.

The following procedure will build up a k-dimensional space dimension by dimension. Let $\boldsymbol{x_1}$ represent the first variable, its base defining the origin of the vector space. The direction of $\boldsymbol{x_1}$ defines the first dimension. The second variable, $\boldsymbol{x_2}$, is placed at the origin at an angle θ_{12} to $\boldsymbol{x_1}$ according to r_{12}, thus introducing the second dimension. All remaining variables are introduced in the same way, ensuring that each new variable is positioned at the correct angle to all previously introduced variables until a k-dimensional space is constructed (assuming each variable introduces some unique variance).

The subsequent task is to introduce a coordinate system with k orthogonal axes. Introducing one axis at the time, the first axis is placed in the direction which maximizes the sum of squares of all vector projections onto the axis. The remaining axes are introduced according to the same condition, subject to the additional requirement of being orthogonal to the previously introduced axes. That is, the m^{th} coordinate axis is positioned so as to maximize E_m, given by

$$E_m = \sum_{n=1}^{k} \cos^2 \phi_{m,n} = \sum_{n=1}^{k} r_{m,n}^2$$

where $\phi_{m,n}$ is the angle and $r_{m,n}$ is the correlation coefficient between the n^{th} vector and the m^{th} axis.

Identifying and extracting factors

Much of the *SPSS* output in a factor analysis is direct reporting of variables described above. Each coordinate axis represents a factor, and E_m is the eigenvalue of the m^{th} factor, which is found in the *SPSS* output Total variance explained. In the same table, the Percentage of variance explained by the m^{th} factor is given by $\frac{E_m}{k}$. The Scree plot displays eigenvalue as a function of component number (factor).

Based on these outputs, the number of factors to extract is decided. Recall that the purpose of factor analysis is to maximize the amount of variance explained in the data with the minimum amount of factors. There are two methods to decide on the number of factors, which should be used in tandem: Kaiser's criterion and the Scree test. Kaiser's criterion states that all factors with an eigenvalue greater than 1 should be kept. Each factor accounts for $\frac{1}{k}$ of the information, but $\frac{E_m}{k}$ of the variance in the data. Consequently, factors with $E_m > 1$ account for a larger proportion of the variance explained than information retained. However, the Scree plot should also be consulted before the final decision is made. The plot consists of two parts: a steep decline at the first few factors, and a relatively flat plateau at higher order factors. The inflection point occurs immediately before the plateau, which represents factors containing mostly uninteresting, noisy variance. The factors prior to the inflection point stand out as they contain more variance per factor than those in the plateau, and we associate this with the underlying constructs. Generally both Kaiser's criterion and the Scree plot produce the same number of factors, but when this is not the case care should be taken to extract a sensible number of factors based on knowledge of the data set (see the next section for an example).

Once the number of factors or dimensions (f) has been chosen, all variables are effectively projected onto this f-dimensional sub-space. The squared length of each projected vector is the variance explained by the extracted factors collectively. These values are reported in the Communalities table. The resulting 'unexplained' variance is therefore simply the information discarded along with the discarded dimensions. The coordinates of each vector are referred to as the loadings onto each factor (or axis), and are reported in the Component matrix. When the coordinate axes are orthogonal the factor loadings correspond to the r-values for each variable-factor pair. Generally, only factor loadings greater than 0.4 are quoted for ease of table interpretation.

The current solution is referred to as the unrotated solution. The variables loading heavily onto one factor form a cluster of vectors intersected by the corresponding axis. However, due to the way the coordinate system was generated, this cluster intersection may not be optimal. Therefore, to optimize the individual factor loadings the entire f-dimensional coordinate system can be rotated. The criterion used is that each variable should load strongly onto only one axis (that is, the variable belongs to one underlying construct only). In an orthogonal rotation the axes are required to remain orthogonal, whereas an oblique rotation allows the axes to move independently of each other. The resulting angles between axes reflect correlations between the factors, which are presented in the Component correlation matrix.

After rotation, the total variance explained by the factors remains the same since the projection of each variable onto the sub-space (i.e. the communality) is unrelated to the position of the coordinate axes. The factor loadings, however, have changed, and are presented in the Rotated component matrix for orthogonal rotations and in the Pattern matrix for oblique rotations. Note that after an oblique rotation the factor loadings are no longer equivalent to the variable-factor correlations. The correlations are presented in the Structure matrix, but this is generally ignored since a correlation in a non-orthogonal vector space includes information that is not unique to the particular variable-factor pair.

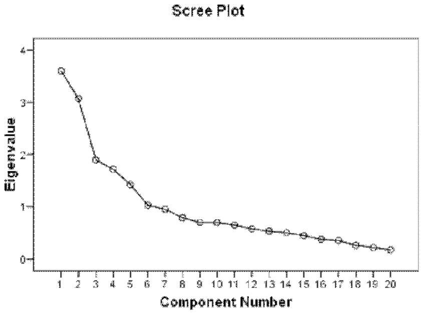

Fig. 1: Scree Plot produced by SPSS for the Physics Goal Orientations survey.

Analysis and interpretation

From the *SPSS* output the data were found suitable for factor analysis (determinant = 0.001, Bartlett's test: $p = 0.000$, and KMO = 0.664). All individual KMOs were > 0.5, except for two variables which had values of 0.484 and 0.483. However, being very close to 0.5, the variables were kept to consider their overall contribution to the analysis.

Kaiser's criterion initially extracted six factors. Investigation of the Scree plot (Fig. 1), however, suggested retention of five factors only. The Component matrix supported this, as the sixth factor only contained one variable, hardly satisfying the critrion as a factor.

The analysis was therefore rerun specifying extraction of five factors. Note that the following tables and figures were unaffected by the number of factors extracted: Descriptive statistics, Correlation matrix, KMO and Bartlett's test, Anti-image matrices, and the Scree plot. The Total variance explained and Component matrix only saw the sixth factor removed. The Pattern matrix, Structure matrix, and Component correlation matrix did change, however.

Having decided the number of factors, the type of rotation was chosen. An oblique rotation (Direct Oblimin) was performed first to allow the data itself to reveal any correlations between factors, which were indeed observed. Had there been none, an orthogonal rotation (Varimax) could have subsequently been performed.

The Pattern Matrix (Table 2) revealed that variable 8 did not contribute strongly onto any of the extracted factors since it had no factor loadings greater than 0.4. This was not surprising as the variable showed a factor loading of 0.638 onto the initially extracted sixth factor, which was discarded. The variable was therefore removed.

Considering that the purpose of the Physics Goal Orientation survey is to obtain statements that collectively give indications about underlying psychological constructs, variables 1 and 4 were problematic. By loading onto two different factors, both variables targeted elements of two constructs simultaneously. The variables were therefore discarded.

Communalities reflect how much of the information in a variable is retained by the factors. Generally, a sample of less than 100 is acceptable if all communalities are above 0.6, and 100-200 is acceptable for communalities in the 0.5 range. Alternatively, if a factor has four or more factor loadings greater than 0.6 it is reliable. With an average communality of 0.58 after extracting five factors, the sample size was considered adequate. Since a reliable factor should have a minimum of four factor loadings greater than 0.6, only factors 1 and 5 currently satisfy this criterion.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Item 6	.860				
Item 3	.701				
Item 2	.614				
Item 7	.612				
Item 5	.417				
Item 8					
Item 11		.890			
Item 10		.802			
Item 18		.789			
Item 1		.584	.469		
Item 13			.822		
Item 17			.778		
Item 16				.709	
Item 9				.660	
Item 14				.650	
Item 20					-.660
Item 19					-.646
Item 15					-.634
Item 12					-.607
Item 4		.416			-.416

Table 2: The Pattern matrix showing the factor loadings after an oblique rotation.

As demonstrated above, factor analysis is not a clear cut process. Decisions have to be made and these are often not presented in research articles. The subjective nature makes it even more important that one has an understanding of the mathematical basis when practicing factor analysis or relying on studies that use factor analysis. As seen in this paper, the factors identified by Duda and Nicholls (1992) could not be reproduced in a physics setting. For a first trial of an adapted survey the structure is very promising, but addition of items and a retrial of the survey is necessary before it is fully developed.

What does Table 2 tell us? First, factor 1 reflects task or mastery orientation and this is clearly demonstrated both conceptually and in the data. It is interesting to note that item 3 on 'group work in tutorials' is in this factor reflecting the focus on constructive meaning making in learning physics. Factor 2 represents the ego orientation and factor 4 is clearly work avoidance. We have called factor 3 the interest orientation, but having only two items more will need to be added for the second trial of the survey. Factor 5 is the cooperation orientation, but it also contains an item (number 20) which does not conceptually belong with the rest of the items, even though all the items group mathematically. Item 20 will therefore be removed from the survey. This highlights one of the most important aspects of factor analysis: the mathematical sophistication of the analysis is of little worth if it is not accompanied by a critical mind.

Conclusion

This paper has demonstrated that surveys used within one area may not be directly applicable in another area. However, certain constructs do emerge clearly despite the change in discipline area. In our case task orientation, ego orientation and work avoidance were readily identifiable. The paper also aimed to give an insight into principal components analysis, and how subjective decisions need to be made when carrying out factor analysis. It is the hope of the authors that this will inspire fellow science education researchers to develop a more profound understanding of this complex statistical method.

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Development of a Physics Goal Orientation survey

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Abstract

A key question in learning and teaching is: What motivates students to learn? In the second half of the 20th century achievement goal theory emerged as a key feature of the motivation literature. This theory focuses on what motivates students toward actions that will result in learning; students have particular goals and beliefs that orient them to select particular strategies and ways of learning and planning their success.

Although motivation and goal orientations influence student learning outcomes, there appear to be no studies on goal orientations in university physics. This study focused on developing a goal orientation survey specific to university physics studies. A pilot study was undertaken in 2006 (Lindstrøm & Sharma, 2008). This paper describes the continuation and conclusion of the study in 2007 and 2008 spanning five administrations, each with sample sizes between 162 and 360 students.

Introduction

Motivation is an area concerned with understanding the reasons for and the consequences of what brings us to learn in the first place. It is the stepping stone to learning and thus an essential part of the learning process. Several theories of motivation exist, but achievement goal theory is perhaps the most prominent (Urdan, Kneisel & Mason, 1999).

Achievement goal theory focuses on students' *reasons* for engaging in academic tasks, because these affect important educational outcomes such as types of cognitive strategies used and how well newly learnt material is retained (Anderman, Austin & Johnson, 2002). The goals described are task specific, rather than individual specific, and can change with time due to individual reasons or environmental influences.

Two different types of goal orientations, known by different names in different circles, form the core of achievement goal theory. The mastery (Ames, 1992), learning (Dweck & Leggett, 1988) or task (Duda & Nicholls, 1992) orientation refers to the aim to increase competence with respect to self-set standards, focusing on mastery, learning and understanding (Linnenbrink & Pintrich, 2001). Mastery-oriented students are intrinsically motivated, value progress and enjoy taking on challenges, and view mistakes as part of the learning process (Anderman et al., 2002). The performance (Ames, 1992), self-enhancing (Skaalvik, 1997) or ego (Duda & Nicholls, 1992) orientation is, unlike the mastery orientation, extrinsically motivated. The focus is on the outcome of a task, competence is normatively measured (i.e., with respect to others) and a key feature of the performance goal is the establishment of one's position in the hierarchy of relative competence.

In recent times, additional goal orientations have been proposed. Work avoidance is one in which the student attempts to maximise performance by minimising effort (Nicholls, Cobb, Wood, Yackel & Petashnick, 1990). Another addition has been prosocial goals (Covington, 2000), which focus on the social aspect and environment of the learning situation; cooperation is one such prosocial goal orientation.

Purpose of this study

When the complexity of the different goal orientations and their interrelationships began to receive attention in the 1990s, it opened up for a new area of research (Covington, 2000). Much of this research is concerned with the similarities and differences between the various goal orientations. A good example is Duda and Nicholls' (1992) study of the dynamic interaction between goal orientations in the contexts of classroom and sport respectively – including both work avoidance and cooperation in addition to task and ego orientations.

A review of the achievement goal theory literature since the 1990s reveals several issues. First, most studies in achievement goal theory are carried out in schools, very few in universities. Second, studies can be domain and context specific, or general. In other areas of motivation, studies in which instrument and measure have the same level of specificity have produced the highest level of correlation (Lent, Brown & Gore, 1997; Choi, 2005). For example, physics students may be competent at solving mechanics problems involving inclined planes (very specific), but still lack confidence in their ability to do well in a physics course (general). Third, no achievement goal theory instrument developed for the tertiary physics context was found. We therefore decided to develop a discipline specific goal orientation survey for tertiary physics. In this paper we report on this development and the preliminary findings from the survey and associated focus group data. The study has approval from the Sydney University Human Research Ethics Committee.

Developing a goal orientation survey for physics

Item selection

Surveys that measure aspects of motivation were carefully perused (such as Skaalvik, 1997; Meece, Anderman & Anderman, 2006; Shimoda, White & Frederiksen, 2002; Duda & Nicholls 1992) to identify adequate items for the ego, task, work avoidance and cooperation orientations. Duda and Nicholls (1992) emerged as the most pertinent work for three reasons: they had already developed and implemented a survey with eleventh grade students with sound statistical results; their survey had all four goal orientations we were interested in; and Duda and Nicholls' (1992) survey had been adapted to and trialled in such different contexts as classroom and sport. Therefore, we decided to adapt items from Duda and Nicholls' (1992) survey to our tertiary physics context.

To be reliable, every orientation should ideally have at least four items that each probe slightly different aspects of the construct and satisfy certain statistical criteria (Field, 2000). We therefore decided to have five items per orientation.

Item development

Duda and Nicholls' (1992) survey items were adapted to a first year university physics context. Specific references that were changed included class size (which are much larger at university) and students' knowledge of other students' performances (e.g., our students do not know their class rank order); the word 'friends' was substituted with 'other students', and 'things' with 'physics'; and references to assessments were changed in light of the university structure (e.g., to 'goof off' has a different meaning at university where attendances are not compulsory and 60% to 65% of the assessment is based on a final examination). Two examples of how statements were altered – one simple, one drastic – are provided here: *"Others get things wrong and I don't"* was changed to *"Others get physics problems wrong and I don't"*, and *"I can goof off"* was completely rewritten to *"I get marks because my lab partners do most of the work"*, while still keeping the sentiment. It was important that each orientation had items covering different relevant aspects of the physics course, e.g., the work avoidance orientation needed to include situations where work was required: studying for the examination, doing assignments, working in tutorials, and answering questions in class.

For the ego and task orientations, eight items each were available from Duda and Nicholls' survey; five items that transferred to the university physics situation were chosen for each orientation. The following is an example of how the selection was made: in the three statements *I feel successful when… "I beat others", "I can do better than my friends"*, and *"Others can't do as well as me"*, the sentiment was the same, so the item *"I do better than others in physics"* was used. Duda and Nicholls' (1992) survey only had three items available for work avoidance and two for cooperation. Two of the work avoidance items were used and three new were created. For the cooperation orientation both items were used and three new items were written; the five items targeted both group work and discussing physics with fellow students.

Validation by experts

Our survey was given to three experts experienced in physics education research and physics teaching to scrutinise its validity. The experts were asked to comment on the following: whether the items were appropriately adapted to tertiary physics, whether the items satisfied the definition of the relevant goal orientations, whether the items adequately encapsulated the relevant aspects of the orientation to which they belonged, and the general wording of each item. The experts only suggested minor changes to the survey, which were incorporated, resulting in the first version of the Physics Goal Orientation survey.

Table 1. Flowchart of versions and administrations of the survey.

Version 1
Administration 1: Week 4 of first semester of 2006 in lectures with 125 responses.
Administration 2: Week 3 of first semester of 2007 in lectures with 352 responses.
Administration 3: Week 13 of first semester of 2007 in tutorials with 331 responses.

↓

Version 2
Administration 1: Week 13 of first semester of 2008 in tutorials with 360 responses.
Administration 2: Week 4 of second semester of 2008 in tutorials with 256 responses.

↓

Version 3
Administration 1: Week 13 of second semester of 2008 in tutorials with 162 responses.

Administering the survey

The Physics Goal Orientation survey was trialled six times over three years with first year physics students at the University of Sydney. This allowed us to check for stability (consistency across different times of administration) and invariance (consistency across different samples). Table 1 shows the time, year, venue and sample size for each administration. Different students were sampled each year, but within each year the same students may or may not have completed the different surveys depending on whether they were enrolled in both semesters and whether they chose to return each survey. In all cases, the first author explained the purpose of the survey from a script, emphasising that completion was voluntary and that responses would not affect marks. Only the first author, who was not involved in course evaluation, was allowed access to the original surveys and data file.

Analysis

Lindstrøm and Sharma (2008) explain details of the analysis and decision making throughout the development of the survey. In the following discussion of each version, only those administrations that provided interesting features, added value or were different to Lindstrøm and Sharma (2008) are presented.

Exploratory factor analysis was performed on each administration using SPSS 15.0. A 'factor' is a collection of items that are grouped together in the factor analysis – it is the technical term for a goal orientation. Factor analysis and the measures reported here are standard for surveys of the type used in our study. (Further details about factor analysis can be obtained from Field (2000) and Pallant (2001). See Streiner (1994) or Floyd and Widaman (1995) for a more complex discussion.)

Data were initially checked for suitability for the anaysis. This including checking that there were no correlations of $r > 0.8$ in the correlation matrix; the determinants of the correlation matrices were always greater than 0.00001; both overall and individual KMO values were greater than 0.5; and Bartlett's test of sphericity always had $p < 0.05$. All analyses were satisfactory according to these tests. Kaiser's criterion (eigenvalue greater than 1) was used to extract factors; the Scree plot was investigated to check that Kaiser's criterion coincided with retaining the factors that occurred before the inflexion point. A Direct Oblimin (oblique) rotation was then applied. The criteria used for retention of an item in the survey was that it loaded greater than or equal to 0.40 on the intended factor only. There is no clear consensus on the exact requirements of sample sizes (Floyd & Widaman, 1995). Generally a 5:1 ratio between participants and items is accepted, provided the sample is over 100 (Streiner, 1994). Field (2000) claims that where each factor has at least four items with loadings greater than or equal to 0.60, the solution is stable regardless of sample size. Our study meets both these constraints.

Table 2 shows all items used throughout the development of the survey; item references are based on this table. Each item was accompanied by a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5).

Version 1

Version 1 was administered three times. Analyses of all three were internally consistent and showed a surprisingly large deviation from the expected factor structure. The second administration sampled both physics majors and non-majors. The data were analysed separately, confirming that the factor structure was invariant across the two samples. The following paragraphs discuss the three main differences between the observed and expected factor structures and how these were logically and conceptually explained.

The task orientation split into two factors, each with two items. The first pair (items 2.2 and 2.9) referred to the effort invested by students in attempting to master physics. These items were conceptually similar to the original definition, and were therefore retained. The second pair (items 2.7 and 2.8) focused on interest. This is a separate motivational construct, beyond the scope of this study, so the items were deleted.

A similar splitting occurred with the work avoidance orientation. Items 4.1, 4.2 and 4.4 correspond to the original intent where a student can achieve a higher mark than deserved by relying on others. Items 4.5 and 4.6, however, were interpreted by students to mean that they can do well with little effort because they take easily to physics. Thus, the last two items were deleted because they did not conceptually align with Duda and Nicholl's (1992) intended work avoidance orientation.

The last item to be discussed is item 1.6 – *"I get a high exam mark"*. This was expected to load on the ego orientation, but loaded both on the ego and the task orientations. Our explanation for this is that a good physics mark at the tertiary level generally not only reflects better performance than others (ego orientation), but also a sound understanding of the subject (task orientation) (we have no multiple choice assessments). Because of this double loading, the item was rejected.

Seven items were deleted from the first version, and seven items were designed to ensure that all orientations had five items each version 2. The new items were designed to capture different aspects of the relevant orientation while avoiding those aspects that the first analysis had indicated did not align with the construct. The original definitions of the orientations were vital during this process. The survey was again validated by the same three experts; minor changes were suggested and incorporated.

Version 2

All items loaded on the intended factors, except for two from the task orientation. Three new items were designed, and validated by the three physics education experts.

Table 2. Overview of all items used in the development of the Physics Goal Orientation survey. The first letter in square brackets indicates a *N*ew item generated by the authors or *O*ld item adapted from literature. The middle number indicates the version in which the item was first included and the last number the last version in which the item appeared. A dash indicates that the item has been retained for the final version of the survey; only these items have an associated factor loading, which are the factor loadings from version 3. Note that 'Coop' = Cooperation and 'WA' = Work avoidance.

I feel really successful when…

Item no.	**Item**	**Factor loading** *Ego*	*Task*	*Coop*	*WA*
1.1	I can answer more physics questions than other students [O,1,-]	0.849			
1.2	I do better than others in physics [O,1,-]	0.809			
1.3	others get physics problems wrong and I don't [O,1,-]	0.798			
1.4	I get things in physics before others do [N,2,-]	0.760			
1.5	I know more physics than other people [O,1,-]	0.592			
1.6	I get a high exam mark [O,1,1]				
2.1	I understand a new physics concept by trying hard [N,2,-]		0.768		
2.2	I solve a problem by working hard [O,1,-]		0.689		
2.3	My efforts to see how different concepts hang together, improve my understanding [N,3,-]		0.674		
2.4	My efforts help me better understand physics [N,3,-]		0.646		
2.5	I understand the course better when I'm studying hard for assignments and the exam [N,3,-]		0.492		
2.6	what I learn in physics makes sense [O,1,1]				
2.7	I learn something interesting [O,1,1]				
2.8	something I learn makes me want to find out more [O,1,1]				
2.9	I do my very best [O,1,3]				
2.10	I understand what is happening in class [N,2,2]				
2.11	I can solve problems that I couldn't do before [N,2,2]				
3.1	I am in a group and we help each other figure something in physics out [O,1,-]			0.832	
3.2	I work in a group on physics problems [N,1,-]			0.798	
3.3	a group of us help each other [O,1,-]			0.794	
3.4	I am in a physics study group [N,2,-]			0.751	
3.5	I have somebody else to discuss physics problems with [N,1,-]			0.590	
3.6	the other students in my tutorial group and I manage to solve a tutorial problem together [N,1,1]				
4.1	others know more than me so they can answer the questions [N,1,-]				0.769
4.2	I can copy an assignment off somebody else [N,1,-]				0.725
4.3	I get marks because my lab partners do most of the work [N,2,-]				0.596
4.4	I can complete an assignment without really having understood the answers [N,1,-]				0.478
4.5	I don't have to try hard to do well in physics [O,1,1]				
4.6	I know I can pass the exam without studying too hard [O,1,1]				
4.7	I can pass the course with minimum understanding of physics [N,2,3]				
	Reliability coefficient - Cronbach alpha	**0.83**	**0.71**	**0.71**	**0.64**

Version 3

Since four stable factors had been identified, four factors were requested in the final exploratory factor analysis. Items loaded as expected. The work avoidance orientation had three items and all other orientations had four or more items with factor loadings greater than or equal to 0.60. The reliability coefficients, Cronbach alpha, are shown in the last row of Table 2. It is widely accepted in social science that alpha should be greater than or equal to 0.70, so all factors are acceptable except for the work avoidance orientation, which should ideally have one more item with factor loading greater than or equal to 0.60.

Some preliminary findings

Factor scores were calculated by applying unit weighting to each item and then determining the average score for each student. This is the recommended method when a survey is used beyond the original sample (Gorsuch, 1983). Here we present two analyses of the survey.

Midway through second semester, students were invited to participate in focus groups to discuss their tutorial experience. Fourteen students from three different courses who all had knowledge of the two tutorial types volunteered. Regardless of course choice or high school physics background, all focus groups had very similar comments about the tutorials. The focus groups were transcribed and the data analysed using thematic analysis. The quotes here represent themes that demonstrate features in the preliminary quantitative findings.

Correlations

First we examine the correlations between the orientations in version 3 (see Table 3). The task orientation is the only orientation that correlates with *all* other orientations. The correlations, however, are quite small, with the exception of the negative correlation with work avoidance of medium effect size. This latter correlation indicates that students who aim to increase their own competence are generally not interested in engaging in work avoidance behaviour. Such a correlation is expected, as very few students would be under the illusion that they could increase their mastery of physics without investing any time or effort.

Table 3. Descriptive statistics and correlations for the four goal orientations in the final survey administered at the end of semester 2, 2008 ($N = 162$).

	Mean (SD)	Ego	Task	Cooperation	Work avoidance
Ego	3.08 (0.659)	1	$r = 0.164, p = 0.036$	$r = 0.139, p = 0.077$	$r = 0.066, p = 0.404$
Task	3.87 (0.478)		1	$r = 0.155, p = 0.049$	$r = -0.380, p = 0.000$
Cooperation	3.25 (0.689)			1	$r = 0.041, p = 0.601$
Work avoidance	2.31 (0.657)				1

The only orientation to exhibit correlations with all the other orientations, the task orientation also has the highest mean score. This reflects that, on average, students who responded appear keen to *learn and understand* physics, and that this desire is positively related to their attitudes towards performance and cooperation, and negatively related to their attitudes towards work avoidance. The correlations between the task, ego and cooperation orientations were supported by student feedback. One high-achieving student showed clear interest in understanding the material and appreciated the value of her group members in this process, but she also wanted to do well in the examination.

> [Q]uantitative questions are really good, cause they're what's gonna be in the exam, and if you do them in the tute (…) they're really, really useful in terms of future study (…) I find the demonstration questions, like where you're actually doing stuff, a bit of a letdown because you wanna know more than what you actually need to, but they [tutors] are like 'no, no, no, you can't do that', and then no one really understands it. (…) [In the ideal group] everyone kind of pools their knowledge in and you generally get most of the answers out. That's what's awesome about working in groups cause I totally get some bits but *cannot* do the others. (…) If I worked by myself, I'd be more inclined to just go 'Oh well, I'll just skip that one, I'll just skip that one'.

Some light was also shed on the type of work avoidance behaviour that was removed from our study, namely the type of work avoidance that results from students knowing the material already and therefore seeing no need to work.

> I think there's two reasons why people [don't do work in group work situations]. I swapped groups one week because I had something on, and I was with a group of guys who were just like that. It's just because they understood it all so they were so bored with it, but they actually did get it. It just made complete sense to them, so like what's the point of doing something I can already do, it's too easy. So that's a fair call. But then a lot of the time when my group, kind of, shits around [*sic*] it's like, with electromagnetism, we have no idea. (…) how do you start when you can't even read the question? So

> it's kind of two extremes; people are not working because they completely don't get it or because they're just so bored they just don't care.

Temporal changes

We also examined how the mean ego and cooperation orientation scores changed with time, as both orientations had four items with factor loadings greater than or equal to 0.60 that occurred in *all* administrations. Using these four items only, it was found that the mean scores for each administration did *not* show much variation or any clear trends. As a representative subset, the 2007 results are shown in Table 4.

Table 4. Descriptive statistics, including standard error of the mean (SEM), for the ego orientation in the 2007 administrations using the four items that were retained in the final version.

Time	Class	Ego				Cooperation			
		N	*Mean*	*SEM*	*SD*	*N*	*Mean*	*SEM*	*SD*
Early sem 1, 2007	FND	119	2.85	0.068	0.738	119	3.53	0.060	0.653
	REG	239	3.01	0.052	0.810	242	3.46	0.041	0.634
End sem 1, 2007	FND	155	3.06	0.069	0.865	157	3.51	0.053	0.660
	REG	192	3.11	0.060	0.828	193	3.55	0.047	0.652

Data were collected at the beginning and end of first semester together with information about student enrollment. Two different classes were sampled: The Fundamentals (FND) class, which is designed for students with little or no prior formal physics instruction, and the Regular (REG) class designed for students with high school physics. Although no statistically significant differences were found, some trends deserve mentioning.

For the ego orientation, the means for both classes were higher at the end of the semester than at the beginning. This may suggest that students became somewhat more focused on examination performance as the semester progressed and they gained some experience with physics studies. That both Fundamentals and Regular students have a strong focus on the preparation for end-of-semester examination was very clear in the focus groups. When discussing the tutorial environments, a female Fundamentals student made the following comment:

> Yeah, cause you know you're actually doing it for the exam. Like, in the end.

And a Regular female student responded in the following way:

> Interviewer: What about the solutions handed out at the end. Do you ever go through them? Are they helpful?
>
> Student: Yes. I think it's really helpful, but again, for the discussion part I want to know which part counts and why... is better, I think. Because you have a really long passage and you don't know which part is really important and which part is not that important. (...) I think, for me, I like the type of marking scheme style of solution rather than just a passage.

For the cooperation orientation it is difficult to say whether the changes seen are robust. However, what was noted across the focus groups was a great variety in student attitudes towards group work – some liked it; others didn't. In a focus group with three high-achieving students, group work received a mixed response.

> Interviewer: Working in groups, is that helpful? (...)
>
> Students A and B: Yes.
>
> Student C: Yes and no. (...) it depends totally on the group and how everyone else is working. And if they're just talking and stuff, it can drag you down a bit, but if they're really smart it's good. [Students A and B agree] (...)
>
> Student A: I think the perfect group is one slacker to keep it lighthearted, one flogger to keep everyone working, one person who's good at maths and one person who's good at visualising. That's like the ideal group.

Two Fundamentals students also disagreed on the usefulness of group work.

> Student D: I think groups are good. Because, if there's something you don't know, and you're in a group of four, probability that someone else might know it is pretty high. So, it's good.
>
> Student E: I learn less, cause I just talk to them about other things. (…) I find it easier to just work through it myself and just do it at my own pace.

A Regular student put it very clearly and succinctly:

> In theory, the idea of having groups (…) is good, but when it comes down to it you really end up just talking together. I think group work is good, but it has its limitations.

Both classes showed medium to strong correlations between the early and end of semester scores for both orientations (Ego: FND: $r = 0.344$, $N = 87$, $p = 0.001$; REG: $r = 0.498$, $N = 135$, $p = 0.000$; Cooperation: FND: $r = 0.379$, $N = 85$, $p = 0.000$; REG: $r = 0.433$, $N = 138$, $p = 0.000$), and the correlations are stronger for the Regular students than the Fundamentals students. This suggests that the latter undergo more of a change in attitude towards performance than do those with high school physics experience.

Discussion

The Physics Goal Orientation survey was successfully developed for a tertiary physics context between 2006 and 2008. The survey was adapted from Duda and Nicholls' (1992) goal orientation surveys for year 11 students, which covered the topics of 'classroom' and 'sport'. The development covered three versions of the survey trialled with three different cohorts of first year university physics students across six administrations. The final survey includes 19 items that measure the four goal orientations *ego*, *task*, *work avoidance* and *cooperation*. The ego, task and cooperation orientations have five items each and have been confirmed by factor analysis to be statistically acceptably measures. The work avoidance orientation has only four items, but this may be due the relatively few responses to the final administration ($N = 162$) or a statistical anomaly. In future administrations of the survey, we recommend inclusion of the three items that were not retained for the final version to investigate whether these produce viable factor loadings in a different sample.

We report two sets of preliminary findings based on the survey data. Correlations between orientations showed found that the task orientation correlated statistically significantly with *all* other orientations; there were no other correlations in addition to these. Of particular interest is the small but positive correlation with the ego orientation, which suggestings that a desire to understand and learn material is weakly but positively associated with a goal to perform well. Such a correlation has been observed in other studies as well (Linnenbrink & Pintrich, 2001; Wolters, 2004). The medium strength negative correlation between the task and work avoidance orientations suggests that students who wish to learn physics are not interested in engaging in work avoiding behaviour. Theoretically, one would expect such a negative correlation, so this observation strengthens the validity of the instrument. Investigating the mean scores of the ego and cooperation orientations, no clear findings emerged; however, the data suggest that first year university physics students with a high school physics background have a slightly stronger performance focus (higher ego orientation score) than students without high school physics. This, however, may be the result of a selection effect in terms of who chooses to attend lectures and tutorials *and* complete the survey. Perhaps a broader selection of the students without high school physics feel compelled to attend lectures and tutorials due to their unfamiliarity with the subject, whereas those students who have studied physics before and do not have a strong ego orientation are more likely to not attend class?

A major strength of this study is the development of an instrument to measure tertiary physics students' goal orientations, which had not been found in literature. The survey was trialled and validated with several different cohorts and subsets of the first year students. A limitation of the study is that only four items were retained for the work avoidance orientation, only three of which had a factor loading greater than or equal to 0.60. (This may have been an anomaly in the last version of the survey, but it should be tested again when the survey is used to measure students' goal orientations.) The preliminary findings suggest avenues for further research.

Many interesting research questions can be pursued using the Physics Goal Orientation survey. In general, it would be valuable to characterise physics students' different goal orientations and the correlations between them. Are physics students similar to other groups of students? Are there differences between various sub-groups of physics students (e.g., majors vs. non-majors, third year vs. first year students)? Much research in secondary education has focused on how students' goal orientations correlate with academic performance. Most conclude that the ego orientation exhibits a positive correlation with academic performance, whereas there is generally no correlation with the task orientation important and challenging university course mastery goals predicted higher grades. Thus, the deep-processing cognitive strategies associated with mastery goals may be essential for high achievement when the task has a high degree of challenge or when the processing of complex, difficult material is necessary. Is this the case for tertiary physics? Is there a negative correlation between work avoidance and performance? If so, can the work avoidance orientation be used as an indicator of students at risk of failing their course? In addition, do any of the goal orientations correlate with students dropping out of physics after one or two semesters (if they have this option)? It may also be valuable to pursue the interest orientation that emerged during our development of the survey.

As discussed in the Introduction, achievement goal theory is only one aspect of the broader field of motivation. It may be interesting to view further research into physics goal orientations in the context of a larger theoretical framework by including, for example, self-regulation theory and intrinsic and extrinsic motivation. Self-regulation is defined by Pintrich (2000, p. 453) as “an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features in the environment”. In a university environment where students are expected to be independent learners, it is essential for their success that the students be self-regulated. Intrinsic motivation refers to behaviour performed purely out of interest without relation to external consequences, whereas extrinsic motivation is externally driven (Deci, Ryan & Williams, 1996). Considering how students’ goal orientations are strongly affected by their learning environment and peers, one might even wish to study goal orientations from a sociocultural perspective (Walker, Pressick-Kilborn, Arnold & Sainsbury, 2004).

In summary, the newly developed Physics Goal Orientation survey measures the four main variables within the achievement goal theory in a physics specific context and demonstrated some disciplinary and local context features. The value of a Physics Goal Orientation survey for tertiary physics is evident from the suggested research questions above. Investigating physics students’ goals can help us as teachers and researchers understand our students better and thereby tailor the way we design our courses to better suit our students’ needs.

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Self-efficacy of first year university physics students: do gender and prior knowledge matter?

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Abstract

Self-efficacy is a construct which represents a person's belief that he or she can perform a particular task. It is of interest because it has been found to correlate with academic performance as well as people's choice of subjects and career. While self-efficacy is a relatively widely studied concept, it has not received much attention in tertiary physics. This paper aims to fill this void by focusing on three aspects. First, we developed and validated a short Physics Self-Efficacy Questionnaire. Second, we investigated whether gender and prior knowledge mattered to students' physics self-efficacy. Third, we investigated whether there was a correlation between students' physics self-efficacy and their end-of-semester physics examination marks. The Physics Self-Efficacy Questionnaire was administered to the first-year physics cohort at the University of Sydney at four times during the year (sample sizes between N = 122 and N = 281). It was found that both gender and prior knowledge have a significant effect on self-efficacy. Females consistently reported lower self-efficacy. However, prior knowledge showed a more complex effect, including a suggested 'male overconfidence syndrome', where the highest self-efficacy of *any* subgroup of the first year students was found in those males who had never studied physics before. The time at which the questionnaire was administered was also considered, and it was found that students experienced a drop in self-efficacy close to the examination in first semester, but this trend was not observed in second semester. When investigating the relationship between students' physics self-efficacy and end-of-semester physics examination marks it was found that correlations seemed to only develop after a relatively long time of physics study (of the order of a year or more) and that females developed such a correlation faster than males. Our findings therefore conclude that gender and prior knowledge do matter when studying physics self-efficacy, which may have important consequences not just for the study of self-efficacy in itself, but also for the way tertiary physics is taught.

Introduction

Despite the fact that students live in an increasingly technological society, their interest in science is declining across the developed world.[1] There is also the belief that physics in particular is a challenging subject. To change this belief we need to first understand its various facets amongst current students. One important facet is self-efficacy which represents a person's belief that he or she can perform a certain task,[2] physics in this study. Although measures of self-efficacy show certain consistent features, there are important variations which make studying self-efficacy across different subjects and student groups critical for understanding which variables influence self-efficacy. Whereas undergraduate physics students' attitudes and beliefs have received much attention in recent years,[3-5] the research conducted on self-efficacy in tertiary physics education is sparse.[6] Consequently, this study focuses on tertiary students' self-efficacy in physics.

This research had three overall purposes. First, to develop a questionnaire to measure students' *physics* self-efficacy in tertiary education. Second, to investigate differences in self-efficacy for males and females, both with and without prior formal senior high school physics instruction, in their first year of university physics studies at different times of the year. Third, to carry out a study of first year students' physics self-efficacy and academic achievement across one academic year.

Background

Self-efficacy is defined as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives".[7] It has consistently been found to be a good predictor of academic achievement, study strategies, and persistence in the face of difficulty, [8-9] and of choice of academic major and career.[10]

There are different levels of self-efficacy ranging from global life skills ("When I make plans, I am certain I can make them work"), through general academic self-efficacy, domain specific self-efficacy (e.g., a specific university course), down to task-specific self-efficacy (e.g. personal belief in ability to perform uncertainty calculations within a physics course).[11,12] Of importance is that the correlation between a self-efficacy measure and the achievement measure is greatest when the two measures are matched in their level of specificity.[11,12]

Self-efficacy and academic tasks

Self-efficacy is a dynamic construct which can be influenced and changed by feedback on academic tasks. The two main categories of such feedback are mastery experiences and social persuasion. Mastery experiences are situations in which students master a task, in turn influencing their belief in their capability to achieve their potential.[13-15] In physics those tasks could be solving problems, leading to solving more challenging problems, or understanding new concepts or how concepts are linked. Social persuasion, on the other hand, occurs via two different situations. The first case is when one observes a peer of similar ability mastering a task, thus reinforcing the belief that one can also perform the same task. The second case is when positive appraisal based on actual performance is provided, emphasizing that the students are making progress[13,15] boosting their self-belief in personal achievement potential.

In subjects with which students are familiar, firm beliefs about performance capabilities are developed, and students show fairly stable self-efficacy.[16] A certain internal resistance to change is necessary to avoid being greatly affected by temporary anomalies in performance, but there is a fine line between a healthy and unhealthy resistance. It has been found that it is not uncommon for students to keep an unrealistic self-efficacy in the face of repeated counter-evidence.[17] In such cases of poor performances the correlation between self-efficacy and performance is reduced. Furthermore, students who do not respond to feedback increase their risk of failure.

Unlike students who are familiar with the subject, novices are not expected to have formed stable self-efficacy beliefs related to that subject. Their belief in their potential to achieve *should* be tentative only and easily changed in response to feedback.[16] However, evidence exists that initial self-efficacy can be surprisingly resistant to change, even in the face of clear counter-evidence.[18] Cervone and Palmer[16] showed that people require several rounds of feedback before a stable and well-calibrated self-efficacy is established. These findings were in agreement with Tversky and Kahneman's[19] description of the 'anchoring and adjustment' strategy where, upon receiving feedback, people adjust their self-efficacy to yield a final value which is *biased in the direction* of the original self-efficacy (anchor), rather than adjusted *to* the performance value.

Measures of self-efficacy depend on when they are made. One construct used to explain temporal variations in an individual's self-efficacy is "test anxiety" about assessments such as assignments, quizzes, group presentations and the final examination. By far students get most anxious over higher stake tests, such as end of semester examinations.[20] In a large meta-analysis of 562 studies, Hembree[21] concluded that test anxiety is inversely related to self-efficacy, a finding more recently confirmed by Ruthig, Perry, Hall and Hladkyj.[22] In addition, in another meta-analysis of 151 studies, Hembree[23] found that with respect to causality, it is test anxiety that causes poor performance rather than previous poor performance causing test anxiety. Short and long time scale changes are also evident in test anxiety.[21] Spielberger, Gorsuch, Lushene, Vagg, and Jacobs[24] found that students studying to become science teachers experienced a decrease in overall test anxiety from their first to second year at university, but still had increased levels of test anxiety before tests.

Self-efficacy and gender

Generally females report lower academic science self-efficacy than males,[8] and the same result applies with physics.[9] The general difference emerges in middle to late primary school,[8,25] but there is no consensus in the literature on what causes such gender differences.[6] Some studies have found that many gender differences in self-efficacy disappear when previous academic achievement is controlled for.[8] However, Cervone and Palmer[16] observed that in the absence of prior knowledge, males reported a statistically significantly higher self-efficacy than females. As experience was gained this difference declined, but was not eliminated by the end of the study. An interesting point to note is that Arch[26] found that females tended to devalue their performance, and in general were more self-critical, which may provide some insight into the *reason* for the lower academic self-efficacy of females.

The gender difference seen in self-efficacy translates to test anxiety: females self-report higher test anxiety levels in mathematics and science than males, observed from year 3 of primary school.[21] In addition, the 'harder' the subject, the higher the associated test anxiety (i.e., in order of increasing anxiety: biology < physics ≈ chemistry < mathematics).[20] In a meta-analysis of 30 studies Becker[27] found that males consistently outperformed females in academic achievement tests in the 'harder' sciences (biology, general science, and physics), but not in the softer sciences (geology and earth sciences). However, she also found that this effect was on average greater for studies which focussed on gender and science, suggesting experimenter effects or publication bias. It should be emphasised, however, that the gender difference occurs both for test anxiety[21,23] and for self-efficacy[16,25,28] even when there is no difference in academic achievement. When interpreting such data it is useful to be aware of Hembree's[23] meta-analysis of 151 studies in which he found that high school males with high test anxiety were less likely to take more maths courses than females with high test anxiety, thus skewing the gender differences even further.

Pajares[8] discusses the gender difference in terms of males and females operating with different 'metrics' when self-reporting both test anxiety and self-efficacy. Along similar lines Wigfield, Eccles, and Pintrich[29] suggest that males and females have different self-reporting standards. If males and females indeed use different metrics, then analyses of self-efficacy and test anxiety need to consider gender in order to provide meaningful interpretation.

Purpose of the study

Current literature strongly suggests that self-efficacy instruments provide better measures if they are specifically aligned with the subject of study.[11,12] Further, the length of the instrument is critical for two reasons. First, longer surveys aim to identify several different constructs (or factors). Each construct is a combined measure of several items which all need to exhibit a statistical relationship with the intended construct across different administrations of the survey. If that does not happen, then individual scores (called factor scores) cannot be systematically calculated for each construct for comparison across the different administrations of the survey. That is why it is more complex to develop longer instruments than shorter ones. Dalgety and Coll,[6] in their administration of a 17-item chemistry self-efficacy questionnaire to first-year tertiary chemistry students, found that the factor structure varied significantly across three separate administrations of the study, so composite factor scores could not be calculated. Second, the practical length of an in class survey is constrained by the time allotted to it and by the duration of students' interest. Therefore, if the aim is not to measure different constructs within self-efficacy, a short self-efficacy instrument can be combined with other constructs on one survey. In addition, such a multi-item survey can be used to provide answers to other interesting research questions of which self-efficacy is only one aspect.

Hence, the first aim of this study was to develop and evaluate a short, one-factor instrument for physics self-efficacy which would result in a single score per individual. No such instrument was found in the literature at the inception of this study. The second aim was to investigate physics self-efficacy of males and females with and without prior formal senior high school physics instruction across one academic year. Such a study was considered to be of great interest since very little self-efficacy research has been carried out on tertiary physics students to date. The third aim was to observe the relationship between physics self-efficacy and academic achievement at different times of the year. A correlational relationship has been reported in literature, but comments on how such a correlation varies with time was not found.

Part I: Development of the Physics Self-Efficacy Questionnaire

The development of the questionnaire went through five distinct phases, as summarised in Table I. Each phase is briefly described below.

TABLE I. Overview of the development process of the Physics Self-Efficacy scale.

a. Selection of items
Existing items and scales were surveyed.
Four items were chosen from Jerusalem and Schwarzer's[34] General Self-Efficacy Scale and one item was written based on general perception of all items perused.

↓

b. Validation by experts
Three physics education experts critiqued the chosen items.
Minor changes were made upon their feedback.

↓

c. Initial trial
The questionnaire was trialled with 111 first year physics students in June 2006.
Principal components analysis confirmed the validity and reliability of the questionnaire.

↓

d. Confirmatory trial
The questionnaire was administered to 379 first year physics students in March 2007.
A confirmatory factor analysis established the validity and reliability of the questionnaire.

↓

e. Invariance and stability
The questionnaire was administered to different groups of first year physics students four times throughout 2007.
Exploratory factor analysis provided a consistent factor structure.

a. Selection of items

An extensive survey of self-efficacy scales was carried out.[6,30-32] The chemistry self-efficacy scale by Dalgety and Coll[6] was given serious consideration since teaching and learning in chemistry and physics have many parallels. However, the scale was not utilised because it was particularly specific on individual aspects of the authors' first year chemistry course and, as stated earlier, the factor structure was inadequate. The Maryland Physics Expectations (MPEX) survey[30] and the Colorado Learning Attitudes about Science Survey (CLASS)[33] were also considered as they are specific to tertiary physics education. However, they were not used because of their focus on students' attitudes, beliefs and assumptions about physics, rather than on their self-efficacy. The style in which the items on the chemistry self-efficacy scale, the MPEX survey, and CLASS are written and the content they cover influenced the development of the Physics Self-Eefficacy Questionnaire.

Both individual items and whole scales found in the literature were perused and critically evaluated to develop a broad base of possible items. Together with Bandura's definition and theories of self-efficacy,[2] we developed a sound understanding of the construct of self-efficacy and how it is measured. Ultimately Jerusalem and Schwarzer's ten-item General Self-Efficacy Scale[34] was chosen to form the basis of the Physics Self-Efficacy Questionnaire, based on four reasons. First, this short scale is established and is translated into 30 different languages. Second, the items are general and appropriate enough to be adapted to our local teaching and learning context. The third reason for choosing the General Self-Efficacy Scale was that it has a focus on student agency, in that all of the items emphasise how students have the ability to act in ways which allow them to improve their performance. Lastly, the General Self-Efficacy Scale had consistently yielded satisfactory internal consistencies across several research projects, as measured by Chronbach's alpha, between 0.75 and 0.90[32] as well as adequate factor loadings.[34]

All of the items in the General Self-Efficacy Scale were scrutinised for adaptability and appropriateness of use in our specific situation and the local teaching and learning context. Four items were chosen; two were subjected to minor changes, and two underwent extensive changes where the items were made relevant to the local context but still conserved the intent of the items. One example of an extensive change is as follows: item 7 in the General Self-Efficacy Scale was 'I can remain calm when facing difficulties because I can rely on my coping abilities' which was changed to 'I will remain calm in my physics exam because I know I will have the knowledge to solve the problems'. One additional item was designed, based on the understanding the authors had developed for the concept of self-efficacy (item 5 in Table I). For each item students were asked to indicate on a five-point Likert scale whether they strongly disagreed (1), disagreed (2), were neutral (3), agreed (4), or strongly agreed (5). With a total of five items, the draft questionnaire was short, as intended. As a factor requires at least four items with factor loadings greater than 0.6,[35] it was decided to present this version for validation by experts. If they considered the length an issue more items would be considered.

b. Validation by experts

Jerusalem and Schwarzer's[34] original questionnaire and the five proposed items were then given to three experienced physics education experts who were asked to comment on the validity of the items. The experts were satisfied with the items suggesting only minor changes, which were incorporated in the final version of the questionnaire (see Table II). Another validation of the questionnaire is via the short practical scale developed at the same time as our work by Gungor, Eryilmaz, and Fakioglu.[36] Their physics self-efficacy scale also has five items and is quite general. It is pleasing to see two physics self-efficacy scales developed in parallel studies in Australia and Turkey.

TABLE II. The Physics Self-Efficacy Questionnaire.

	Physics self-efficacy items	*Factor loadings*
1.	I generally manage to solve difficult physics problems if I try hard enough	0.704
2.	I know I can stick to my aims and accomplish my goals in physics	0.821
3.	I will remain calm in my physics exam because I know I will have the knowledge to solve the problems	0.775
4.	I know I can pass the physics exam if I put in enough work during the semester	0.737
5.	The motto 'If other people can, I can too' applies to me when it comes to physics	0.694

c. Initial trial

The questionnaire was administered in-class to first-year physics students at the end of the first semester in June, 2006. The authors introduced the voluntary questionnaire, emphasising that responses would not affect results. One hundred and eleven students completed the questionnaire. The first author, who handled the original data files, was not involved in student assessment. The data were then analysed by principal components analysis, using the Statistical Package for the Social Sciences (SPSS) version 15.0. With only five statements in the questionnaire the sample size was satisfactory,[37] and analysis of the data found it suitable for exploratory factor analysis. The condition for factor extraction was based on a combination of Kaiser's criterion of eigenvalue > 1 and an investigation of the Scree plot, both of which clearly indicated one factor only. As there was only one factor, factor rotation did not apply. The five items had factor loadings in the range 0.694 to 0.821 (see Table II), confirming the intended factor structure (at least four factor loadings over 0.6).[35] The factor explained 56% of the variance (values over 50% are acceptable according to Streiner),[38] and the reliability of the questionnaire was confirmed by a Cronbach's α of 0.796.

d. Confirmatory trial

A factor structure is never completely confirmed until a confirmatory factor analysis is carried out on an independent data set. The questionnaire was therefore administered with a fresh first year physics cohort in March 2007. The same procedures were carried out as in the previous year. Three hundred and seventy nine students completed the questionnaire, a return rate of 81%. A confirmatory factor analysis (using Amos 7.0) confirmed the construct's validity (values in parentheses indicate requirements for validity); $\chi^2 = 2.127$, $p = 0.831$ ($p > 0.05$). Main fit indices also showed a very good model fit:[39] RMSEA = 0.000 (< 0.05) with a 90% confidence interval of [0.000, 0.042]; RMR = 0.009 (< 0.05); GFI = 0.998 (> 0.95); NFI = 0.994 (> 0.95); and CFI = 1.000 (> 0.95).

e. Invariance and stability

Final checks on the questionnaire were for invariance and stability. A questionnaire is said to be invariant if the factor structure for data from different samples from the population is consistent. Furthermore, if the factor structure is consistent when the questionnaire is administered at different times, it is said to be stable. Males and females in two different classes were sampled four times in the year (more detail is provided in the next section). No anomalies in the factor structure were found between either gender or times of administration. As the questionnaire was robust the data used for the invariance and stability checks were further examined for trends in student self-reports of self-efficacy.

Part II: Self-efficacy for females and males with and without senior high school physics instruction

The Sample

Two different first year physics classes at University of Sydney were sampled in first semester, 2007. The Fundamentals (FND) and Regular (REG) classes are designed to cater for students' prior knowledge. The Fundamentals class (*N* = 234) is designed for students with no formal senior high school instruction in physics. It covers skills and methods while teaching mechanics and waves. The Regular class (*N* = 351) assumes two years of senior high school physics background and covers mechanics, waves, and thermal physics, where the first two topics are covered more deeply than in the Fundamentals class.

In second semester the students from the Fundamentals and Regular classes have a choice of either enrolling in classes based on their interest or not continuing with physics. Approximately equal numbers of Fundamentals and Regular students enrolled in the larger second semester class, called the Environmental class (*N* = 246). Hence, the Environmental class was sampled in second semester 2007. The Environmental class focuses on aspects that are relevant to environmental and life sciences, covering properties of matter, electromagnetism, and modern physics, and has been specifically designed for this merging of students.[40] Note that in this paper students carry the labels of FND and REG for *the whole year*, even though they are merged in second semester. This is done because the labels reflect the students' high school physics background, which is a variable of interest in this study.

The structure and assessment of all the classes are similar. Each semester has 13 teaching weeks and one examination study week followed by two examination weeks. During each teaching week students attend three one-hour lectures, one one-hour tutorial, and one three-hour laboratory. The summative assessment is through assignments, collaborative laboratory work, and participation in collaborative tutorials, together with a final examination held during the examination weeks. Even though the structure and assessments are fairly standard, interactive practices are embedded into the curricula.[41]

Data Collection

The self-efficacy questionnaire was administered in weeks 3 and 13 of first semester and again in weeks 3 and 13 of second semester. For logistic reasons, the week 3 administrations were in lectures while those in week 13 were in tutorials. The self-efficacy items were the first five questions of a two-page questionnaire addressing various aspects of the classes. For each questionnaire the students were given a short (three-minute) talk by one researcher informing them of the purpose of the research and the privacy protocols. The return rates were (78-91)% for the students attending the lecture or tutorial which corresponds to (53-61)% for all enrolled students.

Information about students' year 12 course selections and gender were obtained with informed consent. Only those students in the Fundamentals class *with known* non-physics background and those in the Regular class *with known* physics background are included in the ensuing analysis. This explains why the number of students in any analysis is smaller than the total number of students who completed the course requirements.

Analysis and results

To use the newly created questionnaire we decided to apply unit weighting to each item to produce factor scores for each individual student. In cases where questionnaires are administered and analysed beyond the original sample, this is indeed the recommended method.[42] Physics self-efficacy scores thus ranged between 5 (lowest) and 25 (highest).

To investigate whether students were interpreting the questionnaire in a similar manner across different administrations of the instrument, we decided to look for correlations of self-efficacy scores between administrations. As none of the self-efficacy distributions was normal, Spearman's ρ (which is a non-parametric correlation analysis) was carried out. The statistic Spearman's ρ is interpreted in the same manner as Pearson's r.

There were large correlations between the pair of questionnaires administered in the first semester ($\rho = 0.61$, $N = 193$, $p = 0.000$) and those in the second semester ($\rho = 0.68$, $N = 92$, $p = 0.000$). The correlations between any two questionnaires administered in different semesters were smaller ($\rho = 0.40$ to 0.51, $N = 88$ to 108, $p = 0.000$ for all). There was more internal consistency between two questionnaires from the same semester, as opposed to two questionnaires completed in different semesters.

Table III shows the means and standard deviations of the self-efficacy scores for females and males in each class at each administration. We see four interesting features. First, females consistently self-report lower self-efficacies; second, Fundamentals students report lower self-efficacies than Regulars in second semester, but not so in first semester; third, there is a marked pre-examination drop in self-efficacy in first semester, but not so in second semester; and fourth, upon entry the males in the Fundamentals class report the highest self-efficacy of any group at any administration. The first two of these findings were investigated by conducting four two-way between-groups ANOVAs (one for each time self-efficacy was measured), including both gender and prior knowledge. The last two findings were based on t-tests and perusing trends in Table III.

TABLE III. The means and standard deviations (SD) of the self-efficacy scores for males and females in each class at each administration. Only students with no formal instruction in senior high school physics are included in the Fundamentals (FND) class, while only those with formal instruction in senior high school physics are included in the Regular (REG) class. The two classes were taught separately in first semester but merged into the Environmental class in second semester. The Fundamentals and Regular labels are retained to reflect students' senior high school physics experience.

		Early semester 1			End semester 1			Early semester 2			End semester 2		
Gender	Class	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Female	FND	51	17.76	3.12	66	16.88	2.52	38	17.18	2.64	43	16.93	3.13
	REG	66	18.06	3.54	59	16.83	3.04	30	18.17	2.67	36	18.47	2.41
Male	FND	39	19.90	2.91	52	18.87	2.80	26	17.88	2.96	31	18.58	3.01
	REG	125	19.20	2.65	94	18.60	2.41	28	19.14	1.80	35	19.74	2.45

Females consistently self report lower self-efficacies: Looking at the impact of gender in the four two-way between-groups ANOVAs three of the four analyses revealed a statistically significant main effect (the measurement early in second semester bordered significance). The effect sizes measured by η^2 indicated a medium effect (according to Cohen,[43] a small effect size is around 0.01, medium is 0.06 and large is 0.14). [$F(1,277) = 17.396$, $p = 0.000$, $\eta^2 = 0.059$; $F(1,267) = 32.123$, $p = 0.000$, $\eta^2 =$

0.107; F(1,118) = 3.219, $p = 0.075$, $\eta^2 = 0.027$; F(1,141) = 9.867, $p = 0.002$, $\eta^2 = 0.065$].

Fundamentals report lower self-efficacies than Regulars in second semester, but not so in first semester: In the four two-way between-groups ANOVAs the main effect for prior knowledge did not reach statistical significance in first semester [F(1,277) = 0.262, $p = 0.609$; F(1,267) = 0.231, $p = 0.631$] when the students were separated by prior knowledge, but it was statistically significant in second semester when all students were enrolled in the same class [F(1,118) = 5.750, $p = 0.018$, $\eta^2 = 0.046$; F(1,141) = 8.456, $p = 0.004$, $\eta^2 = 0.057$]. Medium effect sizes were observed for prior knowledge in second semester.

Pre-examination drop: Paired-samples t-tests showed that the pre-examination drops seen in first semester were all significant, except for that of the Regular males. Note that the sample sizes were somewhat smaller than those in Table III since only those students who responded to both first semester questionnaires were included [FND females: mean (early) = 17.92, mean (end) = 17.18, N = 39, t = 2.048, p = 0.048; FND males: mean (early) = 19.91, mean (end) = 18.64, N = 33, t = 2.469, p = 0.019; REG females: mean (early) = 18.23, mean (end) = 16.63, N = 48, t = 4.418, p = 0.000; REG males: mean (early) = 18.81, mean (end) = 18.74, N = 73, t = 0.242, p = 0.809]. In second semester there were no pre-examination drops, confirmed by t-tests which revealed no statistically significant differences.

Males in the Fundamentals class report very high self-efficacies: When comparing all the mean self-efficacy values in Table III, Fundamentals males at the very beginning of the year reported the highest values, while Regular males at the end of the year reported the second highest values.

Finally, the interaction effect between gender and prior knowledge did not reach statistical significance at any time [F(1,277) = 1.603, $p = 0.207$; F(1,267) = 0.112, $p = 0.738$; F(1,118) = 0.087, $p = 0.768$; F(1,141) = 0.167, $p = 0.684$].

Part III: Study of physics self-efficacy and academic achievement across one year

Additional data collected

The sample was the same as that described in Part II. Academic achievement was measured using the end of semester examinations. Assignment and laboratory marks were not used because they are group work efforts which do not reflect individual achievements. The examinations are 3 hours long with 12 questions. The first six questions (30 marks) are conceptual questions while the remaining six (60 marks) are more traditional questions requiring both calculations and interpretation of answers.

Checks on academic achievement and self-efficacy data

Three checks were carried out on the data: correlations between first semester and second semester examination scores, tests for statistical difference between examination scores for males and females, and correlations between self-efficacy and examination scores for various subgroups (separating by gender and prior knowledge).

The first and second semester examination scores were first checked for internal consistency using Pearson's correlation coefficient r as the data were normal. There were large and statistically significant correlations between first and second semester examination scores (FND: $r = 0.75$, $N = 105$, $p = 0.000$; REG: $r = 0.77$, $N = 113$, $p = 0.000$) demonstrating internal consistency.

Next we checked whether the gender difference in self-efficacy seen in Table III could be explained by gender difference in academic achievement. When we conducted t-tests, the only statistically significant difference between genders was for the Fundamentals students who showed significance (males: mean = 46.9, $N = 74$, SD = 14.5; females: mean = 42.5, $N = 92$, SD = 14.1; t = 1.987, $p = 0.049$). Note, however, that this difference was not observed in second semester. Hence the gender difference in self-efficacy cannot simply be explained by different levels of knowledge, as measured by the examination results.

Lastly, we needed to see if our results confirm current understandings as the literature generally suggests a robust correlation between self-efficacy and academic achievement. The effect of prior experience was expected to be the strongest in the correlations between self-efficacy and academic achievement in first semester. For the Fundamentals students there was no correlation at any time during the first semester, neither when analysed for the whole class, nor when split by gender. The Regular class and the second semester correlations were more complicated and at the same time interesting. Consequently only those students who completed both semesters were studied as reported below.

Results and analysis

The group of students who sat either the Fundamentals or Regular examination in first semester *and* sat the Environmental examination in second semester were identified to allow us to track one particular group for a whole year. This is the sample for the study of self-efficacy and academic achievement. Figure 1 shows the mean self-efficacy scores for males and females. Note that the standard error of the mean is about ±0.5 for all means. Since the trends mirror those in Table III, the smaller samples are valid for interpretation using correlations with examination marks. Two sets of correlations between self-efficacy and examination scores were conducted as described below.

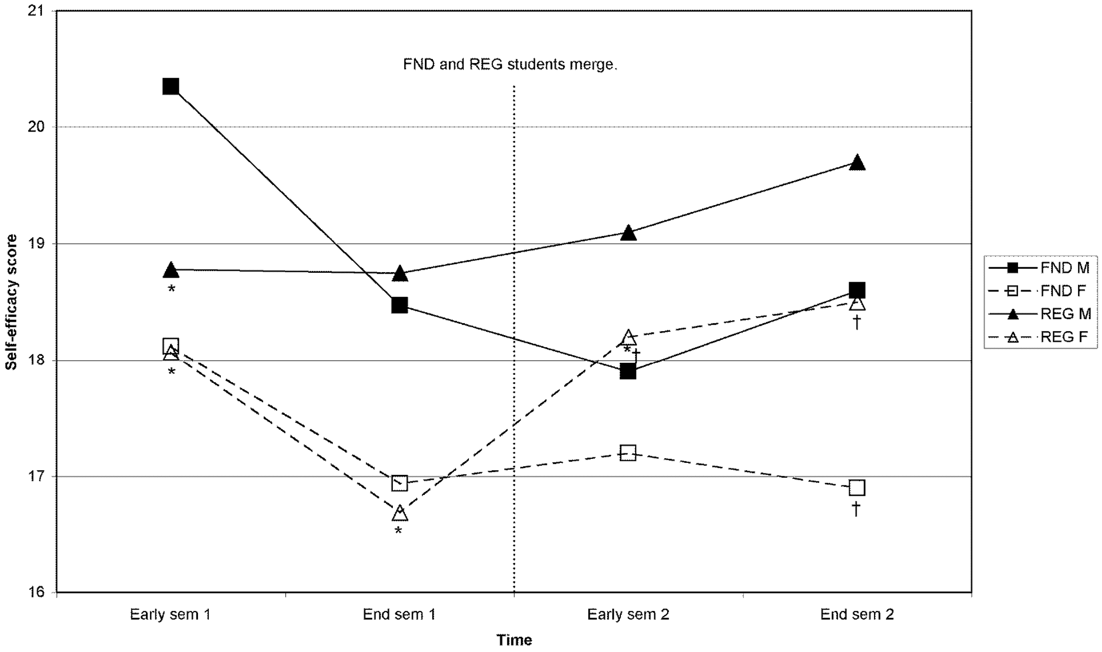

FIG. 1. The mean self-efficacy scores for females and males who had completed both semesters. Each mean has a standard error of about ±0.5. A star indicates a statistically significant correlation between self-efficacy scores and first semester examination scores. A dagger indicates statistically significant correlation between self-efficacy scores and second semester examination scores.

Correlations with first semester examination marks: We calculated correlation coefficients for self-efficacy measures from early and late in each semester with the first semester examination scores. Each point which showed a statistically significant correlation is marked by a star on the graph (Figure 1). Neither the Fundamentals males nor females showed any correlations, but Regular females were correlated in all three cases while Regular males were correlated only at the beginning of the year.

Correlations with second semester examination marks: Early and end second semester self-efficacy scores were correlated with second semester examination scores. Each data set which showed a statistically significant correlation is marked by a dagger on the graph. In this case there was *one* occurrence of a correlation for the Fundamentals class, namely for females at the end of the semester. Regular females were correlated early in the semester while females from both classes were correlated at the end of the year.

In summary, Regular females consistently show correlations between self-efficacy and examination scores throughout the year. The Regular males, on the other hand, only occasionally exhibit correlations, whereas only one occurrence was detected for the Fundamentals class. A further check was carried out to see whether the same trends were found when analysing the data for only those students who responded to all four questionnaires and had sat the two examinations, emulating a longitudinal study. In this case the sample sizes for the various groups were: *N*(FND females) = 16, *N*(FND males) = 10, *N*(REG females) = 17, and *N*(REG males) = 14. The same trends did indeed emerge validating the above findings.

Discussion

The aims of this study were to develop and evaluate a Physics Self-Efficacy Questionnaire which is easy to use, and to analyse self-efficacy and academic achievement over a year of physics study. These data would be analysed both with respect to gender and prior formal instruction in physics.

Four items on the Physics Self-Efficacy Questionnaire were adapted to a physics context from Jerusalem and Schwarzer's[34] General Self-Efficacy Scale, and one item was generated by the authors. Exploratory factor analysis was conducted on the first administration of the questionnaire in 2006, and a confirmatory factor analysis was conducted on the second administration in 2007, confirming the questionnaire's construct validity.

In agreement with the literature,[9] it was found that females consistently reported lower self-efficacies than males (regardless of prior knowledge) even though their academic achievements were generally not statistically significantly different from males'. This supports the different 'metric' theory discussed by Pajares.[8] The data also suggested that females experienced significant test anxiety prior to the examination in first semester, but not in second semester, which is in agreement with the findings of Spielberger *et al.*[24] that test anxiety reduces with experience with the examination condition. For males, the major result was that the Fundamentals students at the beginning of first semester exhibited the highest mean physics self-efficacy seen in this study. Since this is the only male group which has not experienced formal physics instruction (by the end of semester they have by virtue of taking the Fundamentals class), the finding possibly indicates the existence of a 'male overconfidence syndrome', which is not unknown in the literature.[16]

Correlations between physics self-efficacy and students' academic achievements showed the greatest departure from the literature. Students without senior high school physics exhibited no correlation between the two measures, except for females having developed a correlation by the end of second semester. This is an important observation in that it emphasises the known, but rarely discussed, idea that: self-efficacy in novices should be tentative only and easily adjusted when receiving feedback,[16] but this change in self-efficacy is generally much slower than expected due to a surprisingly large resistance to change in the face of clear counter-evidence.[18]

Drawing all these findings together, the results seem to suggest that both gender and senior high school physics instruction have similar effects on students' self-efficacy. However, no interaction effect between these two variables using a two-way ANOVA was detected. In terms of correlations between self-efficacy and academic performance, females with experience in formal physics instruction exhibit statistically significant correlations, but males (regardless of experience) for the most part do not. This may indicate that females are more receptive to feedback and adjust their self-efficacy accordingly. This idea is supported by the findings for the Fundamentals students in which the females change from performing substantially more poorly than the males in first semester, to being academically on par with the males in second semester. Seemingly, they learned from their feedback and changed not only their self-efficacy, but also their study behaviour to improve during semester two. This result also suggests that the Fundamentals class achieved its goal of getting novices up to speed in one semester, but it worked better for the women. We found no other studies with which to compare this interpretation as there are only a few papers on resistance to change, and none of these discuss gender differences. Interesting insights could be gained by further research into this matter. However, results from investigating students' physics attitudes using CLASS[33] have found that the level of prior instruction affects how 'expert-like' students' attitudes are. More instruction leads to more 'expert-like' attitudes,[3,5] but Gray *et al.*[5] note that females exhibit less 'expert-like' attitudes than males. Hence, the importance of considering prior knowledge and gender in tertiary physics has been recognised in parallel by other research groups.

Implications for the teaching and learning context

If our interpretations of the findings are correct, the implications for teaching and learning bring us into an educational minefield. The gender issue has been a long-standing hot topic with strong opinions in both camps. However, if we listen to the findings of this study, rather than the politics of the debate, we see two issues that need to be addressed.

First, the findings suggest that the type of feedback required by males and females is different. Since self-efficacy is a measure of a person's belief in his or her ability to perform a certain task, once a person has passed through several rounds of testing and subsequent feedback, one would expect to observe a correlation between performance and self-efficacy. We find that this is truer for females than for males. The first year students described in this paper experience many different types of feedback. There is group work in lectures, laboratories and tutorials[44-46] where feedback is via social persuasion, watching peers work, and solve problems. Such interactive learning has been found to benefit the academic achievement of females more than males.[47] We also provide feedback in terms of mastery experiences with a range of problem-solving tasks in assignments (and examinations). Our findings then suggests the question: are we providing feedback in a way that better addresses females, or are males just more resistant to change?

Second, the already well documented observation that females report a lower self-efficacy than males when their performances are comparable deserves some serious attention. *If* self-efficacy affects students' choice of further study in the same way for males and females, then we may need to reconsider how we address students when encouraging further physics studies. More research is needed to elaborate on this issue, and further research must explicitly separate males and females in their analyses.

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