Using Link Maps to Help Novices Navigate Through the Rough Seas of 1st Year Physics

(with updated version of the Map Meeting material from 2007)

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Abstract

There currently exists a high demand for people with basic scientific knowledge and well developed problem solving skills. This calls for a paradigm shift in physics teaching, to make physics more accessible to a larger student body. The researcher developed a study aid for novices, called Link Maps, which did not emphasize the mathematical aspect of physics. Link Maps were implemented in semester 1, 2006, with the 1st year physics Fundamentals class through weekly one-hour tutorial-type classes, called Map Meetings. These focused on familiarizing the students with the Link Maps, and giving them a strategy for using these in problem solving. Participation was voluntary, so the high-attendance group, named persistent Map Meeters, was self-selected. The effectiveness of the intervention was measured by two questionnaires and the final course exam. Student feedback reported the intervention as helpful for understanding the lecture material. Results reflect this, indicating a very positive effect in the persistent Map Meeters’ belief in their own abilities to do physics. In the final exam these students obtained a statistically significantly better mark ($p = 0.004$) than a non-attending group with similar academic background, suggesting that their confidence was well founded.
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And for letting their daughter and sister follow her dreams, supplying nothing but ever encouraging words from 20,000 kilometers away—my beloved family.

Statement of Student Contribution

The original idea for this project is my own. Over the course of several years reflecting on my own learning and teaching experiences I have developed a prototype learning theory, called Link Theory, which resulted in Link Maps, the study aid implemented in this project. All of my ideas that spawned this project were conceived of before I had read any literature on education, psychology, neuroscience, or cognitive science. However, now that I have a firm foothold in these areas, I can attest that my original ideas sit well within the existing framework, even though they do combine various areas in rather unconventional ways.

The idea of implementing the Link Maps through Map Meetings were also my own idea, based mostly on the theoretical foundation of Link Theory which again is a result of personal experience. I conducted three out of four Map Meetings per week, whereas my supervisor, Dr. Manjula Sharma, conducted the last one. She is referred to throughout as my ‘fellow researcher’. The idea to the reflective journal kept after each Map Meeting to more effectively assess how they could be improved, I got from the ‘Tutuor training course’ organized by the faculty of science for all students who start working as university tutors or demonstrators.

All Link Maps were my own creation. Similarly, all problems on the Map Meeting problem sheets, which are not exam problems, as well as the problem solution sheet, are my own work. The two questionnaires were written by myself, unless otherwise specified. The methods chosen for analysis are mostly my own, except for the following. Dr. Rachel Wilson, my lecturer for a course in quantitative analysis, suggested that the rankings simply be represented by bar graphs rather than repeated tests of comparison. Factor analysis I had to learn as this is the standard way to analyse goal orientations (as was done in Duda and Nicholls, 1992). As I could not find any good texts thoroughly explaining factor analysis, the explanation in appendix E is my own, based on knowledge of 1st year linear algebra and basic statistics.

I certify that this report contains work carried out by myself except where otherwise acknowledged.

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20th October, 2006
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1. Introduction

1.1. Situating the project

This project is a result of a decade of reflection on my own learning in various educational settings. Throughout the years I have encountered many different teaching methods, from the exceptionally good to the appallingly poor. Although my experiences are unique to me and I am by no means representative of all students, there are teaching methods that seem to have an overall greater effect on a class than others. Having acted as a ‘peer teacher’ since I started school, as well as having some teaching experience at all levels from primary to tertiary education, I have had many opportunities to expand my understanding of how students of a range of ages and abilities best learn.

This has ultimately lead to a prototype learning theory, which I have given the name Link Theory, covering some, but not all aspects of learning. In short, it aims to propose an ‘atomic’ theory of knowledge construction. These atomic parts refer to the smallest pieces of knowledge a person can have, concepts such as ‘tree’ or ‘green’. In the same way as chemistry focuses on atoms and their bonds, the second fundamental concept in Link Theory, which gave rise to its name, are the links or associations between these atomic concepts. One such link exists between the concepts ‘tree’ and ‘green’, as most people get an association to the colour green if the word ‘tree’ was mentioned to them. However, a theory of learning is of no use if it cannot be implemented, thus the focus of this thesis is on a study aid, named Link Maps, developed on the basis of Link Theory. To date, the researcher has not found any type of concepts maps resembling Link Maps in literature. Both Link Theory and Link Maps are in the early stages of development, and I must stress that the overall goal of this study is to develop a structure for the Link Maps and their implementation, and explore whether they are viable learning tools and strategies. The findings will then inform on their future development, as well as instructing further work to be carried out on Link Theory. Thus, my research question is

*Are Link Maps a valuable study aid for 1st year physics students with little prior knowledge of physics?*

The specific objectives are as follows:

- Identify what type of students take advantage of extra help offered.
- Investigate the effect of the intervention on student’s self-efficacy (defined in sec. 2.3.).
- Determine whether the concept of goal orientation is a valid construct in physics.
- Evaluate what aspect of the intervention students found the most helpful for learning physics.
- Evaluate the effect of the intervention on student’s performance in the final exam.

As mentioned, Link Theory and Link Maps only cover some aspects of learning, thus the Link Maps were distributed in a mixed tutorial and lecture type environment called Map Meetings which focused on integrating the Link Maps with standard teaching practices. This was done to create a more coherent setting in which to implement the study aid, as well as providing ground for evaluating the usefulness of Link Maps in an authentic setting. The Link Maps were the focus of the Map Meetings, used both to present a review of the most recent topic covered in lectures, as well as serving as a reference and structure aid for students when solving physics problems.

Naturally, a vast body of literature covering all aspects of the above ideas already exists, so it is important to situate my work with respect to the current literature. Link Theory and Link Maps touch on a large variety of fields, from psychology to neuroscience, rendering it impossible to gain in-depth knowledge within all fields in the scope of this thesis. However, an overview of the most relevant areas is given in chapter 2, immediately after an introductory chapter on Physics Education Research. Chapter 3 first gives an overview of the theoretical background of experimental research within the social sciences, followed by details on the experimental design and implementation in this project. The experiment was undertaken at the University of Sydney, in the School of Physics with the two 1st year Fundamentals classes during semester 1, 2006, and has the approval of the University of Sydney Human Research Ethics Committee (see appendix A). Analysis and interpretation of the results as well as strength and weaknesses of the study are reported in chapter 4, whereas conclusion and further work are discussed in chapter 5.
1.2. Physics Education Research and its role

Physics Education Research (PER) is a relatively new field that emerged when it was realized that physics is sufficiently different to other fields to simply be included under the general umbrella of Education Research, “...the how and the what of learning are inseparable aspects of learning” (Ramsden, 1987). Or in the words of McDermott (2001): “Physics education research differs from traditional education research in that the emphasis is not on educational theory or methodology in the general sense, but rather on student understanding of science content”. However, as any applied science, PER also relies on a solid theoretical background.

For centuries, the area of physics has been infamous for being exceedingly difficult, and much prestige is still associated with its study. In society, physics is generally a subject people are ‘allowed’ to be illiterate in; admitting that one has no clue what \( E = mc^2 \) means is more of an ice breaker than a negative reflection on oneself. Traditionally this has been unproblematic, giving status to those especially interested students venturing into this world of scary looking equations and mysterious topics such as quantum mechanics and general relativity. However, times are changing. With the recent technological revolution and increasing demands for employees with profound skills in problem solving and logical reasoning, physics seems tailor made for the education of a person of the 21st century (Van Heuvelen, 1999; Rigden & Tobias, 1991). However, if physics is to successfully make the transition from a subject for especially interested people to one that is part of general education, the target population has changed sufficiently to require a paradigm shift in physics teaching.

There are three main reasons why physics is very different from many other subjects, something both its students and educators should be aware of to optimize learning. Firstly, it focuses on depth of understanding of a few key concepts, rather than quantity of information. Seemingly trivial, this has important consequences. Unlike areas where students either do or do not have some piece of knowledge, learning physics is concerned with gaining a more profound understanding of what initially may appear to be simple concepts. Secondly, a considerable proportion of physics education is concerned with the complex process of developing analytical skills, such as logical reasoning, problem solving and critical evaluation of conclusions. Since there are so few fundamental laws and concepts in physics, it is essential that students become well versed in the ‘when’, ‘how’, and ‘why’ of their application. Finally, a characteristic difficulty associated with physics is what has become known as misconceptions or alternative conceptions. The term refers to student understanding that is not in line with currently accepted scientific theories, such as the impetus model of moving objects where students believe that any moving object will eventually come to a stop, contrary to Newton’s first law. The process of making student conceptions more congruent with scientific theories is referred to as conceptual change, a large field within PER. Failure to recognize the above points can make physics unnecessarily difficult to learn for unwary students, something those teaching physics should always keep in mind.

The traditional lecture style familiar to most students has repeatedly been proven highly inefficient (Wells & Hestenes, 1995; Hestenes, Wells, & Swackhamer, 1992; Hestenes & Wells, 1992), yet it prevails as the central educational method both in higher years of secondary school as well as at university. Alternative teaching methods, such as Overview, Case Study Physics and the Modeling Method, have shown significantly higher gains in student learning (eg. Wells & Hestenes, 1995; Van Heuvelen, 1991), but none of these are easily implemented. Thus, an effective and effort efficient alternative to traditional lecturing is in demand. Studies have also shown that the quality of the lecturer has minimal impact on the information absorbed by the students, suggesting that “instructional methodology is a more serious problem than teacher competence” (Wells & Hestenes, 1995). It also implies that the ease with which students learn physics depends greatly on the study aids available to them (text books, formula sheets, lecture notes, etc.).
2. Theoretical background

This project focuses on the learning of physics for novices at the university level, and thus the current status of the areas relevant to this topic will be reviewed. As mentioned earlier, a distinguishing feature of physics is that it consists of relatively few central concepts that are highly interrelated across several domains in the field. To get a good grasp of the foundations for learning basic physics it is important to know about the nature of knowledge and its acquisition, and the motivational aspect that brings students to learn and persevere with the subject, focusing here on novices. In this chapter I will explain the key educational concepts underlying this project.

2.1. Constructivism

The main pillar upon which the field of PER (and education in general) rests is known as constructivism. This is an overarching theory which proposes that knowledge is not transmitted from a teacher to a passive student; rather students are required to be active participants in the learning process to construct the knowledge in their own minds.

The idea of constructivism emerged in the late 1920s from the works of Jean Piaget, a Swiss natural scientist and developmental psychologist, and Lev Vygotsky, a Belarusian psychologist, due to dissatisfaction with the then current educational methods. Education was essentially transmissive: students were to listen to the teacher, learn by rote, and regurgitate certain pieces of knowledge at the teacher’s demand or in tests. The problem with this method was that students were rarely able to apply their (apparently) acquired knowledge outside of the classroom setting (Hesketh, 1997). Changing the focus from the teacher to the learner in the learning process revolutionized the field and became known as the theory of cognitive constructivism.

Constructivism has important consequences in that learners do not merely make a copy of the information to be learnt, they assimilate it with their existing knowledge structure, interpreting the new knowledge in light of what is already known. Consequently, it is possible that certain erroneous associations will result. By focusing on the learner as an active participant in her own learning process the role of the teacher changes dramatically from transmitter to facilitator. The teacher cannot learn the information for the student, she can only guide and optimize the environment in which the student is learning.

There are several camps within constructivism with their own interpretation of the theory. Piaget claimed each individual should create their own version of ‘truth’. His contemporary, Vygotsky, on the other hand, emphasized the importance of culture, language and context in knowledge construction. Discussion amongst people to collectively reach a socially tested higher order ‘truth’, was essential. This became known as social constructivism and is a dominant area within constructivism today (see for example Driver, Asoko, Leach, Mortimer, & Scott, 1994; Cobb, 1994; Phillips, 1995).

2.2. Cognitive science

Cognitive science is the scientific study of either mind or intelligence. The field is highly interdisciplinary, relying on psychology, neuroscience, linguistics, philosophy, computer science, anthropology, biology and physics. It is not within the scope of this thesis to cover cognitive science extensively, so only the areas most relevant to the project will be discussed in brief.

The physical brain plays an essential part in human interaction with the outside world, so we need to know the basics of its operation. Neurons are cells within the body which main purpose is to process and transmit information. Each neuron has a myriad of dendrites, small protuberances organized in a radial branch-like structure called a dendritic tree (see fig. 1). This is thought to be the information receiving part of the neuron. Each neuron also has one axon which is a much longer protuberance. This branches out to connect to other neurons at its end points, called synapses, transmitting information at the synapse/dendrite interaction site. Of special relevance is that learning appears to be related to the physical growth of synapses in the brain (Redish, 2003).
With 100 billion neurons, each having 7000 connections to other neurons on average, it is impractical to base a theory of learning solely on neuroscience. The theory that focuses on the larger scale concept of memory belongs to the field of cognitive neuroscience. This distinguishes between three general categories of memory. Of all the external stimuli we are constantly bombarded with, the sensory memory works as a filter. The selected information proceeds to the short-term memory in which data can be held up to a few minutes. For retention, the information needs to be transferred to the long-term memory where it can be stored for decades.

The working memory is an alternative name for short-term memory, and with information either perceived through the senses or retrieved from long-term storage, it is here that active cognitive processes take place. Whereas no upper limit to long-term storage capacity has been observed, the capacity of the working memory is severely limited. ‘Cognitive overload’ refers to a situation in which a person tries to process more information than her working memory can handle (see recent review by van Merriënoor & Sweller, 2005). Only a few ‘chunks’ of knowledge can be active at any one time, where a ‘chunk’ represents a coherent set of knowledge with obvious internal associations. For example, to a physicist, force, mass and acceleration constitutes a clear chunk as they are associated through Newton’s second law. However, to a first year student, these three concepts are unrelated and so are considered three chunks; taking up a larger portion of the student’s working memory. Strongly associated chunks make up what is known as schemata or mental models (Redish, 2003). They describe robust patterns that are strongly associated across a variety of contexts, and thus provide the framework for problem solving and logical reasoning. Works such as Chi (2000) explore how memory, constructivism and mental models are associated in learning processes.

A significant area within PER is known as ‘conceptual change’ (Vosniadou, 1994; Johnston & Southerland, 2000; diSessa, in press). Often individuals’ mental models about the physical world, based on a lifetime of interaction with its surroundings through ‘everyday experience’, are not congruent with current scientific models. This means that teaching physics does not just entail instilling the accepted scientific models, it requires the student to accept inconsistencies in seemingly coherent personal models of the world followed by a change towards the models taught.

It is essential to consider concepts such as working memory and mental models in education, as what may represent a coherent set of ideas to a lecturer and thus trivial to discuss, will constitute too many unconnected concepts for a student to keep in her working memory, making her unable to follow the lecturer’s discussion.

2.3. Motivation

When it comes to learning theories we cannot avoid dealing with motivation, ‘—what brings us to learn something in the first place?’. This is a very different aspect of learning compared to constructivism and cognitive science, but equally important to consider in an actual learning situation.

The concept of 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). In other words, it is a person’s belief in herself that she can successfully carry out a certain task. Self-efficacy is determined by several factors, such as upbringing, reactions from other people to personal actions, personal
successes in undertaken tasks, etc. Self-efficacy is interesting because it is an important contributor to an individual’s success or failure. Those with a strong belief in their own abilities will be more likely to take on challenges, persist in the face of discouragement, and put in more effort to successfully complete a task, whereas people with low self-efficacy are more likely to avoid challenges that would result in a positive learning experience and take disappointments as a confirmation of lacking ability rather than as obstacles to be overcome (Schunk & Hanson, 1985). Thus, two individuals with equal abilities may experience large variances in successes due to differences in self-efficacy. One reason for this is that students with low self-efficacy may use valuable working memory during exam study worrying about the exam, battling thoughts of anxiety and low self-esteem instead of focusing on the material to be learnt (Tobias, 1979, 1985).

There are generally considered to be four major psychological processes that affect self-efficacy. These are self-appraisal of capabilities, motivation, belief in one’s own coping abilities, and selection processes affecting one’s future (Bandura, 1994). Only motivation is dealt with in this project, and so none of the other processes will be discussed here. Motivation is defined as an ‘internal state that instigates, directs and maintains behaviour’ (McInerney & McInerney, 2002), and can be both intrinsic and extrinsic. Intrinsic motivation results from the interaction between the task at hand and the learner; the individual is focused on improving her level of competence for her own sake. Extrinsic motivation, on the other hand, relates to learners being motivated by external factors, such as doing better than their peers or making their parents proud. The reward comes from without rather than within.

One approach to motivation is goal orientation theory. Studies of high school students’ motivation in the general settings of ‘classroom’ and ‘sports’ have identified four different goal orientations, called dimensions: task orientation, ego orientation, cooperation and work avoidance, and each dimension is associated with a certain belief in how success is achieved (Duda & Nicholls, 1992; Skaalvik, 1997).

- Task oriented students focus on acquiring skills, understanding the material and mastering the task at hand. Task orientation is associated with the belief that success is a product of effort, understanding and collaboration.
- Ego orientation is defined by a focus on establishing superiority over one’s peers, believing that success relies on greater ability and attempting to beat others.
- Cooperation oriented students value interaction with their peers in the learning process.
- Lastly, work avoidance describes the goal of minimum effort – maximum gain, and is associated with success coming to those who, for example, are liked by the teacher or are just plain lucky (Duda & Nicholls, 1992).

2.4. Concept 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 as diagnostic tools for knowledge evaluation, and the rules for their construction generally depend on their purpose as well as subject area. The concept maps developed by Novak are used extensively as evaluation tools, and follow certain rules of construction, such as being read from top to bottom, moving from general to more specific concepts as one descends down the map (Novak, 1998).

Knowledge maps are another type of visual aid which do not have this requirement of direction, but rather consists 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), as well as proving useful as reference tools in problem solving (O’Donnell & Dansereau, 1990; cited in Patterson et al., 1992). Students taught by a lecturer using knowledge maps as communication aids have been show 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). The use and success of visual maps are well documented in textually rich subjects such as biology and psychology. Physics, however, may seem textually rich to a novice, whereas an expert sees the subject as having very few fundamental concepts. A visual map aiming to represent and teach physics based on these key concepts, providing an important bridge between experts and novices, has not been found in the literature.
2.5. Learning models

To produce useful teaching strategies, several learning models have been built under the umbrella of constructivism. An important difference between a learning theory and a learning model is that whereas a theory attempts to explain a certain aspect of learning, a model aims to be applicable and thus is required to 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 change markedly as the learner develops from novice, via competent learner, to expert, as do the requirements on the optimal methods of teaching. All physics lecturers are experts within their domain, characterized by having both breadth and depth in their knowledge. To reach the stage of expertise, the learner has displayed a 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, Woords, Duohon, & Parker, 1997). As a consequence, students in their final year of university education (eg. physics honours students) 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 himself. Thus, an important aspect of teaching novices is 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 (eg. 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, Meter, Etten, & Freebern, 1997).

The third factor focused on in the 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 prevent 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. It is essential for lecturers to be aware of this fact.

2.6. Experimental background

The experimental aspect of the social sciences deserves special attention to outline its strengths and weaknesses. There are several different types of experiments ranging from rigorous, strongly quantitative experiments, where only the independent variable is manipulated to affect the dependent variable, to completely qualitative, “ethnographic” experiments such as a researcher’s observation of natural social phenomena. These have very different aims. Quantitative experiments aim to objectively establish relationships between variables, similar to equations in physics, whereas qualitative experiments generally try to identify interesting issues deserving of further investigation. Only experiments relevant to this project will be discussed here.

One important experimental issue for physics education researchers is ethics. Pittenger (2003, p. 110) describes ethics as “the process of studying moral standards and examining how we should interpret and apply them in various situations”. Because PER relies on students in experiments, the researcher must always justify her actions with respect to both the project outcome and the participants. Since the goal of PER is to improve student learning it is of a very benign nature, and ethics generally only mildly affects the type of experiment that can be conducted.
2.6.1. Types of experiments in educational research

Most closely related to the so-called scientific method are the *true experiments* in which participants for the treatment and control group(s) are selected by true random assignment. All groups are treated equally, except with respect to the independent variable controlled by the researcher, to which only the treatment group(s) is/are exposed. This method is the only one allowing for control and removal of threats to the internal validity of the experiment, and so is the only way to unambiguously determine cause and effect.

*Quasi-experiments* are similar to true experiments, but differ in that the selection process for participants subject to different treatment conditions is not truly random. This type of experiment allows research to be conducted when random assignment of participants is impossible, impractical, or unethical, but the internal validity of the experiment is not ensured as the parameter responsible for the self-selection of participants into different groups may affect the dependent variable.

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 DIIA, 2006), one can assume that the sample is representative of the population, allowing the researcher to accurately estimate relevant population parameters. An important limitation of questionnaires that always must be considered is that self-reporting is not necessarily accurate, eg. 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.

2.6.2. Internal and external validity

When analyzing an experiment, the internal validity refers to whether one can unambiguously conclude that the independent variable caused the change in the dependent variable. Any extraneous or uncontrolled condition related to the independent variable is a threat to the internal validity, and is called a confounding variable. Examples are changes related to time in long duration projects, treatment and control groups that are not strictly 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 as well as 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. Clearly, 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.

2.6.3. The components of an experiment

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 the external and the internal validity must be verified to ensure a reliable experiment.

The first step in conducting an experiment is to select participants. The *population* refers to all individuals the researcher wants to describe. “Defining the population is essential as it determines the conclusions that the researcher may draw from the data” (Wilkinson, 1999, cited in Pittenger, 2003, p. 140). The *sampling population* is a subset of the population which shares the same characteristics as the population from which the final sample will be drawn. This is generally a part of the population to which the researcher has easy access. The part of the population that will be used either as treatment or control group is called the *sample*.

The sample is generally considered representative of the population, but the validity of this depends on the sampling method. Probability sampling is the only method that guarantees internal validity. In this case each
member of the population has an equal probability of being a member of the sample, allowing the probability of each specific sample to be determined. When probability sampling is impractical, impossible or unethical, non-probability sampling is used. Then it is the individuals’ behaviour, not the researcher’s methods, that determines who will constitute the sample. This introduces a third variable which the researcher is not free to manipulate, as the self-selection depends on certain intrinsic characteristics, or subject variables, of the participants (eg. gender, IQ, personality traits, etc.). Note that any such variable is referred to as a third variable, so that there can be several independent variables as well as more than one third variable. Although non-probability sampling may affect the internal validity, it can still “produce useful data when collected and interpreted under the right conditions” (Cochran, 1977, cited in Pittenger, 2003, p. 145).

The treatment can be any independent variable the researcher believes will or will not have an effect on some dependent variable. For practical reasons (eg. time limitations, resources, etc.) the treatment may consist of more than one independent variable. This leads to an ambiguity as far as separating the independent variables, but a separate investigation may help distinguish between them. In other cases, there might be a symbiotic relationship between the variables, so the combination is much more powerful in affecting the dependent variable than any of the independent variables separately.

The final important aspect of an experiment is the test that ultimately is used to assess the effect of the intervention. First of all, the test must be valid, meaning that the test 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 second parameter is the reliability of the test, which itself has two aspects: consistency and discriminatory power. The consistency reflects whether the same person would obtain the same result if the test was repeated, whereas the discriminatory power of a test 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).

2.6.4. The analysis

Within the social sciences data are analysed with various statistical tests. Before a test can be chosen, it is important to characterize the data as either parametric or non-parametric. Parametric data is required to meet the following four assumptions: it must be normal, ie. the distribution must be roughly shaped like a Bell-curve; if there is more than one variable, they must show homogeneity of variance, ie. the variances of the individual variables must be roughly equal; and the variables must be independent and continuous.

The last two assumptions are fulfilled by correct design of the measurement. In cases where the assumption of homogeneity of variance is not fulfilled, parametric tests can still be used as long as the result for ‘equal variances not assumed’ is quoted. If the data are not normal, for example by being strongly skewed or bi-modal, the data are non-parametric. The nature of the data determines whether parametric or non-parametric tests need to be used. The tests for parametric data have a higher statistical power, meaning that they have a greater chance of detecting a real result, but as long as the appropriate test is used, they are all valid.

Statistical tests can be broadly separated into tests of difference and tests of association. For a thorough introduction to statistics and the theoretical background of the most essential tests, see Appendices B and C and Field (2000). Tests of difference test, as the term implies, whether there is a significant difference between the means of different groups. The most familiar of these tests is the t-test which assumes normality. If the data in the two different groups were obtained from different subjects, an independent samples t-test is carried out. When measurements are taken twice on the same set of subjects, eg. pre– and post-test, a repeated measures t-test is performed. The equivalent tests for non-parametric data are the Mann-Whitney test and the Wilcoxon Signed-Rank test. Tests of association, such as correlations, can only be carried out on repeated measures data where two or more variables have been measured for each subject. Unlike tests of difference, which group data according to variables before comparisons are made, tests of association focus on the individual subjects and the relationships between their measures on each variable. They compare one individual’s data to the data of other subjects.

When drawing a sample from a population it is unlikely that two separate samples will be completely identical. This must be taken into account when trying to establish whether a result reflects something real or if it
is simply due to the inherent randomness of sampling. It is possible to calculate the probability that two different samples came from the same population, and tests usually produce a so-called \( p \)-value which is the probability that the measure occurred by chance rather than being a real effect. Clearly, there is no theoretically well defined cut-off point deciding whether a result is real or not. In general a result is said to be significant if \( p < 0.05 \), i.e. the probability that the result occurred by chance is less than 5%.

Parameters such as mean and standard deviation strictly speaking only apply to normal data. However, in cases where reasonably normal looking data do not pass the test of normality, the standard procedure is to quote the mean and standard deviation as the measure of central tendency to allow for a description that has a standard format and thus is easily compared with other data (as done by Mayer & Anderson, 1991; Langan et al., 2005).

Although numerical data is claimed to be objective, qualitative data plays an important role in the social sciences, especially in preliminary studies aiming to identify factors worthy of further research or establishing variables. The researcher’s subjective observations, or short answer responses in a questionnaire can provide valuable information that could not be obtained by numerical means, both of which were used in this project.

The key to a successful experimental design is therefore to choose the right type of measurement with the appropriate analysis for the variables under investigation.
3. The Experiment

3.1. The Sample

The target population for this study was students enrolled in the 1st year physics Fundamentals course in semester 1, 2006, at the University of Sydney. These are students who have no or very little prior experience with formal instruction in physics. The majority are enrolled in either a Bachelor of Medical Science degree (50%) or a Bachelor of Science degree (24%) with the remaining students spread across 20 different degrees. Two hundred and forty four students attended at least one class, of which 64% were female (N = 227). Complete information on all students was unavailable, even for gender, so the number of students contributing to any analysis will always be quoted.

3.1.1. Treatment and comparison groups

The sample was chosen by self-selection due to ethical considerations defining this study as a quasi-experiment. Announcements were made and an information (appendix A) sheet handed out in class in the first week of semester inviting all students to attend Map Meetings, and throughout the semester students were given regular reminders. These Map Meetings were presented as one extra weekly contact hour which intended to present the content covered in class in a slightly different way by using the newly developed study aid called Link Maps. Students were told that voluntary attendance at Map Meetings was hypothesized to positively affect students’ final exam mark. Such interventions involving exposure to extracurricular programs are common in education and are termed ‘enrichment programs’.

Attendance at Map Meetings was relatively stable throughout the semester (see fig. 2). From the trends in number of Map Meetings attended by students (fig. 3) three groups of ‘Map Meeters’ were defined: persistent, intermediate and non-Map Meeters. The persistent Map Meeters were chosen to be those students who had attended 8-10 Map Meetings as this group clearly stand out in fig. 3. Students who had attended one Map-Meeting was included in the non-Map Meeters as they were not expected to be considerably affected by this one attendance. The intermediate Map Meeters comprise the group of students who attended 2-7 Map Meetings. The effect of their attendance would be expected to be highly variable, so this group was not considered when analyzing the effect of the intervention.

From table 1 it is clear that the groups were not identical. The majority (69%, N = 32) of the persistent Map Meeters were Medical Science students. This group displayed a significantly higher average UAI than the non-Map Meeters, confirmed by an independent samples t-test with unequal variances assumed (t = 4.32, df = 52.6, p < 0.001). Considering the subject background of the students in the different groups there were some interesting differences. Firstly, the persistent Map Meeters did not have a particularly strong background in mathematics from the NSW Higher School Certificate (HSC). Fig. 4 shows that none had done 4-
In summary the persistent Map Meeters have a somewhat better science background in biology and chemistry than the non-Map Meeters, but none had studied physics before. However, the persistent Map Meeters had a poorer background in mathematics compared to the non-Map Meeters, whereas there was no significant difference in English background.

Since the persistent and non-Map Meeters did not have comparable backgrounds, two subsets of the non-Map Meeters were selected to allow for more matching and reliable analysis of the intervention. The selection was based on mathematics background and UAI, as these two factors generally are the best predictors of 1st year physics exam marks (Roberts, Sharma, Britton, & New, 2006). The first comparison group was selected to have the most similar background to the persistent Map Meeters by requiring the students to be non-Map Meeters who sat the exam, had not done HSC 4-unit maths, and who had a UAI ≥ 91 (only one persistent Map Meeter had UAI ≤ 91, with UAI = 84.6). This comparison group comprised 40 students with a
mean UAI of 94.9, ie. not significantly different to the persistent Map Meeters (table 2). Nineteen of these students had done 3-unit maths with a not significantly different mean to the persistent Map Meeters so the groups were similar with respect to maths backround. Thus, the first comparison group were considered identical to the persistent Map Meeters in all other respects than Map Meeting attendance.

The second comparison group was composed of the 19 students who had done 4-unit maths. These would be considered the strongest group of students in the class, obviously unlikely to struggle with the mathematical aspect of the Fundamentals course, thus lightening the overall burden of the course. Their mean UAI was comparable to the persistent Map Meeters, but in addition to having a strong mathematics background, four students had also done physics in the HSC (mean = 80.8), giving this group the best prospects for doing well in the Fundamentals physics exam.

3.1.2. Critical evaluation of the sample

The internal validity of the sample was compromised by the unavoidable self-selection of participants, but the choice of various comparison groups provide valid controls. The external validity was also reduced by the same reason, limiting the generalizations that can be made. However, by considering a population defined by the characteristics shared by the treatment group and the first comparison group, some generality of findings can be drawn. In addition, tentative conclusions and meaningful discussions can be made for all groups as long as the limitations in internal validity is considered.

3.2. Design and implementation of the intervention

3.2.1. A hole to be filled

Human knowledge exists on several levels, from extremely detailed to a general overview of what we know. Detailed knowledge is often considered the most valuable, and is generally what determines success in an exam; however, it has no value unless one knows where it sits in the overall knowledge structure. This may sound trivial, but it is one of the greatest challenges faced by 1st year students with no prior knowledge of physics. In lectures they are bombarded with new concepts and examples, receiving considerable amounts of detailed knowledge, but they get very little help in creating an overview of all this information, leaving many students feeling completely lost in a jungle of new concepts, symbols, laws and diagrams.

The goal of 1st year Fundamentals physics is to establish most of the concepts and essential associations that have become second nature to all lecturers and possibly quite familiar to students who have done HSC physics. However, owing to the large amounts of information in the course, the students are constantly challenging the limits of their working memory. Establishing strong links between fundamental concepts is equivalent to creating conceptual chunks, in the terminology of Redish (2003). Once established, a chunk can be treated as one unit of knowledge, thus freeing up valuable space in the working memory. Students who are unsuccessful in creating such chunks may suffer from cognitive overload in which the working memory does not have the capacity to handle all the information required to be active simultaneously to promote learning. Link Maps were developed with these students in mind.

3.2.2. Link Maps

Link Maps were conceived from Link Theory, both being the researcher’s original ideas. Link Theory is based on the idea that conceptual knowledge is structured in a mental web where the nodes represent individual concepts such as mass or force whereas the links between these nodes are associations between concepts, eg. Newtons second law is a small set of strong associations between the nodes force, mass and acceleration. To anyone who has a basic knowledge of mechanics, F = ma is as obvious as France being in Europe, whereas to a student unfamiliar with physics F = ma more closely resembles Montevideo being the capital of Uruguay, the connection is not obvious at all and discussion of one concept does not automatically imply the other.
A Link Map is a visual map resembling the mental web structure students are required to eventually form. Whereas concept maps generally focus on nodes and a myriad of associations, Link Maps were specifically developed for physics in which there are relatively few key concepts. These are combined and dealt with differently depending on the topic, as well as being linked across different topics, reflecting the interconnectedness of the various fields in physics. Consequently, physics is a rather unique discipline in that the difficulty in learning it does not lie in the number of concepts that need to be learnt (i.e. quantity of nodes), but lies in the number of associations (links) required to be formed.

There were ten Link Maps produced for this project, covering the topics of mechanics, buoyancy and waves (see appendix D). There was no standard layout of a Link Map except that all were based on more or less the same seven concepts central to the areas covered, namely displacement, velocity, acceleration, force, energy, mass, and momentum. These concepts were identified as the central ones by carefully going through the mechanics module outline (mechanics constituted 70% of the course). The module outline clearly specified which terms and concepts the students were required to know, so upon perusal of the outline about 70 concepts were initially identified. Inspection of these concepts in conjunction with the researcher’s knowledge of physics brought the number of fundamental concepts down to seven, e.g. by identifying tensile force as simply a special type of force, and density as constructed of displacement (or length) and mass. These seven concepts were then hand written on a white A4 sheet of paper, which became known as the fundament (fig. 5) since it contained the fundamental concepts of mechanics.

By building all maps on the fundament, the researcher’s personal philosophy based on years of studying physics herself was that the students would become familiar with this common structure of the Link Maps. This familiarity was expected to reduce the cognitive load associated with getting to know a new map, as well as improve the ease with which information could be linked across maps. Sometimes only a few concepts were kept if the topic did not deal with all of them, whereas on other occasions one or two concepts were exchanged with others more relevant to the map in question, e.g. for ‘Simple Harmonic Motion and Waves’ momentum and mass were substituted with time and phase. To minimise confusion regarding the change of some concepts between maps, only the two concepts that appeared on the right hand side of the map were ever exchanged with other concepts, making this the ‘variable’ side of the map.

For each topic only the most essential relationships were given, often with relevant equations or diagrams if considered to aid understanding or retention. Fig. 6 shows the map covering Newton’s three Laws. The map is divided into three sections, one for each law, and only the three relevant concepts are included (force, mass and acceleration). The map is constructed in a way that aims to clarify the essence of each of the three laws, including only the bare minimum of information that completely and correctly describes the law, as well as making clear the intimate relationship between them. The large arrows connecting the three laws make the relationships between the laws impossible to miss for the students, whereas the connection between any two laws are clearly and succinctly explained in an unambiguous way on top of the arrow. Simple diagrams help illustrate the physical scenario for each law, providing students with both visual and verbal information to increase the likelihood of retention.

3.2.3. Map Meetings – Implementing the Link Maps

There were several options available to trial the Link Maps. A ‘true experiment’ would involve random allocation of volunteers into treatment and control groups, and a laboratory type experimental set-up where all the experimentation occurred in the lab under careful supervision. A quasi-experiment would imply a more
authentic setting, at the cost of some loss of control over the intervention variables. The latter type of experiment was chosen because the whole intent with the Link Maps is that they be used in a natural setting.

The Link Maps were implemented on a weekly basis in 50-minute long Map Meetings, a hybrid between the compulsory lectures and the workshop tutorials run by the School of Physics. Four identical Map Meetings were held each week, with three of these scheduled either directly before or after a compulsory lecture. Students were invited to attend whichever Map Meeting suited their timetable and even if they had not participated from the beginning, they were encouraged throughout the semester to attend. Each Map Meeting was typically attended by 10-20 students, three of which were conducted by the researcher and one by a fellow researcher, an academic with considerable teaching experience.

The structure of each individual Map Meeting was carefully planned throughout the semester. A one-page overview was meticulously designed containing the objective and the timeline of the meeting in terms of activities and what the researcher needed to go through. Immediately after each Map Meeting the researcher would write a reflective journal in which she was required to comment on whether the meeting went according to plan, the best and worst parts of the meeting, the general feeling the researcher had about the meeting, and suggest any improvements for next week’s Map Meeting. At the conclusion of each week the main researcher would write a weekly reflection which summarized all four Map Meetings held during the week, including whether the meetings had gone according to schedule, which parts of the meetings worked and which didn’t, what the researchers had learnt this week, and what improvements should be made for the next Map Meeting. The Map Meetings were continually improved during the semester using the reflective journal, but the approximate final structure was arrived at by the 4th Map Meeting.

In each Map Meeting, the first 15-20 minutes were always spent going through the Link Map of the week. For simple maps (three in total) the students made their own map together with the researcher whereas the more complex maps were gone through by the researcher, and the student were given a paper copy of the

Fig. 6: The Link Map covering Newton’s three laws.
map. When the students made their own map, they always used a printed fundament sheet and two paper clips which they were given at their first Map Meeting. For each new map, students were given a transparency on which they would write with borrowed permanent colour pens. With the paper clips, the transparency was fastened on top of the fundament sheet. The researcher did the same with a transparency on top of a transparent fundament sheet projected on an overhead. The researcher then constructed the map together with the students, eg. for the map containing symbols and units the class was asked if anyone knew the symbol and unit for displacement. The students collectively arrived at the correct answer which was then written down on the transparency on top of the concept displacement. In this way the construction of the map was a highly interactive procedure demanding active participation by the students. The philosophy was that by being part of the construction of the map students’ retention of the information would be greater, one of the key principles underpinning Piaget’s constructivism.

When the map was fairly complex it was impractical to let the students make their own maps, so the method of ‘layering’ was developed. This was the researcher’s original idea, developed to help students focus on the part of the map being discussed at any one time, as well as allowing them to be part of the map construction. In this way they would later on be able to mentally unpack the map to isolate whatever relevant information they were seeking.

The researcher started with the transparent fundament or a reduced version of it on the overhead with another transparency overlaid covering only a part of the Link Map (see fig. 7, top panel). This section contained a small amount of information which was discussed interactively with the class. The interactive aspect could be asking the students if they recalled certain relationships covered in lectures, to give specific examples of general statements, or the researcher going through an example while keeping a dialogue with the students. Once the section on the first transparency had been covered, a new transparency was overlaid the previous two (see fig. 7, second panel from the top), thus increasing the information on the map. However, as the information on the first transparency had just been covered, the students’ attention could be focused on the newly added information. This procedure was repeated until the map was complete after 4–6 transparencies. The final map, in some cases, contained a considerable amount of information, but by introducing the students to the map through

![Fig. 7: An illustration of the layering that was used to present the Link Maps in Map Meetings.](image)
layering, cognitive overload was avoided as only a manageable amount of information was presented in each layer. Upon receiving a colour paper copy of the map after it had been gone through, the idea was that students would be able to mentally see the layering and thus isolate relevant parts of the map when subsequently using it. The weekly material was covered coherently, such that a student who had missed the class in which the content had been covered (or had not understood much of last week’s lectures) would still be able to understand the map. In this way, going through the map was equivalent to a condensed mini-lecture on the topic of the week.

In the second part of the Map Meeting (also 15-20 minutes) the students were given a problem sheet with two sections. The first section generally consisted of one or two relatively simple many-part problems written by the researcher, testing only a couple of concepts per part. These relatively simple problems were designed to boost the students’ confidence regarding problem solving, as well as to consolidate some essential physics concepts. These questions were hand written, making the problems less formal, in line with the atmosphere of the Map Meetings. The second section of the sheet typically had one or two past exam problems to give the students valuable exam practice. The students were encouraged to work in small groups (2-4 students) on these problems, and the researcher would go around helping the students when they were unable to make progress. 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). Research has shown this type of peer learning to be highly effective, with its greatest strength being “fostering the acquisition of basic conceptual insight” (Damon & Phelps, 1989), 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 cooperation rests on the theoretical foundation of Vygotsky’s social constructivism. In particular, Vygotsky’s theory of ‘The Zone of Proximal Development’ states that learning is optimized when students at roughly the same knowledge level collaborate and learn from each other (John-Steiner & Mahn, 1996).

The last 10-20 minutes of each Map Meeting were spent with the researcher going through some, but generally not all, problems on the board. Typically the problems students had found challenging were carefully explained, with the researcher not only giving students the correct answer but taking them on the journey of logic, explaining how she reasoned her way through the problem from beginning to end. It was essential that the students had already attempted these questions as it was expected that the students were much more likely to learn and remember how to solve a problem if they had spent some time working on it themselves first. This philosophy is supported by studies showing that learning is most effective when explanations given are direct answers to student questions (Webb, 1991; cited in Cohen, 1994). At the conclusion of the Map Meeting the students would be given a complete set of problem solutions, constructed and hand written by the researcher (fig. 8). These solutions also attempted to show the students the logical reasoning used in arriving at the correct answer, similar to the verbal explanations.
3.2.4. Critical evaluation of the intervention

The main criticism of this intervention is the relatively large number of independent variables (actions) that were implemented simultaneously as part of the Map Meetings. This limits the conclusions that can be drawn on the effect of the Link Maps alone, but when it comes to learning, study aids are never independent of each other - their power lies in the symbiotic relationship between them (Ramsden, 1987). This is also supported by Patterson et al. (1992) who found that students who had been given a strategy for how to use a knowledge map performed better in the assessment of the usefulness of the map, than students who had not been given a strategy. Thus, implementing the Link Maps in an authentic educational setting should not be considered a weakness of the study. All of the different intervention variables (such as a coherent review of the weekly topic, and the problem solving) were included because they gave the student essential strategies for how to use the Link Maps (the review familiarized the students with the map, and the problem solving gave the students practice in how to use it, as the researcher would frequently refer to the map when helping). The measurement instruments were designed to probe possible differences between the intervention variables, but the symbiotic relationship between them should always be considered.

3.3. Design and implementation of the measurement instruments

Two main measurements were used to determine the usefulness of the intervention: two questionnaires and the final Fundamentals physics exam. Other information on the students was also used to account for third variables.

3.3.1. Third variables

The students’ UAI, individual HSC subject marks, gender, and degree were obtained with informed consent.

3.3.2. The questionnaires

Two questionnaires were designed around constructs pertinent to learning and teaching. Those pertinent to learning were student focused, such as self-efficacy and goal orientation, whereas those pertinent to teaching were designed to gain information for course evaluation and feedback on instruction. The questionnaires had 36 and 37 questions respectively, most being simple statements that students were asked to answer how well they agreed with on a 5-point Likert scale ranging from Strongly Disagree (1), through Disagree (2), Neutral (3) and Agree (4) to Strongly Agree (5). There were also a couple of other simple questions (eg. Yes/No) and three short answer questions in the second questionnaire (see appendix E for the questionnaires). The sections of the questionnaires were as follows:

1. Self-efficacy

Both questionnaires had the same five questions targeting self efficacy. The questions were based on the General Self-Efficacy Scale (Jerusalem & Schwarzer, 1993) adapted to a tertiary physics education context.

2. Goal orientations

Questionnaire 1 had 20 questions attempting to reveal four different goal orientations previously identified by Duda and Nicholls (1992), namely ego, task, cooperation and work avoidance. All questions were adaptations made to suit tertiary physics education from Duda and Nicholls’ general high school classroom and sports questions, and were developed in consultation with the fellow researcher who conducted the Map Meetings with the main researcher.

3. Rankings

Several sets of questions were created to produce various rankings, and the students were asked to rate each of the items on a 5-point Likert scale. In questionnaire 1 at the beginning of the semester the topics were reasons why students came or did not come to Map Meetings. In questionnaire 2, at the end of the semester, the usefulness of various aspects of the Map Meetings and the Link Maps, and the value of each type of learning environment (lectures, workshop tutorials, labs, Map Meetings and review tutorials [offered late in the se-
mester for students at risk of failing]) were inquired about.

4. **Various questions**

In both questionnaires there was a series of questions attempting to probe students’ views of physics (eg. did they see it as coherent or merely as a hodge podge of equations).

5. **Short answer questions**

In questionnaire 2 there were three questions related to Map Meetings intended only to be answered by attending students.

The questionnaires were given out in weeks 4 and 13 of the semester to the whole Fundamentals class. As the students entered the lecture theatre they were personally handed the questionnaire, and the researcher held a short informatory talk prior to the lecture. The questionnaires were subsequently collected as the students left the lecture theatre an hour later. The return rate of the questionnaires were (75 ± 3)% based on the students who attended class, and (47 ± 2)% of the total number of students enrolled, which is considered adequate for sampling the diversity in the class (cf. section 2.6.1.).

3.3.3. **The final exam**

The final exam of the Fundamentals physics course was a three-hour exam with 12 questions, six of them typically with a qualitative style and the other six more ‘traditional’ quantitative problems (see appendix F). The qualitative questions do not require any calculations, but a correct answer requires that the student shows understanding of the physical problem at hand and refers to the relevant physical concepts, laws or relationships, as illustrated in fig. 8. These questions are usually simple one-part questions, but occasionally can have two or three parts to them.

The quantitative questions are always multi-part questions and can cover several aspects of a topic such that the students may have full understanding of one part but poor understanding of another part (eg. standing waves and Doppler shift). Certain parts of each quantitative question will always require some calculations, whereas other parts should be answered qualitatively, for instance by interpreting a numerical result or explaining an assumption (Sharma, Mendez, & O’Byrne, 2005).

For most topics covered in the Fundamentals course there was one qualitative and one quantitative question in the exam. The exam was set by the lecturers and marked by staff in the School of Physics, not including the researcher.

3.3.4. **Critical evaluation of the measurement instruments**

The main limitation of questionnaires is whether the students are honest in their response. Most questions in the two questionnaires handed out during this study would be considered fairly neutral, not reflecting either negatively or positively on the students whichever answer they were to give. Only one question would be considered to have a ‘politically correct answer’, namely ‘I think boys are generally better at physics than girls’, a factor which was taken into account in the analysis.

In the second questionnaire there were several questions, including short answer questions, which aimed to probe which aspects of Link Maps and Map Meetings were the most useful. This could potentially lend itself to flattery of the main researcher, but since this questionnaire was handed out after the last Map Meeting was held and the researcher had made it clear to the students that she was in no way involved with any aspect of the exams or the students’ future relationship with the School of Physics, flattery would serve no purpose. The fellow researcher who took one of the weekly Map Meetings was a lecturer in the Fundamentals course and thus involved with the exam, but the students were informed that she would not be involved in the analysis of the second questionnaire. Consequently, the questions targeting the intervention was not expected to be significantly biased.

The style of the 1st year Fundamentals exam is well established and has been used as a diagnostic tool in previous studies (Sharma, Millar, & Seth, 1999).
4. Results: Analysis and Interpretation

4.1. General

The data were analysed using the Statistical Package for the Social Sciences (SPSS). Normality was checked using the non-parametric 1-sample Kolmogorov-Smirnov test, and the appropriate parametric or non-parametric tests were consequently performed (cf. appendices B and C, and Field, 2000, for details on SPSS and statistics).

4.2. Self-efficacy

Self-efficacy is a measure of a person’s belief in his or her abilities to perform a certain task. It has been shown to relate to actual performance (Bandura, 1994), but this result has received minimal attention in the highly academic field of tertiary physics education. Physics is known as one of the harder subjects to study, which has deterred a large population of high school students from choosing it (Binnie, 2004). Thus, anything that can increase a student’s self-efficacy would be considered valuable, not only for the student who would feel more comfortable with the subject, but also for the subject’s standing to the public.

4.2.1. Factor analysis

It is not straightforward to measure a construct such as self-efficacy. Normally it is done using questionnaires in which several questions target the same concept. In this case, five questions (or variables) probing slightly different aspects of self-efficacy were asked. Two examples were “I know I can pass the physics exam if I put in enough work during the semester” and “The motto ‘If other people can, I can too’ applies to me when it comes to physics”. One would expect that a student who agrees to the first statement, would agree to the other as well. The two variables are then referred to as being highly correlated. If the answers to the set of questions display a strong inter-correlation for a large group of people, it is considered a valid measure of self-efficacy.

A factor analysis tests for consistency using correlational analysis, linear algebra and standard statistical measures such as variance (see appendix E for details). Each set of questions for which there is a clear consistency in response is known as a factor, but which underlying concept this factor measures must be suggested by the researcher after perusal of the questions.

A set of five questions targeting self-efficacy was repeated in both questionnaires. An exploratory factor analysis using the principal component method was run on both sets, meaning that no assumptions were made as to how many factors were expected to be found. A clear ‘one factor’ solution was obtained in both cases. These satisfied both criteria that are generally used to identify a factor as being real, namely Kaiser’s criterion (eigenvalue > 1) and being identified in a Scree plot (appendix C).

There are two other essential measures which need to be satisfied for a valid factor analysis. The first of these tests whether the partial correlations between the questions (or variables) are small. As previously mentioned, each question that contributes to the measure of self-efficacy targets a slightly different aspect of the construct. The partial correlations reflect this uniqueness and are displayed as individual KMO values (Kaiser-Meyer-Olkin Measure of Sampling Adequacy) along the diagonal in the anti-image correlation matrix produced by SPSS. The values can range between 0 and 1, and if a question is found to not contribute sufficiently in uniqueness (by having a value < 0.5) it should be discarded. The average of the individual KMO values is the overall KMO statistic, which gives a good indication of whether the sample is suitable for factor analysis.

The second measure is known as Bartlett’s test of sphericity. Because a factor analysis depends on inter-correlation between variables, the correlation matrix containing the individual correlations between each pair of variables, is required to have at least some non-zero off-diagonal elements. Bartlett’s test analyses how similar the correlation matrix is to an identity matrix, and reports the \( p \)-value, which is a measure of the
The two questionnaires used in this project showed KMO values of 0.79 and 0.81 respectively, indicating an adequate sample. Bartlett’s test of sphericity was highly significant \( (p < 0.001) \) in both questionnaires, reflecting that the variables were far from independent. The one-factor solution explained 50% and 57% of the variance respectively in the two questionnaires. The percentage of variance explained reflects the amount of the original information contained in the one measure of self-efficacy. Due to the unpredictability of humans, there will always be a certain amount of variance in the data that does not lend itself to thorough analysis, so reducing the data to 20% of its original size, still keeping 50-60% of the information, allows for much more efficient and meaningful analysis.

The last measure to be quoted is the factor loadings. This is a measure of how well each of the variables correlate with the identified factor. In this case all questions showed roughly equal factor loadings in both cases (0.66-0.76 and 0.68-0.82 respectively). This means that each question targeted an equally important and relevant aspect of self-efficacy, and allowed a pre– and post self-efficacy score to be created for each subject by summing up the individual item scores (between 1 and 5), resulting in a scale ranging from 5 to 25.

The factor analysis thus showed that the five questions designed to measure the underlying construct of self-efficacy were successful in their aim. Each question contributing approximately equally to the self-efficacy factor, and the consistency in the pre– and post-tests indicate reliability in the measure.

### 4.2.2. Analysis of self-efficacy

<table>
<thead>
<tr>
<th></th>
<th>Non-Map Meeters</th>
<th>Persistent Map Meeters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Mean</td>
<td>18.2</td>
<td>17.8</td>
</tr>
<tr>
<td>SD</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td><strong>Post-test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Mean</td>
<td>16.9</td>
<td>17.9</td>
</tr>
<tr>
<td>SD</td>
<td>2.9</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 3: Self-efficacy scores on pre- and post-tests for persistent and non-Map Meeters.

An alternative presentation of the information on self-efficacy is a scatter plot of post versus pre-test score (fig. 9). The straight line is simply \( y = x \) and indicates subjects which did not change their self-efficacy from pre- to post-test. Subjects above this line increased their self-efficacy, whereas those below the line decreased from the beginning to the end of the semester. Table 4 shows the percentage of students in each of these groups. Both persistent and non-Map Meeters have the same number of students showing no change, whereas the persistent Map Meeters have a much higher percentage of students who increased in self-efficacy, and fewer (although still a lot) who decreased. Note that the persistent Map Meeters who showed a very low self-efficacy score on the pre-test experienced a significant boost in their self-efficacy during the semester (fig. 9), whereas the students who initially had a high self-efficacy decreased somewhat. The overall effect is an unchanged mean self-efficacy score with a decreased standard deviation. The non-Map Meeters do not show a similar trend.

These results can be interpreted in terms of the non-Map Meeters losing some of their self-efficacy as they progress through the lecture course perhaps realizing that physics was more challenging than they initially thought. The trend in self-efficacy scores for the persistent Map Meeters, however, indicate that those students who initially had a very poor belief in themselves benefited greatly from the Map Meetings, realizing that physics, while certainly not being easy, was far from undoable. Those displaying a very high score on
the pre-test may have become somewhat more realistic as the course progressed; accepting that doing well in physics requires hard work, but is certainly within reach.

It is important to keep in mind that causality cannot be unambiguously derived from a quasi-experiment. The information obtained from the questionnaires suggests that student attendance at Map Meetings had a positive effect on their self-efficacy. This assumption is supported by students’ response to the short answer questions which will be discussed in section 4.6. These tentative conclusions are promising and valuable and the effect of Link Maps and Map Meetings on self-efficacy deserves further attention in future research on these study aids.

4.3. Goal orientations

Goal orientation theory is one avenue which investigates students beliefs in how success is achieved. As mentioned in section 2.3. on Motivation, Duda and Nicholls (1992) have identified four dimensions, namely ego orientation, task orientation, cooperation and work avoidance. Their studies, however, were on high school students investigating goal orientations in the general areas of ‘classroom’ and ‘sports’, and to date, a similar study in the specific field of tertiary physics education has not been found in literature.

An exploratory factor analysis using the principal component method was carried out on the 20 goal orientation questions. The objective was to reproduce the four factors identified by Duda and Nicholls from which the questions were derived, but quite a different result was obtained. Five factors, cumulatively accounting for 59% of the variance, were retained after an inspection of the Scree plot (fig. 10) which coincided almost perfectly with Kaiser’s criterion (eignevalue > 1). Other checks (as those described in the section on self-efficacy) were carried out and satisfied all the necessary criteria (KMO = 0.665, Bartlett’s test $p < 0.001$).

When more than one factor is identified within a data set, a factor analysis is always a two step procedure. One algorithm is applied for initial identification of the factors (see appendix E for a thorough description). The number of factors to retain is decided upon by the researcher after investigation of the Scree plot as well as using Kaiser’s criterion as a guide. The second step is to carry out an optimization procedure, known as a ‘rotation’ (the name refers to the rotation of a set of axes in $n$-dimensional space which is the actual optimization procedure performed by SPSS, see appendix B). The most general rotation that can be applied is known as an oblique rotation, or Direct Oblimin rotation. This will reveal whether factors are correlated, unlike the more stringent orthogonal rotation which forces the factors to be independent.

<table>
<thead>
<tr>
<th>Self-efficacy score</th>
<th>Non-Map Meeters</th>
<th>Persistent Map Meeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased</td>
<td>19%</td>
<td>30%</td>
</tr>
<tr>
<td>No change</td>
<td>19%</td>
<td>20%</td>
</tr>
<tr>
<td>Decreased</td>
<td>61%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 4: Percentage of students who increased, had no change, and decreased in self-efficacy during the semester.

Fig. 9: Scatter plot of self-efficacy score on post-test versus pre-test for persistent and non-Map Meeters. The straight line is $y = x$, so subjects above this line increased their self-efficacy during the semester, whereas those below the line decreased their self-efficacy. The size of the dots indicate number of individuals.
In this case a Direct Oblimin rotation was performed, with the rotated solution presented in table 5. Examining the questions that loaded onto each factor, these were identified as ‘mastery of physics’, ‘ego orientation’, ‘interest in physics’, ‘laziness’ and ‘smartness’. A non-parametric correlation matrix (the ‘interest’ factor was non-parametric) revealed that the only significant correlation was between the ‘mastery’ and the ‘interest’ factors (Spearman’s $\rho = 0.28, p = 0.002$).

Each factor represents an underlying dimension (characteristic) of a person that cannot be measured directly. A factor is considered strong if it has at least four factor loadings $> 0.6$, thus the first three factors can be considered strong in this case. It is interesting to note that the questions were chosen with four factors in mind, based on previous work by Duda and Nicholls, but only one of these factors came out as expected, namely the ‘ego orientation’. The ‘mastery’ and ‘interest’ factors are both combinations of items belonging to the original ‘task’ and ‘cooperation’ orientations. ‘Mastery’ refers to an individual’s ability to solve problems and understand physics (whether in groups or by oneself). ‘Interest’ refers to the individual’s pure enjoyment of learning physics (with no particular end point in mind such as doing well in an exam), whether this is discussing physics in a group or learning physics individually. This indicates that physics students do not believe that either cooperation or individual work alone brings success, which is not surprising as both are important in the learning process. The original ‘work avoidance’ orientation showed up in the analysis as two factors. ‘Work avoidance’ refers to the concept of ‘minimum effort, maximum gain’, however, this applies to two types of students in the physics context: those who understand the material and those who don’t. The very brightest students will be able to do very well without working too hard simply because they understand the subject easily. They do not belong to the ‘work avoidance’ group as such, but should rather be referred to as ‘smart’. The other factor identified, called ‘laziness’, more closely resembles Duda and Nicholls’ (1992) ‘work avoidance’ orientation. From table 5 it is clear that students with a high laziness score are those who prefer to pass the course without doing the work themselves, eg. by copying assignments. Unlike the ‘smart’ students, the ‘lazy’ ones are not interested in actually learning the course material.

Once the factors were identified each student was given a factor score for each factor. This is a standardized score, ie. it has a mean of 0 and a standard deviation of 1. There are a few different algorithms that produce these factor scores, and the one used in this case is known as the Anderson-Rubin method (see Garbarino, 1996, for details). A factor score is simply the weighted sum of the products of a student’s answer to each item with the factor loading that item has on the factor. Comparison of means were tested among the persistent Map Meeters and the three comparison groups, using the Mann-Whitney test for the interest factor (as the data was non-parametric), and the t-test for all other factors (which were paramet-

![Fig. 10: Scree plot of the 20 goal orientations items identifying five factors.](image)

Table 5: Rotated pattern matrix with factor loadings for the five extracted goal orientation factors.
There were no significant differences with $p < 0.05$ when comparing persistent and non-Map Meeters, although the laziness factor showed a near-significant result with $p = 0.055$ ($x_{av, \, \text{persistent MM}} = -0.36, \text{SD} = 1.05, \text{N} = 23; x_{av, \, \text{non-MM}} = 0.11, \text{SD} = 1.02, \text{N} = 75$), as did the interest factor with $p = 0.066$ ($x_{av, \, \text{persistent MM}} = 0.27, \text{SD} = 0.96, \text{N} = 23; x_{av, \, \text{non-MM}} = -0.10, \text{SD} = 1.05, \text{N} = 75$). Comparing the means for persistent Map Meeters with those of the two comparison groups showed that the first comparison group was not significantly different with respect to any factors, whereas the second comparison group showed differences in the laziness ($p = 0.020; x_{av, \, \text{persistent MM}} = -0.36, \text{SD} = 1.05, \text{N} = 23; x_{av, \, \text{comparison group 2}} = 0.68, \text{SD} = 0.97, \text{N} = 8$) and the interest ($p = 0.026; x_{av, \, \text{persistent MM}} = 0.27, \text{SD} = 0.96, \text{N} = 23; x_{av, \, \text{comparison group 2}} = -0.30, \text{SD} = 0.58, \text{N} = 8$) factors. This might indicate that the Fundamentals course was too easy for the students with the strongest background in mathematics, resulting in a lack of interest in the course.

These findings support goal orientation as a potentially valid and reliable construct in the educational context since the conceptual basis of the items could be meaningfully interpreted within the university physics education context. At the same time, the differences in discipline areas are evident in the unexpected factors arising in this study relative to Duda and Nicholls’ (1992) study of high school students. This makes a strong case for discipline-based educational research.

### 4.4. Rankings

The questionnaires had five sets of questions which aimed to result in various rankings. Students were asked to indicate how well they agreed with several statements from Strongly Disagree (1) to Strongly Agree (5), which was converted to a 5-point Likert scale as described in section 3.3.2. The statements covered reasons for coming or not coming to Map Meetings, and the usefulness of Link Maps, Map Meetings, and the learning environments offered in the School of Physics.

Initially the student responses were analysed using multiple Wilcoxon-Sign-Rank tests. Most of the data did not pass the 1-sample Kolmogorov-Smirnov test for normality, which upon perusal of the responses to each individual question was primarily due to the data being strongly positively skewed towards the Strongly Agree end of the spectrum. When multiple Wilcoxon tests are run on the same data set it is important to control for the family-wise error, i.e. the cumulative probability that a null result is reported as being real. This is done by applying a Bonferroni correction, which requires that for a result to be considered statistically significant the $p$-value must be less than or equal to 0.05 divided by the number of tests performed on the same set of data (Field, 2000, p. 247). Clearly this reduces the statistical power of the analysis, which in this case resulted in a numerical analysis that did not reveal much relevant information at all.

The purpose of the analysis was to get an impression of why students did or did not attend Map Meetings, and which aspects of Map Meetings and Link Maps were useful. This information was intended to be used as a guideline for improving these study aids, as well as trying to separate the effect of the Link Maps from the other variables affecting the final exam mark. Since a solid numerical analysis would not add any value to the interpretation of the data, it was decided in presenting the results in this section to simply display the mean value of the student responses on bar graphs with error bars showing the 95% confidence interval of the mean.

Next follows a discussion of response to individual questions:

#### 4.4.1. Why did students attend Map Meetings?

From fig. 11 we see that the highest ranked reason students attended Map Meetings was to increase their confidence in physics, but there was also a significant number of students who came to one Map Meeting and found it useful, and thus decided to stay. Consequently, Map Meetings was an offer that attracted the keen students who were already hard working and therefore willing to spend yet another hour per week learning physics. This is in agreement with the sample description as the persistent Map Meeters had a significantly higher average UAI than the non-Map Meeters.
4.4.2. Why did students not attend Map Meetings?

There are two interesting things to note in the responses to this question (fig. 12). Firstly, 69% of the 78 students who answered this section of the questionnaire either agreed or strongly agreed to the statement that they could not make it to any of the four scheduled times for Map Meetings. This suggests that a higher proportion of the Fundamentals class would have been persistent Map Meeters had the Map Meetings been at convenient times for all students. The corresponding values for the first and second comparison groups were 74% (N = 14) and 71% (N = 7) respectively. Recall that the total number of students in these two groups are 40 and 19, so only (36 ± 1)% of the students responded to the questionnaire. This does not necessarily mean that the students were less studious than the persistent Map Meeters; all that can be concluded is that of those students who chose to return the questionnaire, the majority indicated that they did not come to Map Meetings because they could not make it to any of the scheduled times.

Secondly, on average, the students disagreed with all other statements suggested as reasons for why they did not attend Map Meetings. This suggests that most students did not come because they were unable to, rather than for some other reason. Lastly, of 22 students who had attended one Map Meeting but chose not to continue, only one agreed to the statement that they found it a waste of time, from which it can be concluded that Map Meetings were considered a valuable study opportunity.

4.4.3. The most useful learning environments for physics

There are three compulsory learning environments offered by the School of Physics as part of the Fundamentals physics course: lectures (3 hr/week), labs (3 hr/week), and workshop tutorials (1 hr/week). In addition, a set of review tutorials (1 hr/week) were offered at the end of the semester as part of a project to help students at risk of failing. The student responses (see fig. 13) show that lectures and Map Meetings were considered the most useful environments for learning physics. The workshop tutorials and review tutorials then follow, whereas students were neutral to the usefulness of labs for learning physics. This suggests that Fundamentals students find passive absorption of material delivered in a structurally coherent way by an expert the most productive way of learning. In terms of the proposed Link Theory the students at this stage have a very weak knowledge base in physics and need the help of experts to construct the initial scaffold in their knowledge structure. Once the overview has become more firmly established, individual work aiming to increase the knowledge within a certain (small) area (e.g. understanding Newton’s first law better) becomes more useful.
4.4.4. When Link Maps were useful

Only two significantly different groups of items separated out of the answers to this question (see fig. 14). All the alternatives offered were considered useful (averages ranged from 3.9 to 4.2 out of 5), but Link Maps were found most useful when studying the course material, compared to when doing assignments or during lectures, labs or tutorials. This is in agreement with the previous section, and supports the main aim of the Link Maps, namely that they are to aid the students’ personal construction (or internalization) of the overview of the subject which is essential to gain any real understanding of it.

4.4.5. What was useful about the Map Meetings?

As with the Link Maps, the most important thing to point out in fig. 15 is that the average response to the usefulness of various aspects of the Map Meetings was very high (mean ranging from 4.0 to 4.5), suggesting that no parts of the Map Meetings should be drastically modified in future implementations. From the general ranking it seems that the more directly exam related an item was, the more useful it was considered to be, i.e. active help with exam questions rated better than general recapitulation of course material which again was more valued than students working on problems themselves. Considering the exam is the main assessment of the course, this is not surprising. It is interesting to note that the Link Maps were considered the least useful part of the Map Meetings (however, still useful as the average rating was 4.0), indicating that the value of this project lies in the whole package of the Map Meetings, rather than being focused on just the Link Maps.
4.5. Various questions

The second questionnaire had 14 questions (Q6-13 and Q29-34, see appendix E) covering various areas such as gender differences and student opinions of physics and Map Meetings. The first set of questions was answered by all students whereas the second set was only to be answered by students who had attended Map Meetings. The analysis can be broadly divided into three categories: gender differences, physics in general, and Map Meetings.

4.5.1. Gender

Two questions were directly targeting the gender issue often faced in physics. Physics has traditionally been a strongly male dominated area of study. Today, 25% of physics students in the HSC (NSW Board of Studies, 2006), and 40% of the 1st year physics students at the University of Sydney (across three main units) are female, so the trend is changing. However, prejudice against women in physics is still documented (Barres, 2006). The Fundamentals physics class is an exception to the rule in that it is female dominated. Using the Mann-Whitney test splitting by gender only two out of the 14 questions showed any significant differences in means. The first one was the gender question “I think boys are generally better at physics than girls” (see table 6). Whether the male students had a neutral answer due to political correctness or personal views is impossible to say, but it is interesting to note that the female mean was lower. Unfortunately the question was somewhat poorly posed with an ambiguous zero, in that it is not clear whether a strongly disagree means that the student thinks girls are generally better than boys or that the genders are equal. Consequently, the question cannot be analysed too deeply beyond stating that the male students did not show any prejudice in their answers. Note that there was no difference in the responses to the statement “It is not uncommon that people think boys are better than girls at physics” when split by either gender or Map Meeting attendance. This question was devised to probe students perception of the general atmosphere in physics, and perhaps bring out personal views in a non-personal question, but this response was also neutral. The only other question that showed a difference in answer with respect to gender was “Physics is one of the most complicated subjects I have ever studied”. Females found physics more complicated than males, an attitude reflected in the numbers of female students in physics.

<table>
<thead>
<tr>
<th></th>
<th>Males N</th>
<th>Males Mean</th>
<th>Males SD</th>
<th>Females N</th>
<th>Females Mean</th>
<th>Females SD</th>
<th>Sig. Mann-Whitney</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think boys are generally better at physics than girls</td>
<td>32</td>
<td>3.06</td>
<td>1.22</td>
<td>69</td>
<td>2.43</td>
<td>1.04</td>
<td>0.015</td>
</tr>
<tr>
<td>Physics is one of the most complicated subjects I have ever studied (including high school subjects)</td>
<td>33</td>
<td>2.85</td>
<td>1.03</td>
<td>69</td>
<td>3.45</td>
<td>1.05</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Table 6: The two statements for which there was a difference in response when analysed by gender.

4.5.2. Physics in general

Students thought the Fundamentals physics course was somewhat harder than expected, but there was no difference when split by Map Meeting attendance. However, there were differences in several questions (see table 7). Persistent Map Meeters found studying physics more interesting than non-Map Meeters and whereas non-Map Meeters were somewhat positive to the statement “Physics is about remembering a lot of facts and equations”; the persistent Map Meeters were on the negative side. Also, persistent Map Meeters agreed more strongly with the statement “Physics is about linking a few fundamental ideas in several different ways” than the non-Map Meeters. The last two statements in particular indicate that one of the goals of Map Meeting was fulfilled, namely to let the students see that physics is about learning how to link a few different concepts in several different ways.
4.5.3. Map Meetings

There was a set of six questions only to be answered by those who had been to Map Meetings, and the response was very positive (see table 8). With a mean of 4.60 the persistent Map Meeters felt that “The maps clarified what the key concepts in physics are” and found the Link Maps a valuable study aid (mean = 4.52). Thus, the Link Maps can be considered to have been very successful in their aim as seen from the students’ viewpoint. Students also thought they would perform better in the exam due to their attendance at Map Meetings, and they had appreciated the atmosphere, feeling less intimidated in asking questions. When asked to indicate whether they thought Map Meetings should be compulsory, 66% (N = 94) of all students answered YES. Broken down by Map Meeting attendance, 75% (N = 24) of the persistent Map Meeters and 60% (N = 45) of the non-Map Meeters were positive to idea of replacing one hour per week of compulsory physics attendance with a Map Meeting (see table 7).

<table>
<thead>
<tr>
<th>Persistent Map Meeters</th>
<th>Non-Map Meeters</th>
<th>Sig Mann-Whitney</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>It is not uncommon that people think boys are better than girls at physics</td>
<td>24</td>
<td>3.50</td>
</tr>
<tr>
<td>Physics is about linking a few fundamental ideas in several different ways</td>
<td>23</td>
<td>3.96</td>
</tr>
<tr>
<td>Physics is one of the most complicated subjects I have ever studied (including high school subjects)</td>
<td>25</td>
<td>3.60</td>
</tr>
<tr>
<td>Physics is about remembering a lot of facts and equations</td>
<td>25</td>
<td>2.84</td>
</tr>
<tr>
<td>The Fundamentals physics course has been harder than I expected</td>
<td>25</td>
<td>3.72</td>
</tr>
<tr>
<td>I think boys are generally better at physics than girls</td>
<td>25</td>
<td>2.52</td>
</tr>
<tr>
<td>I appreciated the atmosphere in the Map Meetings</td>
<td>25</td>
<td>3.68</td>
</tr>
<tr>
<td>Do you think Map Meetings should replace one hour of lectures, labs or workshop tutorials?</td>
<td>24</td>
<td>1.25</td>
</tr>
</tbody>
</table>

* 1-tailed significance due to directional assumption

Table 7: Response to questions about physics in general, answered by all students.

<table>
<thead>
<tr>
<th>Persistent Map Meeters</th>
<th>Non-Map Meeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>I think the Maps are a valuable study aid</td>
<td>25</td>
</tr>
<tr>
<td>The maps clarified what the key concepts in physics are</td>
<td>25</td>
</tr>
<tr>
<td>I think I will do better in the exam because I went to Map Meetings</td>
<td>25</td>
</tr>
<tr>
<td>It was less intimidating to ask questions in the Map Meetings</td>
<td>25</td>
</tr>
<tr>
<td>It made a positive difference that the teacher was female</td>
<td>25</td>
</tr>
<tr>
<td>I appreciated the atmosphere in the Map Meetings</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 8: Descriptive statistics of the response from persistent Map Meeters to statements about Map Meetings.
4.6. Short answer questions

Fifty one students who had attended at least one Map Meeting answered one or more of the short answer questions, and the general response was very positive. A large number of students expressed their appreciation of the simplicity of how topics were covered in Map Meetings. One of the key ideas behind the design of both Link Maps and Map Meetings was to minimize the cognitive load on the students by presenting only the essential information required to gain an overview of the topic covered that week. Based on the student response, this aim was successfully achieved.

Response to ‘What made Map Meetings worth coming to’: “Simplified and condensed information in a much simpler language that was easy to understand. The diagrams and explanations for each rule helped explain what the key points were. The links [in the Link Maps] helped show relationships between concepts.”

“As a student who have never studied physics before, attending these meetings truly made physics easy.”

The Link Maps themselves were often quite colourful and attempted to make clear the connection between concepts within each map as well as across maps. Even though the maps were rigidly structured around the fundamentals, the researcher still had substantial freedom in her construction of the maps regarding how the weekly topic was presented. Her most important personal guideline was that it showed the information in the clearest and most concise way possible, which meant that maps could look quite different (see appendix C). Students did not seem to be confused by this lack of consistency, and indicated that the maps indeed served their intended purpose.

“Link Maps were very useful for linking the physics equations together, making it visual in colour. This technique was very useful for me to memorize most of the equations, and made it easier to understand the logic behind.”

“Use of concept mapping was good because it allowed different topics within physics to be linked together.”

It was also important to the researcher to respect how difficult most of these students thought physics was. One consequence of this was that each Map Meeting functioned as a condensed mini-lecture completely covering the essence of the weekly topic, without requiring the students to remember what had been covered in lectures. This did not prejudice against students who were already struggling in lectures, and thus gave a valuable confidence boost to those who realized that what they had not understood in lectures did not reflect on their personal incompetence since they were able to follow the material the second time it was covered. As one student put it:

“[Map Meetings] brought together a lot of muddled lecture info in a simple summary.”

“Map Meetings helped us go through things instead of just expecting us to understand all the hard stuff we’d done.”

By covering only the essential areas of the various topics in the Fundamentals course the persistent Map Meeters over time realized that, although they may not have understood all the details and examples in lectures, they could still manage to gain a good overview of the physics taught. This is likely to have played the most important role in maintaining the self-efficacy of the persistent Map Meeters, supported by student statements:

“I’m pretty sure I will pass... I’m just not very confident with myself - you gave me confidence.”

“Map Meetings are really good. Now I have a confidence with physics. Thank you!”

This confidence was not brought on simply by the Link Map and the topic review alone; the exam practice
the students got in Map Meetings was rated as the most useful aspect of the meetings. Even though the Map Meetings presented topics in a simple and easy to understand way, the exam questions the students worked on in the second part of the Map Meetings were quite complex, providing valuable exam practice. When the researcher worked through the questions in the last part of the Map Meetings, she not only gave the students the correct answer, but tried to show them how to logically attack a seemingly complicated problem if they were at a loss as to where to start. The solution handouts were written in a similar way. This method is often not emphasized in lectures, but was very well received by the Map Meeters.

“The problem solution handouts (…) helped me learn how to think logically before I attempt answering the question.”

“Knowing that we could actually work exam questions out made me a lot more confident with physics.”

The students also commented on the positive atmosphere in the Map Meetings and the friendliness of the researchers. Apart from making the Map Meetings more inviting, students felt less intimidated to ask simple questions and thus increased their own learning by receiving answers to something they did not understand.

“I was a lot more comfortable asking questions than in tutorials where the teachers seem a lot less open to less intelligent questions.”

Students also found it very helpful to cooperate with their peers in the problem solving session. This was similar to the peer cooperation in workshop tutorials (Sharma et al. 1999), except that only the keen students attended Map Meetings and thus perhaps had a more positive attitude than the average student in workshop tutorials.

“Discussing questions as a small cooperative group [made Map Meetings worth coming to]. Tutorials are not working for me because people in my group are not cooperative.”

When asked how Map Meetings could be improved, the main response was to have more or longer Map Meetings, possibly with homework given out each time.

In summary, the qualitative response is in agreement with the quantitative response, in that students were very pleased with all aspects of the Map Meetings and considered them a great help for learning physics and increase their confidence with regards to the final exam.

4.7. The final exam

4.7.1. Total exam mark

Of the 244 students that were at some stage part of the fundamentals class, 217 sat the final exam. The average exam mark for the whole class was 50.4 (SD = 16.9) out of 90. Considering the individual groups, the persistent Map Meeters had a mean of 57.7 (table 9) compared to the non-Map Meeters who achieved a mean of 48.9 (SD = 17.0). Since the academic background of the persistent Map Meeters was only known for 19 of the 32 students, an independent samples t-test with respect to exam mark was performed on the students for which academic background was known versus those for which no background information was available. There was no statistically significant difference (t = 0.58, df = 29.8, p = 0.57, equal variances not assumed), so the persistent Map Meeters were considered to be a homogeneous group.

To evaluate the effect of the intervention, it was much more relevant to compare the persistent Map Meeters with the two comparison groups. From fig. 16 it is clear that the persistent Map Meeters did significantly better than the first comparison group with similar background, confirmed by an independent samples t-test with equal variances assumed (t = 2.95, df = 69, p = 0.004), while being on par with the second comparison group. The fact that the persistent Map Meeters, who did not have a particularly strong mathematics background, performed comparably with the 4-unit maths students is a remarkable achievement.
Although a statistically significant difference was detected between the persistent Map Meeters and the first comparison group, the t-test does not give any indication of whether the difference is large enough to be of importance. The magnitude of the effect is estimated by calculating the effect size, $d$ (described in Minium, King, & Bear, 1993, pp. 364-366) given by

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

where $\bar{x}$ is the mean and $s$ is the standard deviation. Cohen (1988) has suggested that “small, medium, and large effects may be defined as corresponding to values of $d$ of 0.2, 0.5, and 0.8, respectively.” The effect of the intervention when comparing the two groups with similar academic backgrounds was calculated to be 0.72, which is considered a relatively large effect.

The workshop tutorials, offered by the School of Physics for 1st year students since 1995, provide a good comparison with Map Meetings. They also run one hour per week throughout the semester in a non-stressful environment where students work on problems in small groups, and tutors are available to help. The effect sizes in final exam marks measured by Sharma et al. (1999) for attendance at workshop tutorials were $d = 0.25, 0.45, and 0.15$ for Regular, Technological, and Environmental streams respectively. The low-attendance group comprised students who had attended less than half of the tutorials during the semester (between 8 and 13 tutorials were offered in total depending on stream), while the high-attendance group were the remaining students. By dividing the classes into two groups instead of three (as was done with the Map Meeters) one would expect the effect size to be somewhat smaller for the workshop tutorials than for the Map Meetings. On the other hand, since the tutorials are time tabled, the low attendance group consists of students who chose not to come to tutorials, unlike several of the students in the first comparison group in this study who were unable to attend Map Meetings. Due to this factor, one would expect there to be a larger difference between the two workshop tutorial groups, since they (at least to some degree) reflect student commitment to their studies. However, the effect size for the Map Meetings is significantly larger than those achieved by the workshop tutorials, making a very strong case for the effectiveness of the Map Meetings.

<table>
<thead>
<tr>
<th></th>
<th>Persistent Map Meeters</th>
<th>Comparison group 1</th>
<th>Comparison group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>32</td>
<td>40</td>
<td>19</td>
</tr>
<tr>
<td>Mean</td>
<td>57.7</td>
<td>48.8</td>
<td>59.5</td>
</tr>
<tr>
<td>SD</td>
<td>10.5</td>
<td>14.0</td>
<td>16.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>36</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Maximum</td>
<td>80</td>
<td>70</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 9: Descriptive statistics of the three different groups in the final fundamentals exam.

Fig. 16: Mean total exam score for the persistent Map Meeters and the two comparison groups.

Fig. 17: Pie charts displaying the final grades awarded the persistent Map Meeters and the students in the two comparison groups.
It is interesting to note the spread in exam marks for the different groups as well, reflected both in the standard deviation and the range. The persistent Map Meeters show the smallest standard deviation and the highest minimum mark (see table 9), and a frequency analysis showed that 18% of the entire class received a lower mark than the poorest persistent Map Meeter. The same analysis carried out only on the 97 students with UAI ≥ 90 revealed that 9.3% of these students got fewer marks than the poorest Map Meeter in the final exam.

The final grades received by the persistent Map Meeters and the two comparison groups tell the same story as the exam mark (fig. 17) (the exam counts for 65% of the final grade, the remaining 35% are assignments, lab attendance and lab exams). Note first and foremost that none of the persistent Map Meeters failed, a feat not seen in any of the comparison groups. Also, 19% of the persistent Map Meeters received either a distinction (D) or a high distinction (HD), compared to only one student in the first comparison group who achieved a distinction.

The results of the analysis of final exam marks show that the persistent Map Meeters performed very well. Not only did they achieve an impressive mean score, but the spread in scores around the mean was lower than in any other group, reflecting consistency in the strong performance. An obvious question to ask is whether this is primarily due to the intervention or simply because the self-selected group of persistent Map Meeters studied harder. The response would be to remind the reader that the persistent Map Meeters and the first comparison group had the same backgrounds with respect to UAI and mathematics, the most commonly used predictors for performance in 1st year physics exams. There were even four students (10%) in the comparison group who had done physics in the HSC, which would be expected to make this group somewhat stronger than the persistent Map Meeters. No difference was found between the groups in self-efficacy at the beginning of the semester, and it is not unreasonable to expect that this reflects similar motivation in the students as they performed comparably in the highly competitive HSC. Consequently, all available predictors of exam performance failed to show any difference between the two groups. Yet, a remarkable difference was observed in final exam performance.

In summary, this strongly suggests that the Map Meetings had a significant effect, and calls for further investigation to unambiguously establish this fact.

4.7.2. The exam broken down by questions

The exam questions can be categorised into seven topics, most of which had two questions each in the exam (one qualitative and one quantitative) (see table 10). The course (and the Map Meetings) covered the topics in the succession given.

When comparing the mean values of the marks awarded for each question between the persistent Map Meeters and the two control groups some clear patterns emerge. Comparison group 2 was consistently better than comparison group 1 as expected, except in one question (see question E12, fig. 18). The persistent Map Meeters, however, changed from performing worse than comparison group 2 (but somewhat better than comparison group 1) in the first two topics, to being reasonably close to comparison group 2 in the next three topics, and then performing much better in the last two topics. This follows the trend of the Map Meetings. The first two topics were the ones worst covered as Map Meetings were still under construction. Even

<table>
<thead>
<tr>
<th>Qualitative question (10 marks)</th>
<th>Quantitative question (5 marks)</th>
<th>Covered in Map Meeting in week</th>
<th>Exam question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buoyancy</td>
<td>√</td>
<td>2</td>
<td>1 &amp; 7</td>
</tr>
<tr>
<td>Linear motion</td>
<td>√</td>
<td>4 &amp; 5</td>
<td>2 &amp; 8</td>
</tr>
<tr>
<td>Rotational motion</td>
<td>√</td>
<td>8</td>
<td>4 &amp; 9</td>
</tr>
<tr>
<td>Energy and work</td>
<td></td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Linear momentum</td>
<td></td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Simple harmonic motion and waves</td>
<td>√</td>
<td>11</td>
<td>5 &amp; 11</td>
</tr>
<tr>
<td>Travelling waves</td>
<td>√</td>
<td>12</td>
<td>6 &amp; 12</td>
</tr>
</tbody>
</table>

Table 10: Overview of topics covered in Map Meetings and the exam.
though problems were given for the topic linear motion, none of these were previous exam problems. The next three topics were covered in what was to be the standard Map Meeting format. By the time of the last two topics the structure of Map Meetings had been settled and both students and teachers were comfortable with this. Thus, when broken down by questions the exam supports the positive effect of the intervention even more strongly than when simply considering the exam mark on the whole.

A very surprising result was that the two exam questions which were identical to questions solved in Map Meetings, were not the ones the persistent Map Meeters performed best on (exam questions E3 and E4, fig. 18). Question E6, on the other hand, was a qualitative question on thin film interference (appendix F) which the persistent Map Meeters had not been given any problems on (appendix D, Map Meeting #10, week 12). This specific type of interference had not been discussed in the Map Meeting, but the Link Map did have a careful explanation of the basic ideas behind interference, namely superposition of waves and the concept of phase. Seemingly, by gaining a thorough understanding of these two concepts, the students were well equipped to fill in the smaller details themselves and display an understanding of thin film interference in the exam. This strengthens the claim that the persistent Map Meeters did not do better in the exam just because they had solved similar questions before; the Map Meetings truly helped them gain a better understanding of the topics on a more fundamental level.

4.8. Multiple regression

A multiple regression analysis was attempted to identify the predictor variables for the final exam mark. Possible predictors were HSC mathematics, biology and chemistry mark, as well as UAI, the five different goal orientations, self-efficacy score, gender, and number of Map Meetings attended. Multiple regression requires that the predictor variables are not too highly correlated, so for any set of variables that show a significant correlation, one of the variables need to be removed. In this case, the HSC subjects all showed significant correlations with UAI, and so were removed. There were some inter-correlation within the different goal orientations, and none of them showed any significance in the final regression at any stage, so they were removed one by one. Eventually, the only three possible predictor variables left were UAI, gender and
total attendance at Map Meetings, and both of the latter two showed significant correlations with UAI. As the goal of the analysis was to establish the effect of Map Meeting attendance while controlling for several other variables, UAI in particular, this could not be done using multiple regression due to the large amount of inter-correlations. As a successful multiple regression would not contribute much to the overall analysis of the effect of the intervention, the issue was not pursued further.

4.9. Summary of results

This section will answer the specific objectives posed in the preface. The type of students who took advantage of the Map Meetings were students who had performed well in the HSC, indicating that they were dedicated students willing to commit themselves to another hour of physics study per week. None of the persistent Map Meeters had done physics in high school, and they indicated that the main reason for attending Map Meetings was to increase their confidence with regards to the subject. Several students also reported that after having attended one Map Meeting, they found it useful and thus decided to stay. Unfortunately, a large proportion of the class were unable to attend due to time table clashes. A larger proportion of the class could have been expected to attend Map Meetings had these been offered at times available to all students.

Two interesting results emerged out of the data on self-efficacy. Firstly, the average self-efficacy of the persistent Map Meeters did not change from the beginning to the end of the semester, whereas it did for the non-Map Meeters. The latter group experienced a statistically significant decrease in self-efficacy, reflecting a decrease in the students’ belief in their own ability to do physics as the course progressed. Since a low self-efficacy can negatively influence exam performance, such a trend is unfortunate and deserves more attention.

The second interesting result was that although the average self-efficacy of the persistent Map Meeters did not change, analysis showed that students who displayed a very low self-efficacy early in the semester had increased in self-efficacy by the end of the semester, whereas those who had a very high self-efficacy on the pre-test showed an opposite trend by decreasing somewhat in self-efficacy, although still remaining fairly confident in their own abilities. Thus, all persistent Map Meeters ended up being fairly confident, but not over-confident, that they would be able to do well in the exam according to their own expectations.

Twenty questions targeting various goal orientations adapted to a physics context from the more general environments of ‘classroom’ and ‘sports’ were analysed by factor analysis. Clear factors were obtained, but they were not the same as for the environments from which they were adapted. This indicates that the concept of goal orientations is a potentially valid and reliable construct within the physics context, while being unique to the subject, making a strong case for discipline based research. The factor scores were analysed for the persistent Map Meeters and the two comparison groups. The first comparison group was not statistically significantly different to the Map Meeters with respect to any factors, strengthening the assumption that these groups can be considered as equivalent. The second comparison group, however, was shown to score higher on the ‘laziness’ factor and lower on the ‘interest’ factor compared to the persistent Map Meeters, at the \( p < 0.05 \) significance level.

The general student feedback on the Link Maps and the Map Meetings were very positive, with Map Meetings considered to be the most useful environment, together with lectures, for learning physics. None of the main components of the Map Meetings were considered superfluous, reflected in the mean response to the usefulness of these ranging from 4.0 - 4.5 out of 5. The usefulness of Link Maps were rated similarly, with mean scores ranging from 3.9 - 4.2. By the end of the semester the persistent Map Meeters saw physics as a subject which linked a few fundamental ideas in different ways, rather than focusing on rote learning equations, statistically significantly more so than students who had not attended Map Meetings. The persistent Map Meeters also emphasized in their qualitative response how they had appreciated the friendly and relaxed atmosphere in the Map Meetings, and had felt much less intimidated to ask questions than in class, another factor fostering constructive learning of fundamental concepts. Solving old exam problems in class gave the students confidence and regular feedback as to their own knowledge level with respect to what would be expected in the exam. The researcher’s explanations on the board of how to logically attack a seemingly complex problem helped the students develop logical problem solving strategies themselves.
summary, the Map Meetings were successful in providing a coherent but varied learning environment for the Map Meeters, based on both quantitative as well as qualitative feedback.

When comparing the average final exam mark of the persistent Map Meeters (57.7) with the comparison group with similar background (48.8), they were found to clearly outperform their peers ($p = 0.004$, effect size $d = 0.72$). In fact, they performed comparably to the comparison group (59.5) composed of those Fundamentals students who had completed 4-unit maths in the HSC, a group which is generally considered to be the strongest in the class. Also impressive was that the lowest exam mark obtained by the persistent Map Meeters (36) was considerably higher than the lowest mark of any of the comparison groups (21 and 22). This was reflected in the fact that none of the persistent Map Meeters failed the exam, whereas 5 out of 40 students (13%) in the first comparison group failed. When analyzing the exam by questions, it was found that the persistent Map Meeters performed better relative to the two comparison groups the later in the semester the topic was covered. This was independent of whether a similar question to the exam question on the topic had been solved in class or not. These findings are strong result suggesting the effect of the intervention, as the quality of the Map Meetings increased throughout the semester since they were continually under improvement.

4.10. Strengths and weaknesses of the study

The lack of randomly sampled treatment and control groups was an unfortunate, but unavoidable issue due to ethical considerations. It is not necessarily a severe weakness, however. Study aids are, as the name implies, aids only. There will always be students in a class who spend an absolute bare minimum amount of time studying, and if the intervention does not show an effect on these students it does not necessarily reflect on the intervention, but rather on the students. In that respect, by providing an authentic setting, it became clear that it was the students with relatively high UAIIs (the most high achieving students) who chose to take advantage of the study aid offered. The selective choice of two comparison groups allowed appropriate analysis to be carried out, which strongly suggested a positive effect of the intervention on the treatment group.

A clear strength of the study was the diversity of the measurement instruments. The questionnaires provided several different types of feedback, from information on students’ personal attitudes towards physics in general, to direct feedback on Map Meetings and Link Maps. The exam, on the other hand, was a direct measure of student understanding of physics. All feedback agreed on the positive effect of the intervention.

Lastly, the study adds to the body of literature on concept maps, self-efficacy, goal orientation theory, and on variables influencing students with little prior knowledge of physics.
A decade of reflection on my own learning and various teaching experiences has resulted in a prototype theory of learning, called Link Theory. From this I developed Link Maps, a study aid targeting the specific challenges and issues students usually face when studying physics. The aim was to help students not by focusing on details, which is often the approach in lectures, but by focusing on students gaining a good overview of the subject.

Link Maps were trialled in semester 1, 2006, in the School of Physics with the Fundamentals class. These are students with little or no prior experience with formal physics instruction, who were invited to participate in this project. The treatment group was thus self-selected, but for a preliminary study of this size, this was the only ethical option.

The Link Maps were implemented through weekly Map Meetings, a hybrid between lecture and workshop tutorials. Students were carefully introduced to the weekly map through a 10-15 min ‘review lecture’ in which the researcher built up the map step by step to clarify the information it contained. Next, the students worked in small groups to practice using the map in problem solving, some of them exam problems. The Map Meeting was concluded with the researcher solving some selected problems on the board, clearly drawing the students’ attention to the use of the Link Map in the process.

The effect of the intervention was measured by two different means: two questionnaires handed out at the beginning and the end of the semester to the whole Fundamentals class, and the final exam. The questionnaires were designed around constructs pertinent to learning and teaching. Those targeting students own learning revealed that by the end of the semester the persistent Map Meeters saw physics as a subject linking a few different ideas in different ways. It was not just about remembering facts and equations. In this they were statistically significantly different to non-Map Meeters. The intervention also appear to have had a positive result on the students’ self-efficacy compared to the non-Map Meeters. The persistent Map Meeters found all aspects of the Map Meetings and the Link Maps useful, suggesting that no drastic changes are required in the format of either of these. In the short answer questions the students reported Map Meetings as helpful for understanding the lecture material, working with peers, and learning how to logically attack seemingly complex problems. This gave them the skills and the confidence to pass the exam.

The results of the final exam were impressive. The persistent Map Meeters obtained an average exam mark of 57.7 out of 90, nine marks higher than for the first comparison group with similar background. This result was not statistically significantly different from the seemingly better prepared second comparison group who had done 4-unit maths in the HSC. The persistent Map Meeters were also more consistent in their strong performance. This was reflected both in the smaller standard deviation in mean exam mark, in the high minimum mark, and the achievement that none of the persistent Map Meeters failed, a feat not equalled by either of the comparison groups. Analysing the exam by questions it was found that the persistent Map Meeters did progressively better compared to the comparison groups on topics covered later in the semester. Although I cannot unambiguously claim a causal relationship, this seems to reflect how the Map Meetings were continually improved throughout the semester. The lack of correlation between exam questions solved in Map Meetings and achievement on questions in the final exam, suggests that the students gained a better understanding of physics in Map Meetings, not just experience with specific questions.

Based on the two measurement instruments, the effect of the Link Maps and the Map Meetings is considered very successful. This also gives credence to Link Theory, the theoretical background for the Link Maps, encouraging further development. A true experiment with randomly chosen participants would provide less ambiguous results as to the effect of Link Maps and Map Meetings. This is a likely avenue to explore during a PhD project, focussing on further development of Link Maps as well as on Link Theory. To satisfy ethical requirements this will most likely be done by integrating the Link Maps with the existing lecture course in one out of the two or three streams in the Fundamentals and Regular courses. This will allow investigation of the usefulness of the Link Maps when they are not associated with extra contact hours, as well as testing their effect on a larger variety of students, from the most to the least studious. It also allows for proper control groups. Implementation into the Regular course will test the usefulness of Link Maps on students who are not complete novices. Further work on Link Theory would require other study aids or teaching strategies to be developed and trialed to support the various aspects of this theoretical foundation.
**Bibliography**


Appendix D: Map Meeting material

Most Map Meetings contain one map, a problem sheet, and a solution sheet.

Map Meeting plan
Reflective journal
The fundament sheet
Week 2: Buoyancy (with Symbols and units map)
Week 3: Pressure
Week 4: Kinematics
Week 5: Kinematics (no map)
Week 6: Newton’s three laws (with Vectors and scalars map)
Week 8: Rotational motion
Week 9: Energy
Week 10: Momentum and collisions
Week 11: Oscillations
Week 12: Waves
Week 13: Waves
Appendix A: Information sheet and ethics approval

Information sheet for Map Meetings
Ethics approval
Appendix F: The final exam

THE UNIVERSITY OF SYDNEY

FACULTIES OF ARTS, EDUCATION & SOCIAL WORK,
ENGINEERING AND SCIENCE

PHYS 1002 PHYSICS 1 (FUNDAMENTALS)

JUNE 2006

Time allowed: THREE Hours

MARKS FOR QUESTIONS ARE AS INDICATED
TOTAL: 90 MARKS

INSTRUCTIONS
• All questions are to be answered.
• Use a separate answer book for section A and section B.
• All answers should include explanations in terms of physical principles.

DATA

Density of fresh water at 20 °C and 1 atm $\rho = 1.00 \times 10^3$ kg.m$^{-3}$
Free fall acceleration at earth's surface $g = 9.81$ m.s$^{-2}$
Speed of sound in air at 20 °C and 1 atm $v = 330$ m.s$^{-1}$
Speed of light in vacuum $c = 3.00 \times 10^8$ m.s$^{-1}$
Appendix E: The questionnaires

Questionnaire 1
Questionnaire 2