A CASE STUDY OF UNIVERSITY STUDENTS' EXPERIENCES OF INTRODUCTORY PHYSICS DRAWN FROM THEIR APPROACHES TO PROBLEM SOLVING

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor Philosophiae in the Department of Physics, University of the Western Cape.

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To David Brookes
who taught me to be a teacher

KEYWORDS

Phenomenography

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Institutional, physical and personal context of learning

Relevance structure

Spatio-temporal distribution of knowing

Students' problem-solving strategies

Approaches to introductory physics problem-solving

Students' intentions and conceptions of problem-solving in introductory physics

Introductory physics learning as convention or constituting understanding

ABSTRACT

A CASE STUDY OF UNIVERSITY STUDENTS' EXPERIENCES OF INTRODUCTORY PHYSICS DRAWN FROM THEIR APPROACHES TO PROBLEM SOLVING

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This thesis explores the experience of learning physics through a particular medium: problem-solving, which is seen by many educators as the primary medium in which physics is learnt at university. Situating itself within two theoretical perspectives: phenomenography and actor-network theory, the dissertation explores the variation in the ways of experiencing introductory physics learning through problem-solving. Phenomenography, which is the main theoretical framework, places emphasis on the variation of experience of a phenomenon at a supra-individual level. Learning is regarded as relational, which means that the act of learning is apprehended (in terms of *how* the learning is done as well as *what* is learnt) in the relation between the learner and the phenomenon. Rather than regard the *content* of physics learning as the phenomenon, the study proposes the *process* of learning physics through problem-solving as the phenomenon under investigation. The thesis draws on insights from actor-network theory, particularly with regard to the spatiality of learning. Learning is seen as a function of enrolment.

Fifteen students were interviewed on introductory physics problems encountered in four end-of-module tests. The data were analyzed on the basis of *strategy* - conceived as "moments" of problem-solving, as well as the factors (intentional and contextual) that could be seen to influence the strategy adopted. Two qualitatively distinct problem-solving strategies were identified, deriving from the relative presence of reflective awareness. Further, factors influencing the strategies were identified and found to be indicative of two qualitatively distinct ways in which the students focused on the problems - either on problem content (the physics concepts) or on problem requirement (the formal requirements of the task within the test setting). These findings are seen to constitute the structural aspect of the students' experience of physics learning through problem-solving. With regard to the referential aspect of the experience, the study derives two overall meanings that the students attached to their experience of physics learning through problem-solving, namely physics learning as "reconstituting understanding" and physics learning as "confirming convention".

It is argued that the variations identified in the strategies employed by the students, in the ways they focus on problems, in their perception of the problem-solving settings, in the meanings they attach to physics learning through problem-solving – call for a framework of learning that takes account of spatio-temporal intricacy. The notion of conceptual understanding in the learning of physics should be informed by the specific demands of the medium of problem-solving through which physics is learnt at undergraduate level

December 2001

DECLARATION

I declare that *A case study of university students' experiences of introductory physics drawn from their approaches to problem solving* is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Busisiwe Precious Alant

December
2001

Signed:………………….

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CHAPTER 1

BACKGROUND TO THE STUDY

1.1 Introduction

Redish and Steinberg (1999:24) argue that physics instruction should move away from considering "what are we teaching and how can we deliver it" to contemplating "what do students learn and how do we make sense of what they do". This shift in emphasis in physics education research, supported by many education research groups (for example at the universities of California, Göteburg, Lancaster, Massachusetts, Maryland, Surrey, Washington, Western Cape), pave the way towards the realization that in order to address students' learning difficulties in physics, a stronger emphasis should be placed on the students' experiences of learning physics. With regard to an interpretative framework, which could guide investigations into the different aspects of learning, the Göteburg research group has particularly focused on the importance of both the "what"[i] and "how"[ii] aspects of students' learning in programmes aimed at maximizing what students learn in the long term. An understanding of "how students respond to teaching, how they tackle the everyday demands of learning and studying, what difficulties ... they encounter" (Hounsell, 1984:189) can bring us closer to an understanding of what it means to learn in higher education.

Over the years, the tendency in physics education research has been on much needed, and indeed significant, work aiding our understanding of how physics students conceptualize various topics covered in a physics curriculum. Relatively few studies have focused on the relational aspect of physics learning. In other words, the exploration of what it means "to learn physics", looked at from the perspective of the students in the context of a specific learning experience, remains a relatively uncharted territory (Booth and Ingerman, 2000; Waterhouse and Prosser, 2001).

It is the aim of this research to focus on one of the taken-for-granted media through which undergraduate physics is learnt, i.e. problem-solving, and to explore the meanings that this experience of learning physics through problem-solving has for first year physics students at the University of the Western-Cape, South Africa. The study focuses on problem-solving in physics, yet it is not a conventional study of problem-solving. It does not seek to characterize the "cognitive processes" involved in problem-solving, nor does it seek to find out what makes some students more "efficient" problem-solvers than others. In fact, it is not primarily the intention here to explore students' understanding of physics concepts. Rather, the study seeks to explore the chief *medium* through which physics learning and teaching occurs: problem-solving, and to determine the ways in which the students relate this medium to their experience of learning physics. In other words, it is the students' experiences of the medium in which physics is learnt that this study hopes to explore.

Even if it is not the main aim of the study to explore how students understand physics concepts, this does not mean that students' understandings of physics concepts will play no role in the study. Students' understandings of physics concepts inform how they solve problems, and problem-solving provides a particular window through which students' understandings of physics concepts can be ascertained.

Problem-solving not only takes up a large part of university physics courses, but there is an assumption that students learn physics through doing problems – that successful problem-solving implies an understanding of physics concepts. Yet the relation between conceptual understanding and problem-solving is frequently – notably in the reality of the university physics course - more ambiguous than is generally assumed. This study seeks to explore the nature of this often uneasy relationship, as manifested in the experience of the university physics learner.

1.2 Personal background to the study

To situate the study I need to draw on my own experience as a physics learner. In March 1999, I registered for the course Physics 1 at the University of the Western Cape (UWC). I soon came to realize the prominence of problem-solving within the physics course. In fact, whatever "progress" I was making in my learning of physics was being evaluated constantly through my ability to solve problems - given as homework, as assignments, and in tests. It became evident that in order to "succeed" in the physics course I had to learn to become successful in problem-solving.

Before 1999, I had spent two years doing a first and second year course in "Conceptual Physics". Conceptual Physics had been introduced at the University of the Western Cape in the early 90's. Concerned with the qualitative exploration of physics ideas, the course was aimed, broadly speaking, at providing students with experiences they could use as a basis for making hypotheses related to physics phenomena in their daily lives. In other words, it emphasized the idea that physics phenomena were things that informed people's experiences; people participated in making sense of physics phenomena.

I thought the background that I had gained through two years of Conceptual Physics would provide me with a "flying start" in Physics 1. The reality was totally different. The concept of participation in sense-making that characterized Conceptual Physics was now replaced by the experience of physics learning as a verification or demonstration of a "frozen"[iii] physics content. In this sense, the outcome of what is to be learnt was predetermined by the objectives presented at the beginning of every new topic that was covered. Knowing what we were supposed to learn did not in any way make me understand the work any better. Given the time constraints associated with university learning which places enormous limitations on engaging in any exploratory discussions of new concepts and their understanding, my involvement in the process of learning physics seemed to be reduced to the application of the content of physics. Moreover, this application of physics content was always in a particular context predetermined by a physics problem.

We were initiated into first year physics learning via the model of imitation which aimed at familiarizing us with the disciplinary tools of physics. After a concept had been introduced, problems were selected from the prescribed text. The lecturers solved one or two problems on the board while we copied the problem-solving method. Even in other learning contexts, such as the tutorial and study groups, most of the students duplicated the lecturer's way of solving the problem. Those who were able to solve the problems set in the tests were awarded good marks (I was not always one of them). In the process, the need to solve the problems often appeared greater than the need to understand the physical laws and their relations, although the skill of problem-solving and the understanding of physical laws were assumed by the lecturers to be manifestations of each other.

Where Conceptual Physics had encouraged students to integrate principles conceptually, I soon noticed, in my association with the other students in the Physics 1 class, that the idea of linking things up did not seem to be high on their list of priorities. Getting through the course was their main priority and they were prepared to do so through whatever means they could. I was determined to find the link between what I was doing in class and the outside world - even if it meant being left behind. I had comparatively little pressure on me, unlike the other students in class who had to pass Physics 1 in order to gain entry into either Pharmacy or Dentistry. It became evident that even though I attended the same lectures and did the same work, my goal in learning physics was different from those of the other students in the class. My expectations of learning physics were different.

This insight had profound implications for my own research project on the learning of physics, which by mid-1999 had gradually begun to take shape. I realized that the data that I needed to collect would somehow have to be a collection of things that the students did that were different from what I was doing myself. I kept notes on observations I made in the lectures, in the tutorial sessions and in the laboratory sessions. These observations were crucial for the formulation of the research questions in this study.

1.3 Rationale of the study

My broader experience as a physics student in the context described above contributed to the formulation of the research project. In my own reflections on this experience – as well as in the discussions I had with the other students and staff members in the Physics Department at UWC - the following elements offered themselves as particular areas of investigation:

- my experience of learning physics – and how it seemed to be different to that of other students;
- the differences between myself and other students with regard to the reasons why we were doing the physics course. I was a post graduate Education student with an interest in physics learning; the other students were mostly first year students who required Physics 1 in order to proceed with their undergraduate degrees;

- the centrality of problem-solving within the Physics 1 course, and its ambiguous relation with the idea of "linking things up" (understanding). The lecturers seemed to assume this relation to be clear; many students, on the other hand, clearly regarded the ability to solve a physics problem as something distinct from – and also more important than – say, the ability to explain the physics ideas involved in the physics problems; and

- the fact that some of the spaces (settings) in which the students came into contact with physics seemed to be more closely associated with the idea of understanding than other settings. Of particular interest was the lecture. The lecture was to a large extent presented – by lecturers *and* students! - as the setting where the lecturers provided the students with a "map" which the students would (maybe) make sense of in their own time – somewhere else.

As these questions – stemming from my experience as a physics student - were becoming more apparent, Cedric Linder and Delia Marshall[iv] introduced me to phenomenography. I was by now keen that my doctoral project should provide some kind of "diagnosis" of the first year Physics course, to enable the lecturers to be confronted with – and better understand - what students *really* "take out of physics lectures". As Ramsden points out, "a relational perspective does not look for elegant general laws of learning, but for guiding hypotheses about typical conceptions and approaches that will help teachers convey particular subject matter in certain educational circumstances" (Ramsden, 1988:28). I was particularly impressed by the fundamental importance of *variation in the ways of experiencing* enjoyed within phenomenography, and the systematic way it provided to make sense of the bewildering array of elements that constitute the experience (including my own) of learning. At the same time, I was committed to exploring the learning of physics, not as a field of learning for its own sake, but the learning of physics within the real-life university environment in which I found myself[v]. This preoccupation meant that my study was to concern itself with what was, in my own experience, the chief characteristic of physics in the Physics 1 course, namely problem-solving. And problem-solving was not some "concept"; it was what physics students *did*. But of course, problem-solving was also *how students learnt physics* - or at least how they were supposed to learn physics. My study was about the relation between the aim of the Physics 1 course, physics learning, and its main instrument, problem-solving.

As a point of departure from other studies into student problem-solving with undergraduate students (see section 2.3.2), I have followed a phenomenographic orientation (see section 2.2) to develop the two research questions used in this investigation. The aim of these research questions is to draw extensively upon students' experiences at a collective level in a way not done before to contribute to the understanding of the nature of the learning which first year undergraduate physics students experience through problem-solving.

Research Question 1: What are the qualitatively different ways (strategies[*]) in which first year physics students go about solving introductory physics problems?

Research Question 2: What factors influence the strategy adopted by first year physics students during problem-solving?

Let me, at this point, state what I mean by "experience" – at least in a phenomenographic sense. As would be further discussed in Chapter 2, phenomenography is concerned, less with experience "in itself", than with *variation in the ways of experiencing*. As such, it addresses experience at an essentially collective (supra-individual) level (Marton, 1981). The following four aspects: discernment, variation, contemporaneousness and simultaneity, provide

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[*] With regard to the meaning of strategy versus approach see glossary of terms, pg 1617.

the basis upon which the qualitatively different ways of experiencing can be understood (Marton and Pang, 1999:6). Discernment relates to awareness, which is always awareness of something (an object). In other words, there is "focal awareness". Discernment, however, cannot take place without variation, in the sense that focal awareness is awareness - not of an object as such, but, rather, of the extent to which that object is *different*. The object is focused upon (experienced) *in its variation*. Contemporaneousness refers to the fact that a way of experiencing is *bounded in time* (Marton, 1993). It is, quite literally, a snapshot – an "eternal present". Simultaneity, on the other hand, refers to the potentially relational nature of discernment, which consists of parts related by their *simultaneous* discernment.

Simultaneity, in fact, highlights a particular complexity (of experience), which is most relevant to the present study. Marton and Booth (1997:113) state, "Different aspects or parts of the whole may or may not be discerned as objects of focal awareness simultaneously". They argue, furthermore, that in cases where certain relevant aspects of the object of focus are not in focal awareness, these aspects may be experienced consecutively: "It is generally the case that some ... [objects of focus] are abstracted, separated, isolated. Instead of them being objects of focus simultaneously, they may be separated and experienced one after the other, in sequence. This tells us that certain ways of experiencing are more complex or fuller than others" (Marton and Booth, 1997:113).

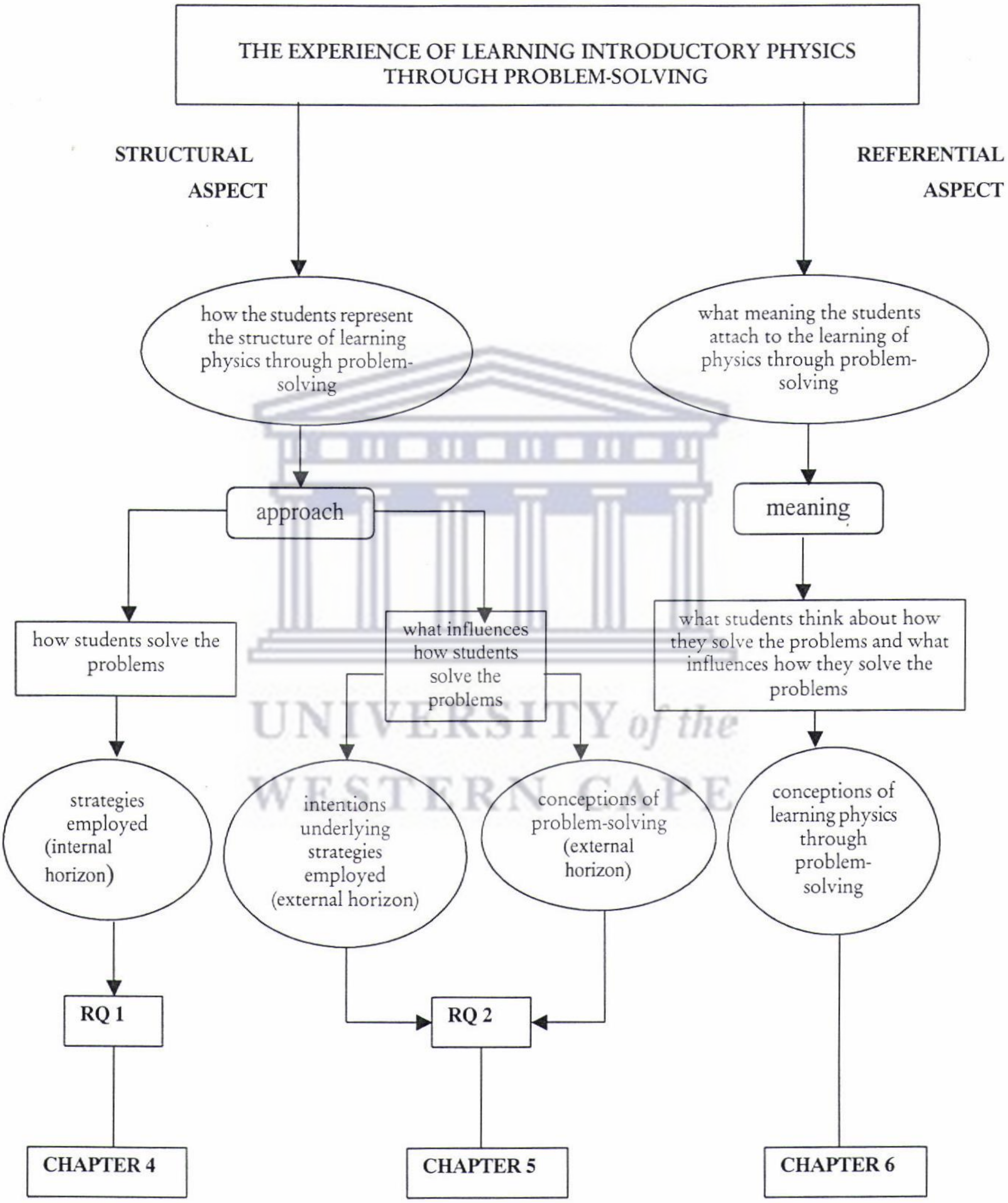
This study explores the *experience of learning physics*. It does not look at the experience of learning physics directly, however, but as *mediated* by problem-solving. This orientation brings about exactly the kind of complexity that Marton and Booth refer to in the passage quoted above. When doing a problem, students are not dealing with only one question, but with a variety of questions. The introductory physics problem tasks used to probe first year physics students' experience of learning through problem-solving are multi-faceted in that they would often refer the students to other questions and to other aspects of solving the problem. In other words, the students' way of focusing on the problem (their ways of experiencing) would to some extent be induced. In the problem tasks dealing with the application of Newton's laws (Modules 1 and 2 tasks), for example, students are explicitly required to draw a free-body diagram. This requirement would constitute, within the larger question, its own point of focus and its own experience. It would therefore be impossible to refer to "the problem" - (and students' ways of experiencing it) - without giving account of the myriad experiences already woven into it. It is indeed this fluctuation of the students' focal awareness during problem-solving that placed a major challenge on the analysis of data.

Another aspect of the experience that I need to highlight, is the phenomenographic notion of structural and referential aspects of a way of experiencing. The aim of an empirical phenomenographic study is to describe the qualitatively different ways in which the students interpret some given phenomenon under investigation. The results obtained in this manner make up the categories of description which represent characterizations of the different ways of experiencing. The "outcome space" is the end-result of the logical and empirical relations within and between the categories of description. Structural aspects are those relations that are projected "towards" the object of focus, while referential aspects are "about" it. In this research project, the structural aspects relate to the students' *approach* (followed in solving introductory physics problems), while referential aspects relate to the overall *meaning* attached to the approach. This analytical distinction of a way of experiencing learning introductory physics through problem-solving is presented in Figure 1 on page 11.

There is a further distinction to be made. The structural aspect (in this study: problem-solving) can in its turn be analytically divided - into what is known as *internal* and *external horizons* (Marton and Booth, 1997:87-88). "Internal horizon" refers to the object of focus (in this study: the physics problem) – the parts of the problem - how different parts of the problem are discerned, how they relate to one another, and how they make up the whole. "External horizon" refers to how the experience is related to the context (and possibly to other contexts as well) *in relation to* its meaning. An important analytical distinction must be stressed at this point. The "meaning" uncovered in the exploration of the external horizon (as part of the structural aspect of the experience of learning physics through problem-solving), is not, at the level of phenomenographic analysis, the same "meaning" as that of the *referential* aspect of the experience of learning physics through problem-solving. The latter (referential) meaning is the "overall" meaning, relating to an approach to learning. The former, on the other hand, presents itself at the level of the problem (the problem-solving strategy). Crucially, the same analytical distinction applies when defining the "object of focus" of this study. At the level of the structural aspect (as revealed in the internal horizon), the object of focus is, as indicated earlier, the (parts of the) problem. Yet at the referential level - which is also the level reflected in the title of the study: the experience of learning physics through problem-solving - the object of focus of the study is *physics through problem-solving*. (The interrelated nature of the understanding of physics concepts on the one hand and problem-solving on the other was emphasized earlier – see section 1.1).

The *structural* aspect of students' experience of learning physics through problem-solving is covered by the two research questions. Research Question 1, which addresses the students' problem-solving strategies, relates to the object of focus of the structural aspect (the problem), while Research Question 2 (addressing intentions and conceptions of problem-solving), relates to the meaning of the object of focus of the structural aspect (see Marton and Booth, 1997:91-94). The referential aspect – the meaning "overall" of students' experience of learning physics through problem-solving - is not addressed directly as a research question, but is fully the subject of Chapter 6, where it is derived in light of the findings of the research questions (which cover the structural aspect).

Figure 1. Schematic representation of the experience of learning introductory physics through problem-solving



1.4 Outline of the study

The study consists of five chapters in addition to the introduction. Chapter 2 is the theoretical framework, which elaborates the perspective underpinning the study, phenomenography. Adopting a phenomenographic perspective to explore students' experiences implies focusing not just on *what* students learn but *how* students learn. A further dimension of phenomenography that is important to the study is its emphasis on *variation* of experience.

Another research perspective that this study draws upon is actor-network theory. Actor-network theory is particularly appropriate to this study because of its interest in contextual effects of learning. Students insert themselves in the power relations of the discipline in various ways, which are expressed in the notion of *enrolment*. Adopting actor-network theory, with its emphasis on spatiality, implies abandoning the traditional view of the individual learner, and replacing it with a view whose unit of analysis is "situated spatially and temporally" (Nespor, 1994:7).

The study blends phenomenography and actor-network perspectives, in so far as it studies the experience of the learning of physics, not from the point of view of the individual, but from the point of view of the phenomenon (object of focus). In addition to providing a broad theoretical perspective for the study of physics learning through problem-solving - on the basis of phenomenography and actor-network - Chapter 2 also gives a brief review of some of the major approaches in problem-solving research in physics, drawing attention to the fact that this research is not of a relational nature, but rooted in cognitivist (representational) epistemology. Constructivism (both individual and social) and information processing receive attention.

The merging of phenomenography and actor-network perspectives does not only have theoretical consequences for the study but is also important from a methodological point of view. Chapter 3 sets out the research method implemented in the exploration of the two research questions. It motivates the interview method used, as well as the selection criteria of the research participants, which were established by means of a pilot study. Chapter 3 further provides insights into the structure of the interview (including how the interview related to other settings of physics learning), and provides, finally, the categories of description used in the analysis of data of both research questions.

Chapter 4 presents the results of Research Question 1. Given the interest of the study in what students *do* during problem-solving, the strategies used by the students are the main focus of this chapter. Two main strategies are identified and are referred to as Strategy A and Strategy B. The differentiation between Strategy A and Strategy B is made on the basis of certain "moments" identified during the problem-solving activity. The findings of the study indicate that the moments of *scanning* and *translation* occur in the strategies of all the students, and that a third moment, referred to as *re-interpretation*, occur in the strategies of a limited number of students. The strategies inclusive of the moment of re-interpretation are categorized as Strategy A and strategies limited to the moments of scanning and translation are categorized as Strategy B. The two strategies denote two qualitatively different ways in which first year physics students go about solving introductory physics problems.

Chapter 5 presents the results of Research Question 2. After providing a description of how the students use the different spatial settings of problem-solving they have been exposed to (for example the lecture, the test, the tutorial and high school), the chapter focuses on the different ways in which the students integrate the spatial influence into their intentions and conceptions of problem-solving. Actor-network theory, with its emphasis on the notion of enrolment, is particularly relevant in this context. Two primary tendencies are identified, as far as factors influencing students' problem-solving are concerned. Two primary tendencies are identified, as far as factors influencing students' problem-solving are concerned. These tendencies correspond to two qualitatively different ways in which the students focus upon the given introductory physics problem tasks, either by focusing on the problem *content* or on the problem *requirement*.

Chapter 4, dealing with Research Question 1, and Chapter 5, dealing with Research Question 2, reflect the *structural* aspect of the students' experiences of learning physics through problem-solving, Chapter 6 provides the *referential* aspect of this experience. In other words, Chapter 6 examines the meaning that students attach to learning physics through problem-solving.

1.5 Description of terms used in the study

Throughout the thesis several terms are used with a particular meaning in mind, which need to be explicated. The order in which the terms are described is logical rather than alphabetical.

PHENOMENOGRAPHY: it is "the study of the qualitatively different ways in which people experience and conceptualize the world around them. The experiential perspective is one of the basic features, various aspects of reality and various phenomena are described in terms of the differing ways in which they appear to people." (Lybeck, Marton, Strömdahl and Tullberg, 1988:85)

ACTOR-NETWORK THEORY: is normally juxtaposed with the sociocultural theory of Lave and Wenger (1991). Sociocultural theory, like all relational approaches, emphasizes the intrinsic link between human action and the context within which the act occurs. Although both the actor-network theory and sociocultural theory emphasize the relational aspect of educational practices, sociocultural theory stresses linkages within "communities of practice", whereas the actor-network moves "beyond the bounds of the community" (Hepburn, 1996:28). Actor-network portrays human action in terms of the efforts of an explicitly distributed and spatialized network of entities whose linkages to one another are seen as ongoing accomplishments. Quoting Callon[vi], Nespor defines an actor-network as "simultaneously an actor whose activity is networking heterogeneous elements as well as a network that is able to redefine and transform what it is made of" (Nespor, 1994:13).

DIALECTIC EPISTEMOLOGIES: At the core of the arguments raised within dialectic epistemologies is the rejection of the Cartesian dichotomy that puts a "demarcation between the inner subjective and the external objective realms" (Cawthron and Rowell, 1978:43). Kuhn (1970) argues that within dialectic epistemologies the socio-psychological factors are no longer at the periphery of the scientific process but constitute its core. The recognition of the socio-psychological nature of knowledge manifested in collective consciousness implies that we seek a unit of analysis that moves away from the psychology of the individual consciousness (as espoused in cognitive psychology), and shifts towards a "psychology beyond the individual" (Marton, 1990).

EDUCATION AS A SPACE-TIME PROCESS: According to Nespor (1994), seeing education as a space-time process implies that we take a different view in dealing with the processes of cognition and learning. The model of learning as an activity that takes place "within individuals' heads" is challenged. The perception of individuals as gradually building up "integrated capacities, composed of attitudes, rules, schemata, domain knowledge, contextual models, etc.", which can be "carried around, called up and deployed as needed in specific contexts" is discarded (Nespor, 1994:7). Research interests focusing on "individual's mental representations of the task" no longer suffice (Nespor, 1994). In other words, learning theories based on research developments in cognitive science become largely irrelevant.

KNOWLEDGE ACQUISITION: from a phenomenographic perspective, knowledge acquisition is regarded as a man-world relation. It comes to us through the experience of the world-phenomena relationship (Marton & Booth, 1997). This implies that knowledge is not fixed, but is constituted in the ways an individual "experiences a phenomenon and in the ability to interconnect appropriate experiences in a meaningful way".

CONCEPTUALIZATION: this is a term used to broadly reflect how someone sees, visualizes, thinks about, understands or makes sense of experiences and phenomena. It is not meant to represent some structure in a person's mind; rather it is a qualitative description of a person-world relationship. Conceptualizations are the characterization of descriptive categories of peoples' explanations.

CATEGORY OF DESCRIPTION: a descriptive category of explanation, which characterizes a conceptualization; it is an interpretation of another person's interpretation.

OUTCOME SPACE: the union of a set of categories of description; an abstract space made up of categories of description "in which individuals move -- more or less freely -- back and forth" (Marton, 1984:62).

STRATEGY: In physics problem-solving literature a distinction is made between a *strategy* and an *approach*. A strategy refers to both qualitative and quantitative steps followed by the problem solver in the resolution of a problem. When talking about students' strategies, I am referring to the "moments" characterizing both the qualitative and quantitative procedures employed by the students.

APPROACH: refers to a *way of thinking about the problem*. Booth (1992) provides two ways in which we can look at the term approach. Firstly, it refers to the overall strategy (whether it is consciously adopted or not) that the student reports to have employed. Secondly, the word approach is used to refer to the initial response that the student gives when confronted with the problem. In other words, it refers to the "best first guess" as to *how* to proceed in the creation of a problem solution (Bodner, 1990). In this study, as is shown in Figure 1, *approach* encompasses the students' strategies *as well as* the influencing factors underlying them.

APPROACH TO LEARNING: the term approach to learning was used by Marton instead of "the level of processing" to avoid mechanistic overtones. Inherent in Marton's use of the term are both *intention* and *process*. Intention relates to what the learner is looking for, and process relates to how that intention is carried out (Entwistle and Marton, 1984:215).

RELEVANCE STRUCTURE: It relates to what is called for to make sense of things, and to the criteria by which some parts of the phenomenon under study are seen as more (or less) relevant.

CHAPTER 2

THEORETICAL FRAMEWORK

2.1 Introduction

This chapter demarcates the theoretical perspectives relevant to this study. The main theoretical perspectives drawn upon are phenomenography and actor-network theory. Section 2.2 situates the study within phenomenography, which is briefly described in the light of certain key concepts: "insider's perspective", "dialectic", "relational", "what" and "how" aspects of learning. The next section provides a review of previous work on the question "how do we gain knowledge about the world". This question, fundamental to phenomenography, brings into focus other (cognitivist) perspectives on learning that have attempted to answer it. In particular constructivism - as formulated by two chief protagonists, Piaget and Vygotsky as well as information processing are discussed. In section 2.4, phenomenography is revisited and discussed in depth, with particular emphasis on its fundamental concern with "ways of experiencing" and "structure of awareness". The phenomenographic dichotomy of a "deep" versus "surface" approach to learning is considered, as well as the implications of a relational approach to learning physics. Factors influencing physics learning are the subject of section 2.5. These factors are considered under the broad categories of familiarity (relevance structure), intention and enrolment. It is at this point that actor-network theory is brought into the discussion. This theory is of importance to the study, in that it reinforces the phenomenographic concern with spatio-temporal dimensions of learning through its emphasis on the question of *enrolment* and institutional / disciplinary context. In this regard, section 2.6 explores the implications of seeing education and hence learning as a "spatio-temporal" process.

2.2 A brief overview of the phenomenographic perspective

This study is about first year physics students' experience of learning physics through problem-solving. A phenomenographic perspective was used in this investigation, which implies a particular way of looking at learning in terms of method and epistemology. From the point of view of method, phenomenography is concerned with what Marton (1981) terms an "insider's perspective" of what the learner is trying to achieve within the process of learning. An insider's perspective (Marton, 1981) is a "second order perspective" which means that our concern is primarily focused on how the *learner* construes the world.

The rationale behind this type of research is the acknowledgement that people act on their interpretation of the situation they find themselves in (Säljö, 1988:36). This is an acknowledgement of the *dialectic* nature of the human-world relation. Phenomenography shares this approach with other research perspectives, such as individual and social constructivism (Säljö, 1988).

Dialectic does *not* mean dualistic. From an epistemological point of view phenomenography explicitly rejects the dualistic treatment of the learner's experienced reality in terms of an "inner" and an "outer" world. The insider's perspective that the phenomenographic method uncovers is not about the "inner world" of the learner, but about how the learner sees her relation to the world. Through its description of students' conceptions, the phenomenographic method brings to the fore "the student's externalization of his or her relation to the learning task" (Ramsden, 1988:20). As such, a conception of a particular phenomenon is not regarded as something that is inside the individual, but as something "*between* the student and the task or the concept" (Ramsden, 1988:20. Emphasis mine). This *relational* perspective has important implications with regard to learning. Learning is not seen as a process taking place "inside an individual's head", but as a relation between the individual and the learning task (phenomenon).

A relational exploration of learning implies that we focus on both the "how" (structural) and "what" (referential) aspects of learning. According to Säljö, the *how* aspect concerns "the general strategies of studying that students use, all the way from their overt behaviour such as when and for how long they study, if they use underlinings or summaries, etc., to the covert activities such as their approaches to learning, i.e. their way of thinking while learning, their attempts to relate what they read / hear to what they already know ... ". The w*hat* aspect of learning "concerns the central issue of how students interpret and comprehend what they encounter in teaching and learning" (Säljö, 1988:5). Both aspects of the relational investigation are equally important: *how* something is learnt is as important as *what* is learnt (Prosser and Millar, 1989:514).

This work adopted a relational perspective in order to explore the relation between the structural aspect (how) and the referential aspect (what) of the experience of learning physics through problem-solving. The referential aspect, which is the subject of the discussion in Chapter 6, relates to the overall meaning that the students ascribe to the research questions (strategies, intentions / conceptions). The structural aspect of the experience can be further divided into internal horizon and external horizon") (Marton and Booth, 1997:87-88). The *how* aspect is covered by Research Question 1, and constitutes the "theme" of awareness. By *theme* is meant the object of awareness. In this study, the theme refers to the physics problems and the principles / concepts / algorithms involved in solving them. In other words, the theme of awareness denotes the strategies with which the students solve the problems. The *what* aspect is covered by Research Question 2, and constitutes the "thematic field". The thematic field refers to "those aspects of the experienced world that are related to the object and in which it is embedded" (Marton and Booth, 1997:98). In this study, the thematic filed consists of those spatial and temporal factors that have a bearing on the students' strategies, as reflected through their intentions and conceptions of problem solving. The research questions are:

RQ. 1: What are the qualitatively different ways (strategies) in which first year physics students go about solving introductory physics problems?

RQ. 2: What factors influence the strategy adopted by first year physics students during problem-solving?

In section 2.4 phenomenography and its implications for this study will be discussed in detail. But for now it seems appropriate to review briefly cognitivist perspectives on learning.

2.3 Cognitivist perspectives on learning

2.3.1 Constructivism

Empiricists emphasize the cause-effect relationship (Cartesian dichotomy) between the "knower" and the "known". This distinction implies a dualistic dichotomy between "mind and matter" or "organism and environment". Knowledge exists "out there" and is taken in "ready-made" from the environment[vii] (Marton and Booth, 1997:6). Constructivism provides an alternative explanatory framework for this "inner" and "outer" dichotomy (Marton and Booth, 1997:13), through its insistence that the human being constructs her knowledge through being internally predisposed towards it. Different emphases exist within this framework. "Nativists" argue that the structures with which we make sense of the world (i.e. nature) are innate, whilst "radical" constructivists regard our understanding of the world as constructed within "experience-mind" interaction (Fuller, 1982). Glasersfeld (1984:22) defines radical constructivism as follows:

> Radical constructivism breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience.

The perspective offered by the radical constructivists projects a view of nature as "an open system – always inviting us to understand its works in different ways as we transform our sensory data through ever *evolving mental structures*" (Fuller, 1982:47. Emphasis mine). Radical constructivism is closely related to individual constructivism, which grew out of the work of the Swiss psychologist, Jean Piaget.

2.3.1.1 Piaget's individual constructivism

Piaget's epistemology is based on what Cawthron and Rowell (1978:52) call a "biologically based conception of the inseparability of organism and the environment". Piaget treats the "individual" and the "physical world" as being mutually adapted to one another through evolution. The notion of a "passive copying of reality" (Cawthron and Rowell, 1978:52) by the individual (as held in empiricism) is contested by Piaget. For Piaget, reality is acted upon and perceived in terms of performed actions. In other words, the individual subject is "an extricable part of the reality which she or he constructs" (Cawthron and Rowell, 1978:54). The move from the traditional positivist (empiricist) position on the relationship between the "knower" and the "known" towards Piaget's dialectic epistemology marked a break from previous understanding of human cognitive development.

The insight that human understanding of the world is constructed in the *experience-mind* interaction is significant in addressing the question of how we come to know something or come to acquire knowledge. Human cognitive functioning is expressed as a dynamic "assimilation-accommodation-equilibration" interaction (Fuller, 1982:47). This model is seen as the mental equivalent of the "homeostatic process" (the process of self-regulation) that takes place in living systems. Human understanding is presumed to tend toward a similar state of equilibration. As Fuller puts it, "if our experience does not match our understanding", disequilibration is certain to result (Fuller, 1982:47). If disequilibration results, the process of "organizing and re-arranging" of one's understanding becomes imperative. This disequilibration occurs every time individuals encounter counter-intuitive experiences. In educational theory, this understanding has given rise to the belief that in order to develop reasoning in students they "need to be puzzled by their own experiences". This approach is particularly evident in the literature addressing conceptual change and learning through metacognition (see Posner *et al.*, 1982; Baird, 1986). In this regard, the notion of the individual learner as the "key participant in learning" (Shapiro, 1989) is of cardinal importance.

At the core of Piaget's epistemology is the concept of internalization. Internalization refers to the "lateral scaling down of imitative movements" (Cawthron and Rowell, 1978:53), which produces internal images and schemes. The internal mental structure assimilates the real event and accommodates it to its specific features. Although Piaget sees the inner – outer relation as a *dialectic*, he clearly emphasizes the pre-eminence of the "inner" within it (Marton and Booth, 1997:12).

2.3.1.2 Vygotsky's social constructivism

As already mentioned, constructivism looks at the creative involvement of individuals in the act of learning and knowledge construction. In my view, where Piaget has been particularly associated with individual (radical) constructivism (Bettencourt, 1993:44), the Russian psychologist L. S. Vygotsky has contributed particularly to the notion of social interaction in the construction of knowledge. His terms "cognitive apprenticeship" and "enculturation" are especially interesting in this regard.

Vygotsky believes in the primacy of culture in shaping development (Howe, 1996:37). For Piaget maturation is the central factor in development, for Vygotsky it is the social world. Vygotsky's view is that knowledge develops through appropriation of culture - through social interaction between the child and more competent individuals. One element in the appropriation of culture is the development of the ability to use societally developed tools, especially language, for mediating intellectual activity (Gautreau and Novemsky, 1996). The ability to mediate intellectual activity can only be acquired through the individual's interaction with others who are more able, such as relatively advanced peers and teachers. Roth sees this process of *enculturation* in the fact of growing up in a particular society and learning its sign system - language - and other culturally determined behaviours and patterns of communication (Roth, 1993:147), hence "cognitive apprenticeship".

In the Vygotskian perspective the psychological processes of learning are seen as inextricably linked to social activity. This implies that learning is seen as an activity that takes place "between the individuals in a social group rather than solely within the individual" (Gautreau and Novemsky, 1996:18). Although Vygotsky considers teaching and nurturing to precede development, he recognizes a "zone of proximal development" and "sensitive periods" within which instruction is most feasible and productive (Gautreau and Novemsky, 1996:18). In this regard, he comes very close to the Piagetian view. He sees the conversion of learning processes into internal developmental processes to occur within these states. We can sum up the difference between Piaget and Vygotsky as follows: where Piaget describes human cognitive development in terms of an internal structure, Vygotsky regards its driving force as mainly external - embedded in the instruction the individual receives from others (Howe, 1996). Within the inner–outer dialectic Piaget sees the "inner" as pre-eminent. Vygotsky, on the other hand, stresses the "outer". In this sense, Piaget (individual constructivism) and Vygotsky (social constructivism) are "mirror images" of one another (Marton and Booth, 1997:12).

2.3.2 Cognitivist perspectives on problem-solving

2.3.2.1 Information processing: an expert centred approach

From an epistemological point of view, information processing can be said to derive from both the empiricist and the rationalist perspectives (Marton and Booth, 1997). As mentioned earlier (see sections 2.3.1 and 2.4) empiricism relates to the notion that knowledge exists "out there", unrelated to the knower. Rationalism (within which constructivism falls) relates to the knower having some kind of internal organizing principle by which she acquires knowledge. This issue is particularly important as far as problem-solving is concerned, for it implies that students will solve problems on the basis of internal schemata[viii].

According to Capra information processing was born out of the interplay between research on the logic of the brain and von Neuman's analogy between the brain and the computer. The hypothesis developed was that human intelligence resembled the processing unit of a computer, leading to the cybernetics' model of the brain as a logical circuit with neurons as its basic elements. Capra (1997:66-68) argues these basic elements - which are discrete - to be the means by which the human nervous system processes information. The process of cognition therefore involves the cognitive system "picking up" these discrete elements which presumably already exist in the outside world. As was pointed out above, this perspective perpetuates the traditional empiricist-inductivist view of cognition. It is a mechanistic view which considers what we know to be the result of the process of "imprinting" of external events in our mind.

To determine individuals' abilities to solve problems, researchers correlated the individuals' performance in problem solving with how well they remembered the information and how they organized it in order to complete each of the steps leading to the solution. In this way, researchers identified "good" task analysis skills in problem solving, which subsequently led to the distinction between "expert" and "novice"[ix] problem solvers (Good and Smith, 1987). Realizing the difficulties encountered in identifying the exact processes involved in expert problem solving, information processing research increasingly alluded to the "tacit" nature of expert knowledge, regarded as essential for "good" problem-solving (Reif, 1982:4). According to Reif, this recognition of the expert's tacit knowledge had a significant impact on the design of instructional models.

Taking into account the difficulties involved in identifying the exact "processes" involved in problem-solving, the focus of problem-solving research on human cognitive functioning shifted from the naturalistic to the prescriptive. According to Fuller (1982), the focus of problem-solving research shifted from descriptions of human cognitive functioning in order to understand it, towards prescriptions of how to *improve* problem-solving. Problem-solving research now targeted human cognitive performance with a view to making it more *effective*, which led to the design of systems exploiting person-computer interaction (Reif, 1982:4).

2.3.2.2 Information processing: towards a learner centred approach to problem-solving

In his overview of research on problem-solving in physics, Maloney questions the extent to which the expert centred approach (expert versus novice) has contributed to our understanding of "how to help students learn to solve problems" (Maloney, 1994:350). How do we make students better problem solvers? Good and Smith respond as follows: "Accurate diagnosis – in teaching as in medicine - must be the first step toward a cure" (Good and Smith, 1987:34). Good and Smith advocate a naturalistic rather than a prescriptive approach to problem-solving which, through the adoption of the kind of "insider's perspective" discussed above (see 2.2), concentrates on what students learn from problem-solving.

Another research study that emphasizes the naturalistic approach to students' problem-solving, is that of diSessa (1993). Rather than describe students' problem-solving or knowledge structures in terms of conceptions inherently inconsistent with expert knowledge, diSessa focuses on the naturally acquired "sense of mechanism" and how it develops towards expert knowledge. His work differs from novice-expert research in that it sees the characterization of students' knowledge systems as primarily important - rather than problem-solving processes as such. Since students are able to "construct" new understandings based on "current knowledge", there must be aspects of this knowledge that are useful for such construction (diSessa, 1993:175). If students' knowledge elements were appropriately organized, they could contribute to (what is regarded as) expert understanding of physics. diSessa consequently challenges the presentation of students' attempts as "a collection of preformed goals" (diSessa, 1993:176) that somehow predetermine what they do in problem-solving - as asserted in expert-novice and constructivist literature.

2.4 Learning as experience

While both Piaget and Vygotsky embrace a dialectic view of learning, the dialectic remains essentially *dualistic*, in that it depends on the notion of representation[x] (Marton and Booth, 1997:9). The same holds true for the perspectives on problem-solving discussed under information processing. The idea of knowing through mental representation is associated with all "cognitivist" epistemologies. Phenomenography is critical of this dualism:

> In order to combine the insights originating from these two camps [individual and social constructivism] that relate to our question 'How do we gain knowledge about the world?' one has to transcend the person-world dualism imposed by their respective focus on what is within the person and what surrounds her (Marton and Booth, 1997:12).

Phenomenography does away with the divide between the inner world of the *knower* and the outer world of the *known*, and treats them as one. Uljens (1996:112) argues that there is no need a "third party" to "evaluate the relation" or "bridge the gap" between the outer and the inner world - as the Piagetians would have us assume. According to the phenomenographic perspective, the individual does not understand the outside world by somehow remaking it internally, but by rather being fully aware of her participation in the human-world relation. In other words, the individual *experiences* the world (Marton and Booth, 1997). Knowledge comes to us through the experience of the human-world relationship. This implies that knowledge is not fixed, but is constituted in the ways an individual "experiences a phenomenon and in the ability to interconnect appropriate experiences in a meaningful way" (Marton and Booth, 1997). A phenomenographic perspective on learning will therefore pay close attention to the *change* in the individual's experiences of the phenomenon.

Phenomenography's main concern is, however, not with individual experience as such. Given its insistence on experience, phenomenography pays particular attention to *variation* – variation in the ways of experiencing the world. "Although one way of experiencing something in a particular case has to be seen in relation to the structure of the individual's awareness, we are above all interested in variation" (Marton and Booth, 1997:108). This variation of experience is seen, not so much as variation of an individual's structure of awareness, but as *dimensions of variation* of experience of the world (Marton and Booth, 1997:108). The totality of individual awareness constitutes the totality of the ways in which the world (phenomenon) is experienced. It is from the latter point of view that variation is presented as *experience of variation*. Marton and Booth put this concern as follows:

> To understand the variation in experience we have to understand the *collective anatomy of awareness* ... This is a shift from individual experience that varies as to focus and simultaneous awareness of aspects of a phenomenon to a *collective awareness*, in which all such variation can be spied (Marton and Booth, 1997:108-109 Emphasis mine).

2.4.1 The phenomenographic theory of awareness

According to Marton (1993), "knowing that we know" is of no consequence, seeing that we are always "aware of something". Cognition, therefore, does not require a representational status. What is regarded to be of significance, however, is the fact that we are not always aware of the same thing. Some things are in the foreground while others are receded into the background (Marton and Booth, 1997).

This view of consciousness is close to that of Gestalt psychology. The term *gestalt* is defined as an ensemble of items that mutually support and determine one another (Pong, 1999:3). Gestalt theory is put forward in support of the idea that for whatever we experience, we perceive a significant whole (a gestalt quality) that is discernable from its surroundings. The gestalt quality exists within a "relevance structure of awareness" which is bounded in and by time (Marton, 1993:236). This conception of awareness is particularly important insofar as it problematizes the notion that the individual learner's awareness is, by nature, stable. In its fluctuation between fore- and background, awareness is subjected to and dependent on time.

Various factors are likely to influence awareness. This insight is of particular significance for the development of Research Question 2 (see Chapter 5). Uljens (1996:9) mentions that, in being conscious of the fact that one is reading, one is always simultaneously aware of "what", "why" and "where" one is reading. Marton states the following:

> Awareness has a particular structure as far as the theme [of awareness] is concerned. The theme appears to the subject in a certain way; it is seen from a particular point of view. The specific experience (or conception) of a theme – or of an object can be defined in terms of the way in which it is delimited from, and related to, a context and in the ways its component parts are delimited from and related to each other, and to the whole (Marton, 1993:10).

In other words, we change our focus of awareness for different reasons, continuously "deciding" what will be conceived as figural and what will be seen as background (Uljens, 1996:9). The word "discernment" is used to describe the process by which certain elements of experience are either foregrounded (i.e. are in focal awareness) or receded into the background.

The theory of awareness sees awareness as being constituted of both a "structural" and a "referential" aspect. The "what" and "how" aspects of learning discussed earlier (see 2.2.) relate to this distinction: structural – how; referential – what. The referential aspect refers to the idea of discernment, in the sense that in order to experience something in a particular way, its total meaning has to be *discerned from its context*. The structural aspect refers to the idea of the delimitation of the parts of the experience and their relationship to and within the whole (Marton and Pang, 1999: 5-6).

A further distinction - of particular relevance to this study - can be made at this point. The structural aspect of an experience may be divided into an "internal horizon" and an "external horizon". The internal horizon refers to relations *within* the phenomenon, while the external horizon refers to relations linking the phenomenon to aspects *external* to it. The two research questions posed in this study give account of this distinction. Research Question 1, relating to the problem-solving strategies employed by the students, refers to the internal horizon, while Research Question 2, relating to factors influencing the strategies employed, refers to the external horizon (see section 4.1).

The following aspects are regarded as fundamental to understanding the ways of experiencing a particular phenomenon:

- discernment (of critical aspects of the phenomenon);
- variation (of experience);
- contemporaneousness (relating to experience always being bounded in time); and,
- simultaneity (depending on discernment, the same aspect may or may not be in focal awareness at a given point in time (Marton and Pang, 1999:6).

2.4.2 A phenomenographic perspective on learning: the deep versus surface approach

Most phenomenographic studies on physics learning have used Marton's categorization of a "deep" and a "surface" approach to learning. This study, however, has placed its investigation at a slightly different level. Rather than addressing the matter of learning *approach* (relating directly to Marton's categorization), the two research questions in the study respectively refer to problem-solving *strategies* (Research Question 1) and *factors influencing* the strategies (Research Question 2). As will be seen in the analysis (Chapters 4 and 5), different tendencies were observed with regard to both issues. With regard to Research Question 1, students were seen to use different strategies on account of their degree of reflection (re-interpretation) of the problem, while with regard to Research Question 2, students were seen to "focus" on the problem tasks in different ways depending on the particular (contextual) factors at issue.

The deep versus surface dichotomy, therefore, does not offer a specific framework of analysis to the study. This does not mean, however, that it is without relevance. In amalgamating the findings of the research questions, it was possible to perceive features in the tendencies highlighted that, even if they did not necessarily coincide exactly with the deep / surface categorization, most certainly demanded an interpretation in the light of it. The extent to which the findings of this study can be paralleled to the deep / surface categorization is addressed in Chapter 6.

Marton's distinction between the deep and the surface approach, based on the three components of students' learning experience, is reproduced in the table below (Marton, 1983: 293, 295).

Table 2.1. Deep versus surface approach dichotomy

DEEP APPROACH	SURFACE APPROACH
1. Focusing on the “text”	**1. Focusing on the “text”**
• Focusing on the author’s intention • Keeping the end point in mind throughout the solution process • Having the phenomenon or the aspect of reality dealt with in the “text” as the object of attention	• Try to memorize the material • Concentrate only on procedures • Hyperintention (concentrate on time limits, memorizing, recall at subsequent test of retention) • Lack of concentration on content
2. Relating	**2. Not relating**
• Relating the parts to each other or to the whole • Relating some of the parts to the text or something outside it • Revealing the underlying structure of the text	• Dealing with the parts in isolation
3. Being active	**3. Not reflecting**
• Finding out things (creative) • Drawing one’s own conclusions making inferences (logical) • Checking the logic of the authors’ line of argument (critical)	• Have a passive, constrained mind

In observing, learners read a text (which could also be a physics problem), Marton argues that we need to look at what the students "take out" of the text. What the student "takes out" is different depending on whether the student adopts a deep or a surface approach. Surface learning pertains to reading the text "in chunks" - as pieces that are not related to one another. Students do not necessarily try to gather data to support a point, but tend, rather, to gather data at random. Deep learning pertains to the simultaneous action of reading and reflecting on what is read. According to Marton and Booth (1997), deep learning causes the reader to change the way in which she does things; it pertains to the students' reorganization of data in order to prove something. Marton and Booth categorize as using a deep approach to learning those students who are consistently involved in a search for meaning in their data presentation, and which results in their adopting a different view of the material studied as well as different structures to present the material. The deep approach to learning has been associated with high-level outcomes whilst the surface approach has been associated with low-level outcomes (Biggs, 1979; Marton and Säljö, 1976; Marshall, 1995; Trigwell and Prosser, 1991).

Marton (1983:292) sees the distinction between the two approaches to lie at three levels, or "components of experience", which are mutually inclusive. The first level relates to an overriding intentionality of the learner towards learning in general. The essential element lies in what the students' intentions are. In other words, it tells us about the students' ultimate goal in learning. In this regard, the deep approach is characterized by an intention to understand the material under study in terms of extracting "personal meaning" from it. On the other hand, students who are seen to adopt a surface approach are motivated by the intention to "reproduce" the material being studied, with no particular intention to make it personal (Prosser and Millar, 1989:514).

The second level pertains to the learners' experiences in relation to a specific context of learning *in which a specific task has to be performed*. Marton (1983) argues that here the students' intentionality is projected towards the task, and their intentions are actualized through the act of performing the task. In performing the learning task (in this case: problem-solving), students seen to adopt a deep approach would be inclined towards relating the individual parts of what is dealt with to each other and perhaps to the whole, depending on the nature of task. On the other hand, in a surface approach, the parts of what is dealt with are seldom related to each other or to the whole. This implies that the "underlying structure" of the task never becomes apparent to the students (Marton, 1983:292).

The third level pertains to how students perceive their role in the act of learning. Do they see themselves as active participants in the learning? Students seen to adopt a deep approach actively search for meaning in the task at hand, whilst in adopting a surface approach the students' minds are said to be "constrained". This implies that students do not make full use of their capability as "constructors of knowledge" (Marton, 1983:293). The reluctance by students to see themselves as responsible for their knowledge constitution results in their failure to seek the logical relations amongst the individual parts and the whole of the phenomenon being experienced.

2.4.3 An example of a (possible) non-representational approach to problem-solving: the "phenomenological primitive"

Although the phenomenological primitive is not used in the analysis of data, it is interesting to discuss it here as an example of the kind of theoretical concern that informs attempts to move beyond a constructivist understanding of what students do during problem-solving. To develop the discussion on how knowledge is acquired through non-representational (relational) means, I draw primarily on two articles: *Toward an Epistemology of Physics* (1993) by Andrea diSessa, and Ference Marton's response entitled *Our Experience of the Physical World* (1993).

diSessa's article illustrates a "naturalistic" or an "experiential" inquiry aimed at exploring what he terms the naturally acquired "sense of mechanism" (a sense of how things work) and how this sense develops towards an expert scientific understanding of physics. As was mentioned earlier (see section 2.3.2.2) diSessa argues that if students are capable of constructing new understandings out of their current (emergent knowledge), then there must be aspects of their current knowledge that are useful for the construction of expert understanding of physics. The question that diSessa seeks to answer is "how experience feeds into knowledge" (diSessa, 1993:106).

diSessa's work focuses specifically on those content aspects of the knowledge that impact on articulate reasoning and problem-solving. In this respect, his notion of "phenomenological primitives" (p-prims) is of cardinal importance. P-prims lie systematically in the "interface between experience and formalizable physics", both in a "genetic" sense (they provide an important knowledge base for learning physics) and in the sense of providing a basis for interpreting the real world in terms of formal theory (diSessa, 1993:111-113). However, as intermediates between the sensory and the idea, p-prims are themselves not observable.

Marton (1993) qualifies as problematic the notion that p-prims are not observable. According to him, the only way in which we could talk about p-prims as unobservable would be if we perceived them as "hypothetical *mental* structures" as opposed to *knowledge* (Marton, 1993:233. Italics mine). While he does not dispute the fact that p-prims are abstracted from experience, he challenges diSessa's claim that the learners (or their cognitive mechanisms) have abstracted mental models from experience. What Marton finds to be lacking in diSessa's line of reasoning (and which would also be missing in a cognitivist approach), is the description of what "lies between the brain and behaviour" (Marton, 1993:234). Arguing that it is possible to observe behaviours and organisms but impossible to observe the "flow of information" between them, Marton makes the point that it is virtually impossible to study "flow of information" as opposed to studying behaviour. Marton consequently argues that we cannot simply attribute all observed patterns of behaviour to "stationary structural entities" (such as the p-prim) as claimed by diSessa (Marton, 1993:234).

According to Marton, diSessa's use of p-prims in explaining how "experience feeds into expertise knowledge" reflects a projection of data as being in themselves "devoid of meaning", and only acquiring meaning after having been "internally processed". In this regard, it can be argued that p-prims are in themselves, notwithstanding diSessa's attempts not to present them as such, inherently dualistic. For this reason Marton proposes an alternative definition of p-prims. He does not perceive diSessa's p-prims as "hypothetical mental structures" but sees them, rather, as depicting "comparatively deep structure layers of our experience" which, in retrospect, turn out to be "our awareness of the physical world". In other words, diSessa's p-prims reflect "aspects of the physical situation just as they reflect aspects of the thinking of the learner dealing with that situation" (Marton, 1993:236). Marton argues that we should perceive them as the different ways in which we look at and think about the physical world. Seen in this way, p-prims can be usefully integrated into phenomenography's study of experience. In phenomenographic terms, p-prims are perceived as resembling the different ways in which we look at and think about the physical world.

2.5 Factors influencing physics learning

2.5.1 Familiarity in problem-solving

Research that has highlighted the importance of familiarity in problem-solving is of great significance to the analysis of Research Question 2.

2.5.1.1 A cognitivist perspective

According to Heller and Heller (1995), it is likely that if the student has seen the problem before and knows the solution, the act of problem-solving is relegated to a matter of simple recall (Heller and Heller, 1995:1). The task, in fact, is perceived as an "exercise" rather than a "problem" (Bodner, 1990:15). Bodner argues that it is therefore only in dealing with new problems (or problems that require more than the recall of learnt problem-solving strategies) that different models of problem-solving come to the fore. He refers to two ways of problem-solving which he qualifies as "anarchistic" and "archistic" (Bodner, 1990:14). An archistic model represents an approach to problem-solving characterized by logical sequences of steps that string together in a linear fashion, from the initial information directly towards the solution. It is associated with the perception of the task as an exercise. An anarchistic model (Bodner uses the term "anarchistic" with reluctance because of its connotations with irrationality) represents an approach to problem-solving which is characterized by reflective exploration of the problem. Associated with experts, it is cyclic and iterative.

2.5.1.2 A phenomenographic perspective

According to the cognitivist perspective, familiarity in problem-solving assumes that students use a particular set of heuristics as a matter of recall; it is rarely seen as a factor in a student's *conceptual understanding* of the subject matter (see section 2.5.1.1 above). Phenomenography changes this view of familiarity somewhat. Familiarity is associated with students' experiences of the problem, and in this sense becomes part of their conceptual understanding. If learning takes place through *change* in conception, familiarity offers, in fact, the very basis upon which such change would occur. Although many studies mention the fact that students are to varying degrees "familiar" with problem-solving strategies, familiarity as a factor in learning physics through problem-solving is generally mentioned only in passing. In my view, the notion of familiarity ties in closely with the phenomenographic notion of "structure of relevance" (Marton and Booth, 1997), in that it mediates the coming about of understanding.

2.5.2 Intentions / expectations in physics learning

Illuminating results have come from the work of phenomenographic studies concerning the relation between people's understandings of phenomena and the approaches they adopt to deal with them (Booth, 1992, Marton and Säljö, 1976, Laurillard, 1979. Säljö, 1979, Svensson, 1976). This work regards *how* students approach the learning task as an equally important aspect to consider as *what* students actually learn (Prosser and Millar, 1989). What is particularly significant is the acknowledgement that the context in which the learning takes place forms part of the attitudes of the learner towards her learning. Working largely with students in higher education, these studies have identified two approaches to learning, characterized by Marton as deep and surface approaches (see section 2.4.2). In light of the increasing recognition of the impact of assessment schemes on students' approaches and the specific demands of certain tasks, the deep versus surface dichotomy is, however, under constant review (see Biggs, 1993; Case, 2000; Marshall, 1995).

According to Laurillard, students' choice of approach does not wholly derive from their intentions but also from factors such as the nature of the problem and the contextual requirements of the problem task (Laurillard, 1984:134). Drawing on these insights, problem-solving activities should be aimed at developing a greater familiarity with the subject matter, which would consequently lead to better understanding. In this way, problem tasks would have "educational value" by advancing learning through conceptual change; the tasks should enable the students to "weave the factual knowledge they have into their own conceptual organization, by enabling them to elaborate the relationships between the concepts and to impose structure on the information they have" (Laurillard, 1984:124).

Ramsden argues in a similar vein. Learning through problem-solving should be geared, not towards the quantity of information a student can reproduce on demand, but towards the quality of the person's understanding (Ramsden, 1988:25). He stresses the need to understand the effects of the learning context, and emphasizes the fact that students' perceptions of the learning context are an integral part of their experience of learning (Ramsden, 1984:114). For example, students are often discouraged from coming to grips with the fundamentals of their subject as a result of examinations, which encourage them to use "tricks and stratagems" in order to pass (Ramsden, 1984:145). Ramsden therefore sees the context of assessment to play an important role with regard to its demands on students' understanding of the key concepts in the subject matter. He urges that the assessment context be treated as "a window through which teachers can study their students' learning – through this window, both instructor and student may see what progress has been made in learning a subject and what specific aspects of the content are partially understood or misunderstood" (Ramsden, 1988:25). By using an instance of assessment (an end-of-term test) in its method of data collection, this study clearly implemented this course of action.

2.5.3 Enrolment in physics learning

The point raised by Laurillard (in section 2.5.2) above about students' approaches not being wholly based on their intentions, may be further developed by looking at the issue of *enrolment* in physics learning. As already pointed out, in an educational setting one would not only expect the students to bring with them prior ideas of physical phenomena, but also "their beliefs about what would constitute understanding in the course and how best to achieve it" (Hammer, 1995:394). In other words, issues such as students' "understandings of themselves and their place in society, of school, of physics, of physics classes etc.", all receive attention within programmes aimed at student learning. Physics instruction, in addition to its focus on physics content, therefore also targets institutional and personal factors that

their learning. In short, enrolment pertains to the
art of establishing an "identity", that of being
sicist / scientist.

s curricula aim to make students physicists / scientists,
following attributes:

> t of habits and attitudes for inquiry;
> of reasoning practices and abilities, and,
> the generally tacit assumptions and values of a community
> 5:394).

To discuss ts I draw on Nespor's (1994) work on how undergraduate curricula (in the physics and management disciplines) shape student learning. For the purposes of this study I focus only on the physics programme. Nespor emphasizes that through being in a university physics program, students are brought into contact with "representations of other spaces and time" (Nespor, 1994:7). This contact happens by virtue of well-defined material space such as buildings and laboratories, and disciplinary tools such as textbooks and equations. Therefore, "identity" and "practice" within disciplines are seen as functions of ongoing interactions with spatially distant elements (whether human or non-human), which form part of networks that have been mobilized along "intersecting trajectories" (Nespor, 1994:13).

It is evident that identities are not seen as being acquired within "communities of practitioners", but rather as coming about through "continuous evolutions that may even be contradictory in nature": "shifting and contested stakes of networking practices" (Nespor, 1994:13). At root, however, one is dealing with a *social space*[xi] that seeks to produce or maintain a certain configuration by "excluding or restricting some people and things from participation while recruiting and reconstructing others to fit into the network" (Nespor, 1994:13). An actor network such as physics can therefore be said to constitute itself, at least in part, through *educational practices* that "shape and sort would-be participants and organize their participation in disciplinary productions of space and time" (Nespor, 1994:13).

Thus, rather than concerning itself with specific tasks, problems, or courses, educational research should be concerned with the "system" or "network". The elements of the network are those defined by the recurrent patterns of intersections of the various space-time trajectories (Nespor, 1994). Of course, knowing is itself distributed (Lave, 1988; see also Marton, 1990). Knowledge need therefore no longer be regarded as a property of the individual learner, but as a *property of the network* that produces space and time by mobilizing and accumulating distant settings in central positions (Nespor, 1994:10). In addition, learning is seen as the *changes in the spatial and temporal organization* of the distributed actors/networks of which we are always part (Nespor, 1994:11).

According to Nespor, the logic and sense of an event or a setting can never be found entirely within a particular setting, because we are continuously moving through different spatio-temporal distributions of knowing. How do the views that emphasize spatio-temporal distributions of knowing relate to the idea of actors entering disciplinary practices? Nespor makes the following points:

- students move along the trajectories that keep them within the narrow range of space-times and distributions that constitute the discipline;
- students are physically mobilized through networks of physical settings; and,
- students begin to construct worlds through discipline-based systems of representation (Nespor, 1994:11).

The idea of a community of practice somehow pre-existing to its situation in space and time (see Hammer, 1995) is put in question by the actor-network theory. Communities of practices are themselves, in fact, "ways of producing and organizing space and time and setting up patterns of movement across space-time" (Nespor, 1994:12). This insight enables us to challenge the Vygotskian notions of "apprenticeship" and "enculturation" mentioned earlier (see section 2.3.1.2). People do not simply move into communities of practice (networks) in an "apprenticeship mode"; individuals are "defined, enrolled and mobilized" along particular trajectories that move them across places in a network (Nespor, 1994:13). Speaking from the point of view of socio-cultural theory, Lave and Wenger advance a similar argument (see Lave and Wenger, 1991).

Against this background, educational perspectives should make sense of knowledge practice as an interaction with others distant in time and space. This prerogative implies paying attention to issues of authority and power. According to Nespor, students insert themselves into power relations in primarily two ways. Firstly, it is by representing experience in the ways of the discipline. This they do in order to become participants in the "disciplinary accumulation cycle". Secondly, it is by representing themselves and their own experience "in stable mobile and combinable forms such as grades and transcripts" (Nespor, 1994:21). These two ways by which students insert themselves into relations of authority are of key interest to Research Question 2.

The emphasis on spatiality set out in actor-network theory has an important methodological consequence for this study. The traditional view of the individual learner needs to be replaced with a theoretical perspective "situated spatially and temporally" (Nespor, 1994:7). It is at this point that actor-network theory significantly overlaps with phenomenography. I have already highlighted the fact that phenomenography, through its concern with variation of experience of a phenomenon, essentially conceives of awareness as a *collective* (see section 2.4). Nespor's proposal of a "geographical view"[xii] in which the individual learner (actor) is simultaneously the *function* of the network and the *creator* of a network, fits in with a perspective that stresses human understanding as "culturally sedimented layers" of the experience of human knowing (Marton, 1990:45). The learner is not bound to a particular context, but is "distributed with shifting boundaries and compositions that spread across space as well as time". Quoting Berger[xiii], Nespor concludes that the notions of development and learning that still depend on "narratives of a unitary or segmentable actor moving through time" can no longer hold. Marton may well, in fact, have expressed this view:

> It is scarcely any longer possible to tell a straight story sequentially unfolding in time. And this is because we are too aware of what is continually traversing the storyline laterally ... such awareness is the result of our constantly having to take into account the simultaneity and extension of events and possibilities (Nespor, 1994:22).

2.6 The implications of seeing education as a space-time process

By specifically focusing on Piaget, Vygotsky, actor-network and phenomenography, I have drawn attention to the necessity of considering dialectic perspectives in educational research. This study's exploration of students' experiences of what they learn and the learning strategies they employ in order to learn physics calls for a *relational* perspective.

Whereas cognitivist perspectives (such as constructivism) are useful for their emphasis on the relational aspect of learning, the arguments put forward in both phenomenography and actor-network theory contradict their model of learning as an activity that takes place "within individuals' heads". The notion (strongly emphasized in the information processing perspective on learning through problem-solving), that "people ... gradually build up integrated capacities - composed of 'attitudes', 'rules', 'schemata', 'domain knowledge', 'contextual modules' ... - that could be carried around, called up and deployed as needed in specific contexts" is no longer valid (Nespor, 1994:7). Instead, the outcome of learning is the result, not only of the interaction between the students and the task of learning (as argued in phenomenography), but also the function of enrolment (actor-network theory).

The theoretical framework of this study is founded in the common ground of phenomenography and actor-network theory. Knowledge is not the property of the individual learner, but the property of the network - or "collective awareness" in phenomenographic terms. Learning is a *change,* both in how reality is perceived (phenomenography), and in the spatial and temporal organization of the distributed actors / networks (actor-network theory). Together these perspectives provide us with a "holistic view" (Entwistle and Marton, 1984) of the experience of learning physics through problem-solving.

CHAPTER 3

RESEARCH DESIGN AND METHOD

3.1 Introduction

As was seen in Chapter 2, the theoretical framework adopted in this study not only takes into consideration the relational aspect of learning as espoused in phenomenography, but also the relational aspect of space-time as espoused in the actor-network theory. In practical terms, this framework translated into the method described below.

3.2 The pilot study

The collection of data for the research was informed by two data sources, namely the author's personal notes based on observations made as a participant (researcher in the first year physics course during 1999) and the results of a pilot study (conducted in Modern Physics). The research participants used in the pilot study were first a group of first year physics students. Using semi-structured in-depth interviews, the research participants were asked to "explore aloud" their understanding of the equation for carbon-14 beta decay: ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$. Two aspects of the equation were explored, namely:

a) What the equation means;

b) How students understand the seemingly contradictory nuclear decay process, that is, the emission of an electron from the nucleus itself.

The analysis of the pilot study paid attention to the students' ability to reflect on past learning experiences. The main aspect of the analysis was, therefore, the students' awareness of the educationally critical aspects of their physics understanding. The willingness and ability of participants to reflect on their understanding of the subject matter was crucial to this process.

As Bell *et al.* (1985:158) correctly point out that students occasionally tend to lose rather than gain confidence in the course of an interview, despite all efforts to make the interview informal and non-threatening. In this regard, White and Gunstone (1992:68) stress the necessity for a rapport between the student and the interviewer, arguing that nothing valuable can come from interviewing students who are frightened, resentful or indifferent. While great care was taken with regard to these considerations, a number of students found it extremely difficult to reflect aloud on their understanding of the problem. They typically responded, "I don't know" when asked for their understanding of the equation, and were either unwilling or unable to proceed beyond that point. These students were thanked for their time and the interview was terminated.

Other students, however, found it relatively easy to reflect aloud on their understanding of the equation, and made it possible for me to pursue the discussion through further prompting and probing. These students became the focus of the pilot study. They had the following factors in common. Firstly, their course grades indicated that they were relatively successful students. Secondly, in reflecting upon the problem, they showed a strong reliance on their ability to recall the equation to calculate the binding energy and, more generally, to remember what the lecturer had said in class. When probed further to elicit the understanding that they had of the release of an electron from the nucleus, the students revealed that they had not really "come to grips" with the section, but had done what was necessary in order to pass the course. While some of the students did try to make sense of the equation, they seemed to lack the physics descriptors necessary to fully explain their understanding.

These observations were significant. My attention was drawn to the difficulty inherent, not only in the process of reflection in learning, but also in the process of probing students' understanding. In this way the pilot study was able to confirm other research findings about reflection in learning, namely that the capacity to reflect is at different levels in different students, and that this capacity clearly distinguishes students who learn effectively from the learning experience from those who do not (Candy *et al.*, 1985). It was on the basis of these observations that for the study, I decided to use students who passed their examinations

Capacity to Reflect

. year physics students experience the learning of solving

esearch participants

ly in the learning of physics within a typical .cs course, it was important that focus be placed on e formal situation in which problem-solving takes place, ne test used was the end-of-term test at the conclusion of done over a year.

ent and selection of the problems

Informed by research studies on the significance of using non-standard rather than standard problems in exploring students' ways of problem-solving (see Arons, 1981; Arons, 1990; Arons, 1997; diSessa, 1986; Good and Smith, 1987; McDermott, 1984; McDermott, 1993; Freedman, 1996), the selection of the problem tasks was a particular challenge. Drawing on the principle underlying most naturalistic research - which stresses the institutional context within which learning takes place - the problem-solving tasks had to be closely related to the context of introductory physics learning.

I had regular discussions with the lecturers of the four different modules on the aims of my study. We came to agree that non-standard problems would be particularly appropriate for the type of exploration I envisaged, and one such problem was therefore included in each of the end-of-term tests. This type of problem can be seen to resemble the kinds of problems characterized as "context-rich" (Heller and Hollabaugh, 1992). Context-rich problems are argued to be different to the problems typically done in class, in that they are "more realistic". They may also be experienced as "complex" in that they call upon students to make decisions about physics concepts and principles - concepts and principles with which they may be relatively unfamiliar. The following characteristics apply to context-rich problems (see Heller and Hollabaugh, 1992:639):

- the problem statement does not always specify the unknown variable; the student must decide upon an appropriate target variable that will answer the question;

- more information may be available than is needed to solve the problem; the appropriate information must be selected based on the particular physics principles that are applied to solve the problem;

- some information needed to solve the problem may be missing; students may first have to determine the physics principles that will solve the problem, then use their common knowledge of the world to recall specific values (e.g. the boiling temperature of water) or estimate values of relevant quantities (e.g. the length of a table); and,

- reasonable assumptions may need to be made (e.g. assume constant acceleration) to simplify the problem and allow for a meaningful solution.

3.3.3 The problems used

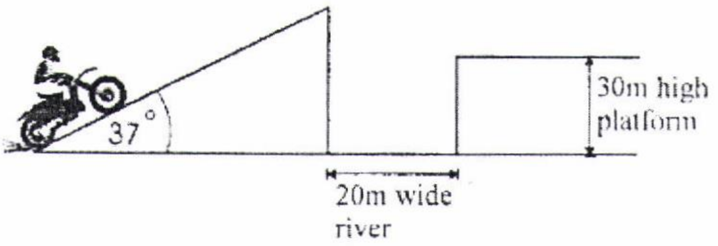
The problems chosen for the study blended characteristics of both standard and non-standard problems.

Note: the following problems tasks are verbatim from the tests.

3.3.3.1 MODULE 1: LINEAR ACCELERATION

The Module 1 problem task tested students' understanding of the application of Newton's Second Law, which they had to apply to a situation of motion in two dimensions (rather than only one). In addition, the problem tested students' understanding of the effects of gravity on the motion of a projectile.

"In the sketch below a stunt driver approaches the ramp on his motorcycle at a speed of 40 m/s. The combined mass of the driver and the motorcycle is 200 kg and the ramp is 100m long. The coefficient of friction between the tyres and the road surface is 0.2. Use $g = 10\ m/s^2$.



(a) Draw a free body diagram of the combined driver and motorcycle. (2)

(b) How will the speed of the cyclist be affected as he travels up the ramp when the engine stalls at the bottom of the ramp? (2)

(c) Confirm your answer in (b) by calculating this speed. {Hint: You first need to calculate the acceleration}. (4)

(d) Will the cyclist make it to the other side of the river? Show your calculations. (3)"

3.3.3.2 MODULE 2: EQUILIBRIUM OF A RIGID BODY

The Module 2 problem task, instead of requiring the students to deal with a uniform ladder at rest leaning against a frictionless wall, expected of the students to consider a leaning ladder with a painter standing on it. Given the coefficient of static friction between the ladder and the ground, the students were asked to work out how much further the painter can climb before the ladder starts to slip.

"A uniform ladder whose length is 10m and whose mass is 50kg rests against a frictionless wall. A man whose mass is 70kg climbs 7.5m up the ladder.

(a) Draw the free-body diagram of the ladder and show all the forces that act on the system.

(b) Calculate the forces that the ground and the wall exert on the ladder.

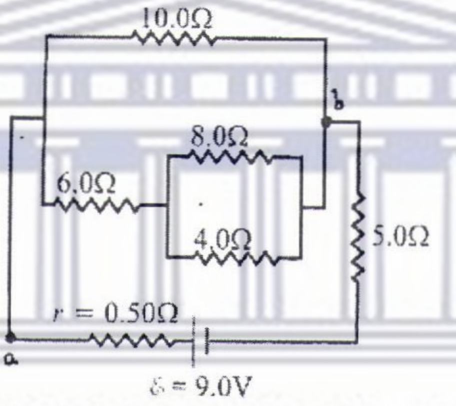
(c) Confirm your result above that the force exerted on the ladder by the wall is equal to the force exerted by the x-component of the ground by taking the moment about another point.

(d) If the maximum value of frictional force that would prevent the ladder from slipping is 700 newtons, how much further can the man climb before the ladder starts to slip?"

3.3.3.3 MODULE 3: CONSERVATION OF CHARGE AND ELECTRIC ENERGY

The Module 3 problem, in addition to requiring of students to work out the equivalent resistance and the current drawn from a battery in a multi-loop circuit, also required them to assume that one of the resistors was a heater. They had to work out the power it used and the cost under certain conditions.

"A 9.0 V battery whose internal resistance (r) is $0.5\ \Omega$ is connected in the circuit shown below: (23)



Determine:

(i) the equivalent resistance of the circuit (8);

(ii) the current drawn from the battery, i.e. the current in the simple circuit (2);

(iii) the terminal voltage of the battery (2);

(iv) the current in the $6.0\,\Omega$ resistor (3);

(v) the potential difference between points a and b (4);

(vi) assuming that the $10.0\,\Omega$ resistor is a heater, calculate the power it uses and how much it costs per month (30 days) if it operates 3.0 hours per day and the electric company charges 10.5 cents per kilowatt-hour (kWh) (4)."

3.3.3.4 MODULE 4: DOPPLER EFFECT - RELATIVE OBSERVED AND EMITTED FREQUENCIES

The Module 4 problem required of the students to describe, using diagrams, the relation of the variables in the Doppler equation for a given frequency when *both* the source and the observer are in motion in opposite directions.

"The driver of car A is travelling at 20.0 m/s and sees a distant car B travelling directly toward him. He sounds his horn, which has a frequency of 500 Hz. The driver of car B hears a frequency of 560 Hz.

(a) Show diagrams to describe the above stated problem. (3)
(b) Use the diagrams in a) to obtain the expression for the speed at which car B is travelling. NO CALCULATIONS! (3)
(c) Calculate the speed at which car B is travelling. (4)
(d) Calculate the wavelength of the sound waves observed by the driver of car B. (2)
(e) Calculate the frequency that will be heard by the driver of car B after he has passed car A at the speed calculated in c). (6)"

3.4 The research instrument: the interview

3.4.1 The interview focus

Altogether fifteen interviews were conducted in the course of the year at the end of the four modules. In light of the research questions, the interviews primarily sought to elicit the following:

With respect to Research Question 1 - dealing with the qualitatively different ways in which the students go about solving the problems - there was an overriding concern with students problem-solving strategies; i.e. they had to explain what they *did* during the process of problem-solving.

With respect to Research Question 2 - dealing with the factors influencing students' problem-solving strategies - there was an overriding concern with students' appraisals of the context of physics learning and how they saw themselves in that context.

3.4.2 The interview situation

Before the interviews took place, a prior analysis was done of the students' attempts at the given problems as reflected on their test scripts. Although the course of the interview was still largely dependent on the student, this procedure helped in formulating the questions to be used during the interview. It is in this sense that the interview could be regarded as "semi-structured". This approach also made it possible to draw attention to discrepancies between students' problem-solving attempts in the test and during the interview (as well as other problem-solving contexts) and to elicit the students' rationalizations of such discrepancies.

This brought into focus the question of "contextual dependency" - the extent to which the different contexts of problem-solving lend themselves to different approaches, strategies and conceptions on the part of the students. Much care was taken, during the interview, not only to elicit the students' comments about their attempts to solve the problems in the light of the test they wrote a few days before the interview, but to get them to effectively demonstrate these attempts.

It may be argued that the research design of the study, through its more or less simultaneous evocation of two particular situations of physics learning, assumes that a subject as complex as students' experiences of learning physics through problem-solving can be elicited by the students' to-and-fro reflective motion between test and interview. Such an assumption would obviously rest on an oversimplification. The complexity of what Nespor (1994) calls the "different spatio-temporal distribution of knowing" (see section 2.5.3) comes to mind in this regard. Laurillard locates the importance of the learning situation (as a particular focus of the interview) within a particular "stage" of the interview, namely the stage of "questions on context" ("context" in the sense of educational *setting*). The students were asked, "why they did what they did" and were encouraged to relate their problem-solving activities to other learning contexts (Laurillard, 1984:132-133).

Following an approach similar to Laurillard's, I endeavoured to create an interview situation that would be as open to various contexts of learning as possible. I encouraged students not only to refer to other settings (such as tutorials, study guides, textbooks, school etc.), but also, where relevant, to draw upon these in formulating their own conceptions with regard to physics learning.

3.4.3 The interview design and method

It is important for both the researcher and the interviewees to understand the parameters of the interview contexts, so as to ensure that the interviewees do not focus on perceived contextual demands, but on the content of the problems under discussion (Booth, 1992:60). In this sense, the validity of the research study is seen by Booth to be dependent on the interview. The two most significant qualities that characterize a phenomenographic interview method are its sensitivity with regard to "shifts in focus" and to "potentially productive turns in the discourse" (Booth, 1992:60-61). The researcher has to be careful, however, to avoid shifts of focus that might turn the student away from the phenomenon of interest to the study and are therefore unproductive. These concerns emphasize the degree of awareness and reflexivity on the part of the researcher (Booth, 1992; Hammersley and Atkinson, 1983).

On the basis of my research questions, the semi-structured interview concentrated on the following:

i.) what were your feelings about the test?
ii.) how did you prepare for the test?
iii.) how did you interpret the problem?
iv.) why did you follow this interpretation?
v.) how did you go about solving the problem?
vi.) why did you go about solving the problem the way you did?

The above questions were adapted from Good and Smith's framework for observation of students' problem-solving practice (see Good and Smith, 1987:33-34; also section 2.3). Good and Smith's framework was adopted for two reasons. Firstly, they clearly advocate the use of naturalistic methods into problem-solving inquiry rather than prescriptive methods. Secondly, they emphasize the use of physics problems aimed at testing students' understanding of the concepts rather than their ability to apply formulae.

The first two questions concerned students' intentions; they elicited the students' perceptions on what they should study for a particular section of work. The aim of the other questions were, firstly, to elicit the different ways in which the students focused on the problems and, secondly, to explore the meanings that the problems had for the students. These questions provided insight into both the structural and the referential aspects of students' experience of learning physics through problem-solving (see section 2.2). The aim was not to help students arrive at the "correct" answer, but rather to explore *how* and *what* they thought during the process of problem-solving.

The interviews followed the structure of a learning conversation. Once again, Laurillard's interview stages serve as a useful example. In addition to the stage of "questions on context" discussed above, she identifies two other (earlier) stages: "teachback", where the student attempts to "teach" the problem to an interviewer who refrains from asking "substantive questions"; and "stimulated recall", where the students are questioned on the detail of their problem-solving through the use of the problem statement as well as through "written work" as an aid to recall (Laurillard, 1984:133).

Even though Laurillard's stages adequately describe the interview structure I adopted, it is important, in my view, to stress one essential aspect, namely *reflectivity*, which characterized the interview method (see section 2.5.1.2). Reflectivity in this instance relates to the constant concern, during the interview, not only to monitor the changes in students' awareness of the aspects of the problem on which they focus, crucially, to arrive at a point where the students are themselves acutely aware of these changes. As Marton and Booth remind us:

> "We cannot be simultaneously aware of everything with the same degree of acuity all of the time. The foreground [in the interview: the aspect of the problem the student focuses on], changes repeatedly, and with each shift other things [aspects of the problem] that are present shift to become functions of the current items of figural awareness". (Marton and Booth, 1997:134).

In the study, these changes in students' "figural awareness" could be both between the test setting and the interview setting (or any other setting referred to by the students), as well as within the interview setting itself. Once confronted with these changes, the students were invited to comment on the reasons therefore. These comments served not only to help characterize the strategies used by the students, but also to explore the contextual factors that brought about a particular way of solving the problem. Documenting all *changes in conception and interpretation* of the problems during the interview was therefore the single most important task. Against this background, the descriptions of the interview data presented itself in the following stages.

Stage 1: What do the students perceive as important regarding the problem before attempting to find the solution?

This stage essentially consisted of "the beginning of the interview reflections" and students' reflections upon being asked to "take the researcher through" how they solved the given problems. It was important to document the students' ability to reflect on the problem solving activity as a whole (see Laurillard's "teachback" stage).

Stage 2: What do the students perceive as important regarding the problem during the working out of the solution?

This exploration enabled me to get to the core of the "relevance structure" (Marton and Booth, 1997:180) that guided the students' approaches in solving the problems. In order to talk about the ways of experiencing the problem, the students' acts had to be explored. For example: Do students respond to the hints given in the problem statements? Do they respond to the questions as they are posed, or do they, rather, respond to "global" questions that arise from their overall interpretation of the problem? These responses were particularly important as indications of students' employment of certain relevance structure: whether it is based on intuitive, personal or formal / conventional knowledge. How were different knowledge structures translated into the students' problem appresentation[xiv]? Finally, there was the question of coherence between what was said at the beginning of the interview and what was said and done during problem-solving. If any inconsistencies existed, the students' awareness (or lack of awareness) of the difference between what they said (their reflections) and what they eventually did (their acts) during the process of problem-solving, was brought to the fore (see Laurillard's "stimulated recall" and "questions on context" stages).

Stage 3: What do the students perceive as important regarding the problems at the end of the interviews?

This question consisted of the "end of the interview reflections" which explored what students perceived to be the ultimate goal in solving the problem - what had been their "overall intention". As such, this stage of the interview related to the students' perceptions and conceptions of the structure, content and learning of physics. Whereas phases (1) and (2) could be seen as primarily addressing students' approaches to problem-solving, phase (3) was particularly useful in ascertaining the meaning of physics learning to which problem-solving approaches relate.

3.5 Analysis of results

A phenomenographic (second-order) analysis was employed, the aim being to describe the qualitatively different ways in which the students experience the learning of physics through problem-solving. According to Booth, phenomenographic analysis aims

> to take the material collected and study it thoroughly, reading it several times and taking different perspectives on it, and always seeking distinctly different ways in which the subjects characterize the phenomenon of interest. The material forms a pool of meaning in that within it are to be found the ways in which the phenomenon of interest is understood by – what it means to- not only the actual research subjects but also the group from which they are a theoretical sample (Booth, 1992:62).

As was mentioned in Chapter 2, the structural aspect of the experience of learning physics through problem-solving, which addressed both internal (*how*) and external (*what*) horizons (Marton and Booth, 1997:87-88) was covered by the two research questions.

3.5.1 Analysis of Research Question 1 results

Research question 1: What are the qualitatively different ways (strategies) in which first year physics students go about solving introductory physics problems?

The strategies with which the problems were solved constituted the students' theme of awareness. These strategies were analyzed on the basis of different *moments* that characterized the students' problem-solving process.

3.5.1.1 Description of the three "moments" evident in the students' problem-solving process

Three moments of problem-solving were identified, which were regarded as constitutive of the students' problem-solving strategies. These were (i) scanning; (ii) translation; (iii) re-interpretation.

(i) Description of the scanning category

The moment of scanning is similar to what is referred to in the literature as "focusing or describing the problem[xv]" (Fuller, 1982: 46). This moment can be compared to what Laurillard describes as the students' "initial approach" to the problem (Laurillard, 1984:130). It denotes one of the many stages and phases that students go through in trying to get to the core of what the problem is about. This moment, in a way, denotes how students describe and interpret the problem at hand through the process of reading and examination of the problem, thus allowing glimpses into the different aspects that inform the strategies that students use. Scanning essentially entails the elicitation of the familiar and dominant features perceived to be the defining qualities of the problem. The following considerations, pertaining to the students' constitution of relevance structure, were seen to be central to this process:

- what are possible sources of difficulty in the problem?
- what is perceived as the ultimate objective of the problem?
- what type of understanding is required to make sense of the problem?

(ii) Description of the translation category

Translation refers to the students' transformation of the problem statement (its perceived structure of relevance: significant concepts, principles and technical terms) into a physical or a mathematical representation. The moment encompasses four of the six-step heuristic to physics problem-solving (see Schoenfeld, 1978): analyzing the problem, exploring the physics to be used, planning the solution, and executing the plan. It is in this moment that descriptions and interpretations of the problem are actualized.

(iii) Description of the re-interpretation category

The research-created interview contexts lend themselves to this moment, in that they provide the students with the opportunity to confront themselves with unanswered questions or concepts. Students get to give an account of how the problem was perceived during the evaluation test and what the shortcomings were of a particular way of looking at the problem. The process of reflection allows for the joint monitoring (by both the researcher and the student) of students' particular ways of experiencing the problems. In this way, the moment encourages new ways of "focusing" on the problem. It implies the discernment of new aspects of the problem to be focused on. A shift of emphasis on the dominant features of the problem may thus be expected. The process of looking at the problem anew requires that the first two moments are relived and experienced again, which relates to what Linder and Marshall (in press) refer to as "mindful repetition". This change has an impact on the overall evaluation of the problem-solution that was worked out initially.

Two types of re-interpretation were encountered. On the one hand there was a re-interpretation which, though clearly deriving from a willingness to reflect on and modify the knowledge structure, remained at a largely explorative level, with no specific interpretive structure being adopted. This type of re-interpretation was identified as *explorative*. On the other hand a certain type of re-interpretation was identified that, through exploration and monitoring of understanding, gave rise to a revised relevance structure which the student could use to assess the solution. This type of re-interpretation was termed *evaluative*.

3.5.1.2 The two qualitatively different strategies used by the students

It was noted that the moments of scanning and translation were common to all fifteen students, while the moment of re-interpretation was apparent in the data of only some of the students. The moment of re-interpretation was exclusively and uniquely a property of Strategy A. This observed variation formed the basis upon which two qualitatively distinct problem-solving strategies were identified:

(i) A problem-solving strategy that involves a way of focusing that brought about a change in the students' focal awareness of the algorithm they employed during the test (referred to as Strategy A); and,

(ii) A problem-solving strategy that does not involve such a way of focusing, meaning that there is no change in the students' focal awareness of the algorithm they employed (referred to as Strategy B).

3.5.2 Analysis of Research Question 2 results

Research Question 2: What factors influence the strategy adopted by first year physics students during problem-solving?

The *what* aspect covered by Research Question 2 constitutes the thematic field of the students' experience of learning physics through problem-solving. In this study, the thematic field consists of those spatial and temporal factors that have a bearing on the students' strategies, as reflected through their intentions and conceptions of problem-solving and the meanings attached to the different settings of problem-solving.

A crucial concept for characterizing the meaning students attached to the various instances of problem-solving across different settings is the concept of *familiarity* (structure of relevance). The aim of the analysis was to discern how the students' familiarity with the problems informed their problem-solving strategies - and from where this familiarity derived. This exploration of familiarity brought to the fore the students' *personal context*, which related to the meaning the students attached to their problem-solving strategies. This level of the analysis (personal context) integrated notions of institutional context / enrolment.

Students' familiarity with the problem tasks was seen to stem from their prior exposure to the spatial / temporal settings of studying: the tutorial, the lecture, school and the test. The interview setting was not singled out as a separate setting for analysis, seeing that it served as a mechanism of reflection through which the meanings of the different settings of problem-solving could be explored.

3.5.2.1 Description of the two questions guiding the analysis of Research Question 2 results

The following considerations served as guidelines to the analysis:

(i) How students used particular settings (and – in the case of studying for example – the different means of studying at their disposal). How the setting was used reflected the influence of the physical context on problem-solving; and,

(ii) - based on the findings of (i): How the students related the physical context to their personal context – bringing to the fore their intentions and conceptions of problem-solving.

The analysis brought to the fore two qualitatively different ways of focusing on the problems, which derived from students' intentions and conceptions of problem-solving. These ways of focusing on the problem were categorized as follows:

(i) focus on the requirements of the problem; and,
(ii) focus on the content of the problem (see Laurillard, 1984).

3.6 Validity and reliability of the study

Three aspects of validity are highlighted in phenomenographic research:

(i) content related validity - the research has to be grounded on a sound understanding of the subject content;

(ii) methodological validity - the phenomenographic perspective should permeate the study from its data collection stage to the analysis and presentation of the results; and,

(iii) communicative validity - the study should have both "internal" (relative to the participants in the study) and "external" (relative to other researchers, both within phenomenography and outside) reference (Booth, 1992:65).

With regard to content validity, the researcher has to have a "deep but open familiarity with the topics taken up by the interviewees" (Booth, 1992:65). As was mentioned earlier (see sections 3.2 and 3.3.2), I had been a participant observer in the Physics 1 course during 1999, and in that way acquired in-depth insights into the experience of the students. Through frequent discussions with the lecturers who taught the different modules, I was also able to get a sound perspective on their expectations and understanding of the Physics 1 course.

The phenomenographic perspective informed all the stages of the study: the pilot study, the selection of problem tasks, the interviews, and the analysis of the data. Particular care was taken with regard to documenting the *variation* in the students' conceptions. At the same time, the analysis of the data in particular was done in such a way as to draw attention to the variation in the experience of the *phenomenon* (problem-solving as a means to physics learning). The study, however, also drew on other research perspectives, most notably actor-network theory. Actor-network theory provides interesting points of convergence with phenomenography – particularly as far as physics learning is concerned (see section 2.5.2) – and it is hoped that this study would be a contribution to future dialogue between these two theoretical perspectives.

Phenomenography deals with descriptions of lived experience. This means that different researchers would arrive at different descriptions, given the differences in their ways of experiencing the world. Comparing a phenomenographic researcher to an explorer, Booth makes the point that if another (second) explorer were to be given "the original charts, the observations and the sightings, the diaries and notebooks", she would be likely to reach similar results to the first, on condition that "both the explorers have similarly thorough experiences of what it is to explore foreign lands, and prior understanding of the sort of territory and culture which might be encountered" (Booth, 1992:66-67).

To what extent can this study draw on other explorers? As shown in Chapter 2 (see section 2.3.2), problem-solving research has to a large extent been dominated by cognitivist "expert versus novice" studies. While several phenomenographic studies have shown interest in students' conceptions of particular physics principles (for example Linder, 1993; Bowden *et al.*, 1992; Prosser and Millar, 1989), relatively little attention has been paid to studying problem-solving *as a process* which takes place in space and time (see, however, Laurillard, 1978 – also diSessa, 1993, and Marton, 1993, as discussed in section 2.4.3). A particular challenge in this study was, therefore, the difficulty of characterizing the problem-solving process - which involves *sequential* objects of focus and therefore a particularly complex way of experiencing (Marton and Booth, 1997:113) - without making it appear like a procedure based on a pre-acquired "sense of mechanism" (diSessa, 1993). This may well be a limitation of the present study, and an area in which future phenomenographic studies on problem-solving in physics could make particular advances.

Chapters 2 and 3 have set the theoretical and methodological frameworks used in this study. This has laid out the foundation for the presentation of the results of the study. The students' strategies (as elicited by Research Question 1) are the subject of Chapter 4.

CHAPTER 4

DATA ANALYSIS AND RESULTS OF RESEARCH QUESTION 1

4.1 Introduction

The aim of this chapter is to present the results of Research Question 1. The results of Research Question 2 are presented in Chapter 5. As discussed in Chapter 3 (see section 3.5), the results were obtained through an analysis strongly informed by a phenomenographic research perspective. A phenomenographic empirical analysis implies a second-order perspective. According to Marton and Booth (1997), a second-order perspective looks across a number of students, seeking commonalities as well as differences in the way the students approach the task. The aim behind such an empirical process would be to describe the qualitatively different ways in which the students interpret the phenomena under study. The results obtained in this manner constitute categories of description which are characterizations of the different ways of seeing or experiencing the world. The logical and empirical relations within and between the categories of description make up the "outcome space", which is the ultimate result of a phenomenographic study (Marton and Booth, 1997). As such the outcome space is a systematic attempt to try to account for the various ways in which people perceive a particular phenomenon (Säljö, 1988:44). This study will have as its outcome the different ways in which the learning of physics is experienced through problem-solving.

As explained in Chapter 3, fifteen interviews were conducted in total. Five students were interviewed in the first module, four students were interviewed in the second and third modules and two students were interviewed in the fourth module. The students interviewed are referred to as S1, S2, S3, etc. depending on the number of students interviewed for each module.

4.2 ANALYSIS ACCORDING TO RESEARCH QUESTION 1

4.2.1 Research question 1: What are the qualitatively different ways (strategies) in which first year physics students go about solving introductory physics problems?

As discussed in Chapter 3 (see section 3.5.1) three moments of problem-solving were identified, which were regarded as constitutive of the students' problem-solving strategies. These were (i) scanning; (ii) translation and (iii) re-interpretation.

4.2.1.1 A brief summary of the content of the four problem tasks used in the study

The Module 1 problem tested students' understanding of the application of Newton's Second Law. Instead of dealing with a situation involving motion in one dimension, the students had to apply Newton's Second Law with motion in two dimensions. In addition, students' understanding of the effects of gravity on the motion of a projectile was tested. Four out of the five students interviewed were categorized as having used Strategy A.

The Module 2 problem, instead of dealing purely with the examples of rigid bodies in static equilibrium, expected the students to consider a leaning ladder with a painter standing on it at a given position. Provided with the coefficient of static friction between the ladder and the ground, the students were asked to work out how much further the painter could climb before the ladder started to slip, if the maximum value of friction that would prevent the ladder from slipping was 700 newtons. Two out of the four students interviewed were categorized as having employed Strategy A.

The Module 3 problem, instead of requiring of students only to work out the equivalent resistance and the current drawn from the battery in a multi-loop circuit, also required them to assume that one of the resistors was a heater. They had to work out the power it consumed and the cost of the energy used under certain conditions. One of the four students interviewed was categorized as having employed Strategy A.

The Module 4 problem required of the students to describe, using diagrams, the relation of the variables in the Doppler effect in sound formula for a given frequency, when not only one, but *both* the source and the observer are in motion in directly opposite directions. The students interviewed were both categorized as having employed Strategy A.

4.2.1.2 What are the differences in the scanning of the problems as reflected in students' strategies?

It was pointed out earlier that the difference between the two strategies identified in the study lies in the *change in students' focal awareness* as they engage with the problem. Whereas Strategy A reflected this change, Strategy B did not. An illustrative data analysis is provided below to show how this categorization was arrived at.

4.2.1.2.1 Illustrative data analysis of what the students using Strategy A focus on in the moment of scanning

The moment of scanning is characterized by the process of organizing what the students know. It is significant to note that the students categorized as having used Strategy A employed this process throughout the problem-solving algorithm – in a sense they never stopped scanning (exploring the meaning of the problem). There seems to be a commitment to attending to the content of the problem, whatever the degree of difficulty presented by it. The following statement illustrates this commitment well: "The thing is I never understood those questions. So, I just thought… I had to think about it this time; today I just have to do it. I said whatever it takes I will think about it and then I thought deeply about it. I read over the question repeatedly to try to make sense of the question… " (S1).

The examples provided below illustrate the moment of scanning and the several ways in which students may organize their knowledge system.

- **scanning (i): the simultaneous identification of problem-type as well as the algorithmic skill necessary for the application of the underlying principle**

S2: *When you look at it you must be able to think about it and draw a diagram that will show you exactly where everything is. Like this one, when you look at it you must identify that, yes, this is the river, this is the other side, just be able to understand what will happen as this person moves from here to there. Look at him as he is moving; what is happening to him, what forces are being applied, and what effects do these forces have on him? (Module 1 problem).*

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S8: *With these questions you are supposed to know the algorithm because there is no way to get R_1 without knowing R_{2X}, so, firstly, you have to link things up. You will have to understand the question, you will have to make your own sketch of the problem, and if you can't draw the sketch, then you'll have difficulties in understanding the problem... You do the first part (working out the force) knowing that you are going to use it in calculating the moments. The ultimate goal is to work out the moment about a certain point. This is where conceptual understanding comes in. You do not memorize these things, you have to understand them. (Module 2 problem).*

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S14: *It is like...with this problem one needs to identify the velocity, that is the velocities and directions of car A and B and understand what happens as car A approaches car B. (Draws the diagrams). Firstly, you have to understand the question itself, understand in which direction either car travels and which car horns the frequency and which one hears the frequency...*

R*: *Why is identifying that information important?*

S14: *It is important because in your calculations (the Doppler equation) you have to indicate the direction by assigning either a negative or a positive sign for the velocities. When a car moves towards you, you know that its velocity is positive. (Module 4 problem).*

Although the problems were focused upon within the conventional context of the application of physics principles, Newton's Second Law in component form and the Doppler effect respectively, the students interpreted the problem in the light of their own familiarity[xvi] with the problem. In all three descriptions, the students focus on the importance of understanding the problem. With regard to the application of Newton's Second Law, this means being aware of the implications of dealing with a "Newton II type" of problem with and without acceleration, which required the students to identify the forces acting in both x- and y-directions.

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*R stands for Researcher

With the application of the Doppler effect, it meant paying attention to the designation of the sign convention. The type of scanning indicated (simultaneous identification of problem-type and algorithmic skill) allows for the conscious delineation by the students of both the qualitative essence and consequential aspects (as per sub-question) of the problem.

- **scanning (ii): "mindful repetition" in attending to the perceived dominant features of the problem**

S2: *The first important thing is when you first look at it; you must understand what the problem is all about…*

R: *What do you mean?*

S2: *When you look at it, you must be able to think about it and draw a diagram that will show you where everything is…since this is a Newton II type of a problem, the forces are very important because … in order to work out your acceleration you need to know the forces acting and the role they play in the x- and y-direction. You need to be excellent in identifying the forces, if you miss one force, then you get the whole thing wrong. This is what everybody should know on their fingertips, drawing free-body diagrams, isolating the body that is very important. You cannot go through this problem without these steps. The next thing is to know how to resolve your forces in the x- and y-direction because once you know that you will have a set of equations to use and from there it is just mathematics. (Module 1 problem).*

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S8: *Yes, I remember that problem, and when I studied, I did some of the problems relating to the ladder. I did the whole problem. I had to understand that when they say that the ladder is in equilibrium it means that it is not moving. One has to understand things like if the ladder were not in equilibrium, then there would be a force added on top of the forces we work out. Friction would be added, because the ladder would be moving in a certain direction, and friction would be in the opposite direction. This brings in another* *force, which is going to create problems when we do the calculations. The thing is, it is not stated anywhere in the question that the ladder is in equilibrium.*

R: *What clues are provided in the question to tell us that the ladder is in equilibrium?*

S8: *It is the first part, which says a uniform ladder.*

R: *So, to you the word uniform means that the ladder is not moving?*

S8: *Yes, and if you did not know this, you would be tempted to bring in an extra force. Friction in this problem is not included. Friction only comes in when something is moving. (Module 2 problem).*

The students focussed on what it meant to understand a problem conceptually and – significantly - what kind of "repetition" is necessary for bringing about this form of understanding. Their analysis of the problem targets what they perceive to be the underlying clues, which are based on their familiarity with the problem. In determining either the presence (with respect to the Module 1 problem) or the absence of acceleration (with respect to the Module 2 problem), the focus is on previous problem-solving encounters. This is apparent in how the students focus on the forces and their effects on the cyclist (Module 1) and the disequilibration that would be brought about by an "added force" on the ladder (Module 2). It is this familiarity with the problem that seems to provide the students with a conceptual framework with which to analyze the problem. This "mindful repetition" can be argued to be the guiding feature of the problem solution.

- **scanning (iii): intuitive interpretation deriving from a perceived difficulty with problem content**

S3: *Well they ask this question about the speed of the motor cycle when... the engine stalls. OK I thought this was going to be really complicated physically, but as I understand it... I*

> *thought OK, if the engine is going to stall, but then the motion is going to continue, and I knew that it was not going to be fast, it could not be fast, I just thought so... I knew the speed would have to decrease. That was my own thinking. (Module 1 problem).*

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> *S5:* *I knew that I had problems with the application of Newton's laws, but I tried my best to answer the question although I made mistakes here and there... I realized that the way you interpret the questions could be problematic... Firstly, they wanted to know... because they've given me the initial speed the next thing they wanted to know is after he has covered a distance of 100m what will his speed be then. It was for the first time that I heard the word. I could not interpret the question because I didn't understand the word stall. (Module 1 problem).*

Although the students claim to have difficulties with the application of Newton's Second Law, they (correctly) set out the principles applicable to each part of the problem: motion on a plane and Newton's Second Law. Furthermore, they highlight what is to be determined, i.e. the horizontal distance covered by the cyclist as he jumps on to the other side of the river. But there is no clear interpretive framework. Contrary to the first type of scanning, where the students are able to discern both the essence of the problem and the algorithmic aspects of the problem (based on a conventional interpretation of the problem), this type of scanning illustrates an analysis based on what is essentially an intuitive interpretation.

The students' concern relates to the use of the appropriate physics descriptors with which to make sense of the problem. In the first description, the knowledge system is guided by intuitive knowledge - as conveyed by the last line "I knew that the speed was going to increase ... that was my own thinking". The perceived difficulty therefore lies in the student having to argue for the cyclist's decrease in speed. In the second description, the difficulty lies in deciphering the meaning as well as the implications of the word "stall" in the light of the application of Newton's Second Law of motion.

4.2.1.2.2 Illustrative data analysis of what the students using Strategy B focused on in the moment of scanning

Whereas the scanning (organization of knowledge system) of the students categorized as having used Strategy A reflected an explicit exploration of the *meaning* of the problem, the scanning of the students categorized under Strategy B was essentially "algorithmic" or "sequential". The exploration of the overall meaning of the problem as well as the features dominant to the problem is kept to a minimum. They were more concerned with finding the appropriate algorithm.

- **scanning (iv): pattern recognition according to convention**

> *S7:* *You just follow the convention; the two conditions for equilibrium, and then you first use the one to find unknown forces like using the reaction forces...and the second one to calculate torque... (Module 2 problem).*

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> *S12:* *You basically had to read the question and then apply...choose the right formula and apply it (Module 3 problem).*

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> *S10:* *(The lecturer) told us that we have to simplify the circuit first before answering any questions. Because I know electricity I just applied my information that I studied. We did some of this stuff in Matric* so it was easy for me. I knew how to do the series and the parallel connections. (Module 3 problem).*

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*Short for Matriculation examinations, the national school leaving examinations in South Africa.

These descriptions point to the criteria according to which the students interpret the problem statement. According to Laurillard, this interpretation focuses "attention, not on the problem itself, but on the problem as set by a teacher in the context of a particular course" (Laurillard, 1984:131). Furthermore, this way of focusing on the problem (particularly prevalent in Module 3) depends strongly on familiarity. The impression is created that the greater the familiarity with a particular algorithm, the lesser the need to engage with the problem conceptually.

This scanning can be contrasted to the "mindful repetition" of scanning (ii) (Strategy A). In scanning (ii) the students' repetition of a (familiar) algorithm was underscored by a conceptual framework. The students categorized under Strategy B did not show a similar concern in their reflections on the problem. They seek to recognize patterns to which they can match formulae. This observation can also be made in the case of certain students whose descriptions focused – partially at least - on the simultaneous identification of problem-type and algorithmic skill (see scanning (i), Strategy A), as is apparent in the descriptions below.

S4: *(Reads the problem). In the sketch below a stunt driver approaches a ramp on his motorcycle at a speed of 40m/s, at a speed ...which means it's* v_0*, I think. (Writes 40m/s on the board and carries on reading.) The combined mass of the driver and the motorcycle is 200kg, (writes on the board mass = 200kg and the ramp is 100m long, distance 100m). The coefficient of kinetic friction between the tyres and the road is 0.2 which is friction, no this is* $\mu_k = 0.2$*. Then the first question says draw a body diagram of the combined driver and the motorcycle. You isolate the body there; the mc will look something like this... I'm not good at drawing. We have the downward force which is the weight acting on the driver and the mc which is mg and then the upward force which is perpendicular to the surface and we call it N because the motion of the motorcycle is this way, then you'll have friction* *in the opposite direction which is downward, you have F_k on this side…*

R: *Is this how you approached the problem in the test yesterday?*

S4: *Actually this is what I do with most of the problems. I don't just have to think about the problem first and what the problem wants because that is going to waste me some time. (Module 1 problem).*

In the first part of the description the student immediately translates identified given problem-provided variables into a free-body diagram. This explicit focus on the given data enables the student to correctly identify the 40 m/s as the initial velocity. (The rest of the students interviewed in this module failed to discern this velocity in their initial scanning). He chooses the system of coordinate reference axes and clearly identifies and labels the 3 forces acting on the cyclist. The student correctly states that the velocity decreases and that in this particular question no calculations are needed. The question whether the student actually understands the implications of the decrease in speed remains unresolved. He does not attempt to relate the algorithm to an "essence" of the problem ("I don't just have to think about the problem first…"), so he may conceivably be following an algorithm learnt in class. The exploration of the overall meaning of the problem as well as the features dominant to the problem is kept to a minimum.

4.2.1.3 What are the differences in the translation of the problems as reflected in students' strategies?

It is in this moment that descriptions and interpretations of the problem are actualized. Translation describes how the students execute those features elicited in the moment of scanning (the perceived significant concepts, principles and technical terms) in making sense of the problem. It particularly comes to the fore in students' transformation of the problem statement into a physical or a mathematical representation. Just as with scanning, we can look at the students' approach to translation from the perspective of a relevance structure guided by a conceptual framework (Strategy A) as opposed to one based on an algorithmic framework (Strategy B).

4.2.1.3.1 Illustrative data analysis of what the students using Strategy A focused on in the moment of translation

- **translation (i): simultaneous application of the underlying principles and the algorithm**

S8: *With these questions you are supposed to know the algorithm because there is no way to get R_1 without knowing R_{2X} so firstly you have to link things up.*

R: *If you were to talk to somebody who has been struggling with these problems, how would you explain the problem to that person?*

S8: *You will have to understand the question first, you will have to make your own sketch of the problem, and if you can't draw the sketch then you'll have difficulties in understanding the problem... You do the first part (working out the force) knowing that you are going to use it in calculating the moments. The ultimate goal is to work out the moment about a certain point. This is where conceptual understanding comes in. You do not memorize these things you have to understand them. (Module 2 problem).*

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S15: *Okay...(drawing a pictorial representation of the problem)...they say that the driver of car A is driving at 20m/s and sees a distant car, car B travelling towards him, he sounds his horn which is 500 Hz and the driver of car B hears a frequency of 560 Hz. So, I took car B to be the listener and car A to be the source. The reason why I say car B is the listener is because its frequency is higher than that of car A. If*

> *two cars are travelling towards each other the listener is supposed to hear a higher frequency than the source…*
>
> R: *Why is that…?*
>
> S15: *It is because the source travels towards the listener, it is unlike a situation where you have the source travelling away from the listener… We use the listener as a reference point…and ask is he moving toward or away from the source…if it's towards the source the listener hears a higher frequency and if it is away from the source the listener hears a lower frequency. (Module 4 problem).*

The students are simultaneously aware of the algorithm required as well as the concepts or principles guiding the various parts of the problem representation. Within this interpretive structure the given information is translated into a pictorial representation. The interpretive structure is evident in the students' willingness to "link things up" (S8) and to provide reasons for their decisions: "the reason why I say car B is the listener is because his frequency is higher than that of car A" (S15). It enables the students to attend to both the qualitative and quantitative aspects of the problem simultaneously.

- **translating (ii): "mindful repetition" in attending to the perceived dominant features of the problem**

> S8: *The definition of a vector is that it is a physical quantity, which has both magnitude and direction. In addition, a force is a vector, so that means if we consider the magnitude of these forces, we have to consider the direction as well. We have R_1, which moves towards the left. I chose my direction to be positive towards the right, so this means R_1 is going in the opposite direction, which means it is negative. R_2 has 2 components, R_{2Y} and R_{2X}. The one that I am dealing with is R_{2X}, because I am looking at the sum of the forces in the x-direction. Because R_2 is at an angle, then I have to consider the angle. R_{2X} is positive. Since there is no other force in the x-direction, I then do the same for the forces in the y-direction. (Module 2 problem).*

In the application of the conditions of static equilibrium, the student reminds himself that he is working with forces, which implies working with "physical quantities that have both magnitude and direction". The student moreover focuses on force as a vector. This discernment enables the student to identify and set up expressions for both the x- and y-components of the forces as well as the direction in which these forces are exerted on the ladder. The student is able to actualize his familiarity with a particular skill (vector resolution) in a way that indicates conceptual understanding.

Mindful repetition was however not only evident in students who regarded themselves as having understood the problem. It was also apparent where students showed awareness of their own shortcomings concerning the content of the problems, as is evident in the description below.

R: *Was this process as you described it clear to you as you were working through the problem?*

S1: *No, it was not clear. I didn't have the idea of the sum of the forces in the x- and y-direction. I had in mind the idea of the normal and the friction forces. What was clear was that friction had to be calculated because it relates to the acceleration. Because as the thing is accelerating, friction is acting downward and as they accelerate because they are on the ramp, the normal force acts on them. Therefore I concluded that the friction and the normal forces had to be calculated and from there, I calculated my things. I knew that to calculate the normal force I had to use the forces acting in the y-direction because the normal force is perpendicular to the incline, and I knew that my frictional force was acting downwards in the opposite direction in the negative x-direction, so I had to calculate my forces in the x-direction. (Module 1 problem).*

The student is unsure about how to solve the problem. She, however, applies her understanding of acceleration to the given information and systematically proceeds towards a solution. The initial understanding involves the association of friction with the body's acceleration. In addition, since there is contact between the motorcycle and the ramp, the student is able to further link the frictional force with the normal force. It is through these associations that Newton's Second Law in component form comes to be applied, as the summation of the forces acting in both the x and y-directions.

- **translation (iii): intuitive interpretation deriving from a perceived difficulty with the problem content**

In scanning (iii) I described an analysis focusing on the qualitative aspect of the problem. By contrast, the following descriptions represent a "strategic" matching of the given variables with appropriate equations in order to work through the sub-questions of the problem. The translation not only fails to give account of the relation between the symbols within a given equation, but also of the relation between the equation and the concepts involved. The following descriptions bring to our attention how the dominant features of the problem come to be constituted in cases where intuitive knowledge guides the interpretation.

The moment of scanning showed the students working with what seemed to be a qualitative understanding of the problem. The translation moment – which is the translation of the problem statement into a mathematical representation – however yields something different. We observe the students focusing on "what the teacher is looking for" (Laurillard, 1984), rather than dealing with the requirements of the concepts perceived to be involved in the content of the problem (in the descriptions to follow: Kirchhoff's loop rule and Newton's Second Law). One could argue that this development is the result of what was identified during the moment of scanning as "a lack of appropriate physics descriptors".

S13: *Working out the terminal voltage of the battery there... there was something about...should we have used that Kirchhoff's loop rule or whatever...to work out the terminal voltage?*

R: *What is your understanding of terminal voltage?*

S13: *Isn't it the voltage across the terminals?*

R: *Explain how would you have used Kirchhoff's law to work out the terminal voltage of the battery?*

S13: *(T)hey say something like...if you go across a resistor from positive to negative then this side is positive and that one is negative, it is like going down, meaning it (electric potential) goes down. IR becomes negative, that's what I did. So I took... I did not know how to work it out for the parallel ones on the side so I took the resistance as the equivalent resistance and the current as the equivalent current; that is how I did it! (Module 3 problem).*

Although the student expresses difficulties with the question at hand, she is prepared to explore how she used Kirchhoff's loop rule. In her questioning of how she understands Kirchhoff's loop rule, the major source of difficulty that comes to the fore is her failure to focus on what the loop rule expresses in rounding the circuit (conservation of energy - i.e. the net potential change is zero). The way the student uses Kirchhoff's rule to work out the terminal voltage creates the impression that she is aware of the fact that if a charge were to move around the closed loop, its energy may be decreased in the form of a potential drop (IR). (Numerous research studies on students' conceptions of electric current point to the abstract nature of the concept of electric potential – for example, see Cosgrove and Roger, 1983; Warren, 1983). Thus, in determining the terminal voltage of the battery (which is the potential difference across the *emf* terminals), the student uses Kirchhoff's rule by equating the terminal voltage with the potential difference across the resistance ($R_{eq.}$) in the expression: $V = IR$. The R in this equation does not refer to the external resistance only, but encompasses the internal resistance of the battery as well, which explains why the terminal voltage is finally given by: $V = \varepsilon - IR$ (with R referring to the equivalent resistance). In the student's understanding the terminal voltage is given by both the *emf* and the product of the current and the equivalent resistance.

S3 : *I wrote something like this: Force is equal to mass times acceleration, and then I realized that I am getting away from what I am supposed to do. I had 2 things in mind, Newton's law and the equation of motion in a straight line. Then I thought I am going to have to put this thing in component form… So, I said a force is equal to mass times acceleration. It looks simpler than the one where you have to say this squared minus that so I thought... let me just use this. I said the force here was 2000 Newtons, and the mass was 200kg…I found the acceleration to be 10 metres per second. I had to think about… if he was moving at 10 metres per second squared, how fast that was and everything given this distance. I ended up using the other equation:* $v_f^2 = v_o^2 - 2as$, *I tried to find acceleration using this equation.*

R: *But then you had already worked out the acceleration there...Why did you have to calculate it again? What were you hoping to achieve?*

S3: *I was just... trying to make sure that I am doing the right thing. And so I said the speed was 40... and then the initial speed was zero, and the acceleration and the distance…I had to assume that... here the speed is 40, I know that... this is where all the principles come in. Maybe it is because I knew that I was trying to find acceleration, and so I thought, let me just make this zero, and calculate the acceleration at this point. (Module 1 problem).*

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S5: *(Drawing a free-body diagram)…I have the gentleman here, his acceleration is due to the kinetic friction…this is my normal force, this is my weight, and my weight is always vertical. This is the surface and the normal force is always perpendicular to the surface. Here the normal force is not perpendicular to the surface so I work out* $mg\cos\theta$, *my* θ *is against the normal force (N). Since I know that my normal force* $mg\cos\theta$ *must be equal to zero because there is no vertical acceleration. Therefore* $v_0 = 40m/s^2$. *Since* $F_k = \mu_k mg\cos\theta$, *then I will substitute the answer back into*

> *Newton's Second Law formula…I know the mass and I can then work out the acceleration, … since I have worked out my acceleration I have the distance and the initial velocity, I can then work out the final velocity using:* $v_f^2 = v_0^2 - 2as$. *(Module 1 problem).*

The description shows a limited use of the appropriate physics descriptors with which to explain how the speed of the cyclist would change as he goes up the ramp. In the moment of scanning both students claimed to have used Newton's Second Law to work out the acceleration. Noting the difficulties in its application in component form, S3 strategically uses $F = ma$ to work out acceleration (due to gravity). She subsequently uses the kinematic equation: $v_f^2 = v_0^2 + 2as$ to confirm the acceleration. S5 on the other hand, having brought to the fore the difficulties inherent in vector resolution (a skill which is often taken for granted in the application of Newton's Second Law in component form), comes to attribute the frictional force as the *only* force that brings about the cyclist's acceleration. This procedure reveals a rather astute way of applying Newton's Second Law. According to the student, the forces acting in the x-direction are given in the expression: $F_k = \mu_k N = ma$, while the forces acting in the y-direction are given by the expression: $F_y = N - mg\cos\theta = 0$. Since $F_k = \mu_k mg\cos\theta$, the student feels justified in substituting the equivalence of the normal force (*N*) into the equation for working out friction. In this way $F_{net} = ma_x$ is interpreted as $F_k = ma$. (It is therefore friction – rather than the resultant force - that is focused upon). This use of Newton's Second Law is an example of what Hewson (1987) calls the ability to "Newtonize" (Ramsden[xvii], 1988:56). The student is using Newton's law, but using it in his own way!

4.2.1.3.2 Illustrative analysis of what the students using Strategy B focused on in the moment of translation

In this category, the students' problem analysis and execution of the features elicited in the moment of scanning (the perceived significant concepts, principles and technical terms) are characterized by a procedure of "pattern recognition and formulae duplication" (Caillot and Dumas-Carre, 1989). The students' association of problem solving with the determination of a numerical value is evident in that they almost seem to have an "over awareness" of the test requirements (Ramsden, 1988). They furthermore use the mark allocation as a guide for the time they need to spend in engaging with the problem, rather than to focus on the content of the problem and the result that the translation represents. There appears to be no inclination to explore conceptual coherency in the act of translation. (The effect of these factors on students' problem-solving will be further discussed in Chapter 5).

- **translation (iv): application of the algorithmic requirements of the problem according to convention**

S4: *We now have to work out the speed,*

$speed = \frac{distance\ traveled}{total\ time\ taken}$ *; we are given the distance 100m divided by the total time taken. No… no it seems like we don't have the time, this would then be hopeless. How do we work out the speed…OK this is how we do it. We need to get the time first in order to get going. What I thought at that particular moment in the test was that any equation that I could apply that would give me the time, I am going to use it. Therefore, I looked at my equations and I said* $\sum F = ma$.
If we make t the subject of the formula we will have:

$$t = \frac{0 - 40m/s}{4.4m/s^2} \ldots$$

R: *Why is your final velocity zero?*

S4: *Because I'm not given the final velocity. When I'm not given a variable I always put in zero ... (carries on with the problem) ...and* $mg\sin\theta$ *... since we do not have negative time, we ignore the minus sign. So, the speed will be equal to... we will apply the equation of motion... (Module 1 problem).*

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R: *What about the internal resistance, you won't include it?*

S11: *I did a couple of examples from the textbook and saw that they never include it, so I came to that conclusion myself, that it is not necessary to include it when working out the equivalent resistance. (Module 3 problem).*

******

S11: *To determine the current through the simple circuit, I used the formula:* $I = \dfrac{\varepsilon}{r + R}$

R: *What does this formula mean...?*

S11: *Firstly, I know that this is the formula to use because I have the emf and I have calculated the resistance and I'm given the internal resistance so...*

R: *Does it mean that if you were not given maybe two variables you wouldn't have used that formula...*

S11: *Yes.*

R: *So when you finally worked out the current and found it to be 0.89A, how did you interpret it?*

S11: *I said this is the current that flows through the circuit... (Module 3 problem).*

We observe in these descriptions how the moment of translation is essentially a manipulation of the equations to determine the required unknowns. Through the use of the equation of acceleration (as the ratio of a change in velocity over the change in time -S4), the final velocity is arbitrarily given a null value and the negative sign simply disregarded because, as the student argues, " we do not have negative time". This kind of practice would fit McDermott's (1984) observation that even students who do well during assessment do not necessarily use a qualitative understanding in applying the ratio. The decision whether or not to include the internal resistance in determining the equivalent resistance and the current going through the simple circuit, seems to be driven by equation manipulation more than anything else. The influence of the presence of the internal resistance on the current in the simple circuit is not brought to focal awareness in S11's reflection.

> *S4:* *To find the sum of the forces...the main thing I have to calculate is acceleration. To get acceleration we have to apply Newton's law which states a body will remain in a state of uniform motion unless acted upon by an external or resultant force ... because this body is moving it is not at rest, we are going to apply Newton II which states* $F_{net} = ma$. *(Module 1 problem).*

The student pays attention to the hint that acceleration has to be calculated first before one can calculate the velocity of the cyclist at the edge of the ramp. Without any hesitation, the student links the cyclist's acceleration to the forces acting on him. This is a significant development. For the first time in this module we observe a student connecting the first part of the problem (i.e. the drawing of the free-body diagram) with the second part of the problem (i.e. the application of Newton's Second Law in order to find the acceleration necessary to determine the speed at the edge of the ramp). As we shall see in S4's and S7's descriptions below, however, there is no actual exploration of the identified concepts.

> *R:* *... Why would the cyclist's speed decrease?*
>
> *S4:* *...What I can say is...you see with this motor cycle, I think there is no force applied on it, you see the initial force that pushes it to go up. I do not see that force. The only forces that are acting on the body are the ones I have already mentioned.*

> *I mean a force that will be initially given, let us say that this was not a motorcycle but a ball. You give a ball an initial velocity, you push it up and it will go up the incline at a certain speed. Even the ball will decelerate...because it will have to overcome the incline...Once I read a physics book that was back in Matric, I have not read the one we are using now. Mostly these are the things that I learnt at high school, that when a body goes up an incline its acceleration is downward. So, as it goes up it decelerates, no, no ... is it always? This one as it goes up its speed will be decreasing ...(Module 1 problem).*

The student correctly focuses on the forces acting to confirm that the speed of the cyclist does indeed decrease as he goes up the ramp. Firstly, the student points out that when the cyclist stalls, there is no force exerted in the direction of motion. The only forces acting on the cyclist would be the ones already noted in the free-body diagram. However, when asked to explain why the force would decrease, it is evident that he did not expect the question and his response is not as quick and to the point as his response to the question on the effect of stalling on the cyclist's speed. He seems to be "ruffled" by the question. He then uses an analogy to argue his point. Upon realizing the difficulties inherent in his explanation, he shifts his focus from the forces acting on the cyclist and points to the incline as the agent that retards the motion of the cyclist. Ultimately the student resorts to the authority of the textbook. This failure to explore the taken-for-granted application of previous knowledge and concepts is further illustrated in the description below.

R: *Just explain what that notation: $\sum F = ma$ stands for. Think of someone who has never done physics before, and you had to explain to her what it means. What would you say? Like what do you mean by a resultant or net force?*

S4: *To get the force acting on the body you have to find the mass and the acceleration. How can I explain it... er...resultant force ...I think ... the only situation in which I can explain the resultant force is that it is the force applied on this body.*

R: *The forces exerted on the body...?*

S4: *Not all the forces.*

R: *Make me understand that…*

S4: *Not all the forces…I can say if this was a ball and it was given an initial force then I could say that that is the initial force … That is the resultant force, the force which is given to the body initially, that I can say, is the resultant force (long pause). (Module 1 problem).*

What the reader will immediately observe is the student's uneasiness in relating what a resultant force is. The long pause may be read as a sign of reluctance to pursue the question of the difference between the initial and resultant force any further. In fact, the student regarded the injunction to explore the concepts beyond the symbolism of the equations as tedious (the student clearly does not see the need to explain) (see appendix 2, p. 178).

The student refers to the notion of an "initial" force to explain what a resultant force is. According to the student, the initial force is the resultant force. However, if we consider what he said earlier on, namely that the *absence* of an initial force would cause the cyclist's decrease in speed, there is clearly a contradiction in his reasoning. If there is no resultant force there can be no change in velocity.

R: *…(W)hen you say the system is in equilibrium, what does that mean?*

S7: *OK, I will say that…. can I just finish the problem please… (laughter) … (after some time). OK, I used the first condition of equilibrium to calculate R_1…the reaction force, the force that the wall exerts on the ladder, and that is what I found, now, I am going to use the second condition of equilibrium and I am going to choose a point of origin. The point I choose is here at the bottom, …(laughter) (he works on the problem for some time). After choosing a point of origin, I am going to take the forces about this point i.e. torque and how is that going to help me? It will help me find the distance that the man has to climb. When the ladder starts to slide the man will be some distance up the ladder, OK…I am going to use his*

> *weight in calculating the sum of the torques. (Module 2 problem).*

In reading the problem statement, the student's attention is drawn to the following: (i) the drawing of the physical representation of the problem as well as a free-body diagram (the forces acting on the system are correctly identified and clearly labelled); (ii) the fact that the ladder is "uniform"; (iii) the static frictional force that would prevent the ladder from slipping and (iv) the fact that the system is in equilibrium which, according to the student, implies the use of the first and second conditions of equilibrium. Again, it is difficult to ascertain what the level of the student's understanding of the two conditions is, because he does not attempt to reflect beyond the symbolism of the equations. What we observe is a mere declaration of the conventional application of the two conditions of static equilibrium.

4.2.1.4 What are the differences in the re-interpretation of the problems as reflected in students' strategies? (Strategy A)

As mentioned in the introduction, the moment of re-interpretation only featured in certain students' problem solving strategies – categorized as Strategy A. There will therefore be no "Strategy B" under this heading. The moment of re-interpretation was characterized by students' questioning of their own ways of focusing on the problem. In this sense, the moment of re-interpretation can be seen as an example of *scanning for change*. The students are seen to engage in a search for an interpretive framework with which to make sense of the problem task.

Strategy B was largely characterized by the re-enforcement of the conventional problem solving algorithms associated with the problem tasks at hand. On the other hand, Strategy A involved a kind of reflection, which prompted a "stepping back" in the exploration, and execution of the problem solutions. It is this stepping back, as evidenced in the moments of scanning and translation, which led to the different ways of focusing on the problem tasks – which are also different ways of re-interpreting.

As explained in section 3.5.1.1 in Chapter 3, the interview context lends itself to the moment of re-interpretation. Two types of re-interpretation were identified: explorative and evaluative. Evaluative re-interpretation is reflected in the descriptions of certain students of how they evaluate the reasonableness of their solution representations. At issue are the criteria for evaluation of the solution, which brings to the fore issues that do not only relate to the content / context aspects of the problem, but also to the level of *commitment* to the problem solution (see Laurillard, 1984:131). As such, evaluative re-interpretation was found to be underpinned by relatively appropriate physics descriptors. Explorative re-interpretation, by contrast, did not give rise to an evaluation of the solution representation, in that it failed to formulate a specific knowledge structure. It was notably identified where a knowledge system presented itself as *intuitive*.

4.2.1.4.1 Illustrative data analysis of what the students (Strategy A) focused on in the moment of re-interpretation

- **re-interpretation (i): evaluative re-interpretation**

The descriptions below offer examples of students not just exploring the problem task, but questioning their own interpretations or algorithms. In this sense the students arrive at a change in understanding, which is a shift in focus.

> *R:* *OK, now that you have worked out acceleration, how did you proceed from here?*

S2: *Instead of $v_0 = 0m/s$ I should have used 40m/s, obviously I understood it wrong …It will make sense then to use the correct values of v_0. We will use the equation: $v_f = v_0 + 2as$, we will have $v_0 = 40m/s^2$. Our acceleration is the one that I calculated $-7.6m/s^2$. You do not have to put a negative sign if you are working it out, 'cause that just shows that it is in the opposite direction (Module 1 problem).*

Once the acceleration is worked out the student proceeds to using the kinematical equation: $v_f^2 = v_0^2 - 2as$ to find the magnitude of the velocity of the cyclist at the edge of the ramp. During the test S2 assumed that the cyclist started from rest ($v_0 = 0m/s$). She now sees the initial velocity as 40m/s. In the next description we see how the student tries to make sense of her unresolved understanding of the implications of the negative acceleration, when she tries to use the new values of the initial and final velocities.

S2: *Er … because I'm looking at that 40 as my initial velocity, so now I want to see at what speed will he be travelling here at the edge… and we get 58.8m/s…*

R: *Does it make sense?*

S2 : *His final velocity is bigger than the initial one…I was thinking it would be less because the speed will decrease… (Module 1 problem).*

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S2: *This (whether to include the negative sign or not in the equation) confuses me sometimes. Nevertheless, I think if we use it (the negative sign of acceleration) here, it would make sense. My final velocity will be less, ya. OK let us try it again, let us put a negative sign. My answer does not make sense with positive acceleration. The final velocity cannot be greater than the initial velocity in this case because the velocity has to decrease … because the engine cuts out there, so obviously the speed will decrease as the motorcycle goes* *up. Yes (doing the calculation),* $v_f = 8.9m/s$, *but yesterday I did not get something like this.*

R: *Let us look at what you got. (S2 and R look at test script). Yes, yesterday you took your initial v to be 0m/s. Are you happy with your calculation today?*

S2: *Yes, because I have checked that everything is right. (Module 1 problem).*

The student now begins to see the importance of including the negative sign in working out the final velocity of the cyclist. She is able to evaluate her new result (58.8 m/s) against her expectations of a decrease in velocity. Through monitoring how she went about doing the problem in the test *and* during the interview, she has become aware of changes in her own understanding of the problem. She is able to interconnect ideas: she focuses on the fact that the engine cuts out at the beginning of the ramp and appreciates the need (albeit in a limited way – for purposes of mathematical calculation) to use the negative sign as a result of it. She is therefore able to justify the decrease in velocity as the cyclist goes up the ramp.

Research on problem-solving has highlighted the importance of "cognitive monitoring" (see Dufresne *et al.*, 1992). Although phenomenography has no such cognitivist view it does propose that students bring certain relevance structures to a learning situation and that these learning structures mediate the constitution of understanding. And closely related to the idea of monitoring what one does in a learning situation is the recent theoretical development in phenomenography of the concept of "reflective learning"[xviii] by Linder and Marshall (in press: draft page 25), which derives from the notion of metacognition.

The above (S2) illustration of "reflective monitoring"[xix] of what students do during problem-solving indicates that through conscious reflection and testing of their ideas, students do in fact show themselves capable of developing their relevance structure in this way. A further illustrative example is given below.

S8: *I am thinking of another way of getting R_2. I think there are 2 ways of working out R_2. Let us make a triangle. This is R_2, this is R_{2X}, and that is R_{2Y}. These are all vectors. I know the value of R_{2X} and R_{2Y}. I can substitute those values and use Pythagoras' theorem to work out R_2. In order to get R_2 we need to sum those two up… I do not think that the way in which I did it is correct because as I said I did not include R_{2X} in getting R_2.*

R: *Why do you think you should have used R_{2Y} and R_{2X} and not R_2? And how would you have used R_{2Y} and R_{2X}?*

S8: *R_{2Y} and R_{2X} are components of R_2. That is why…I would have said the moment about the point = distance from the point where R_{2X} originates to R_1…yes that is what I was supposed to have done. R_{2Y} and R_{2X} are forces, hey…then the distance from the point would be 8 times R_1 because $R_{2X} = R_1$. This would be positive. The distance from the point to R_{2Y} … wait a minute, …how do I get the distance using R_{2Y}? The distance would be minus* $10\cos 53^{\circ}$. *I've got the weights as well, the distance from the point to the weight of the painter will be 2.5m, they say that the painter is 7.5m from the top of the ladder; we know that the length of the ladder is 10 so you just subtract 7.5 from 10m. (Module 2 problem).*

Our attention is drawn to the student's use of his knowledge of vector resolution in order to change the way he understood the problem during the test. By focusing on the forces as vectors, the student realizes that he should use Pythagoras' theorem (i.e. the square on the hypotenuse of a right angled triangle is equal to the sum of the squares on the two sides) to work out the force that the ground exerts on the ladder (i.e. R_2). The student's competency in resolving vectors moreover provides the framework within which the student is able to trace and rectify the result he obtained during the test (by using the product of R_2 and the 8m distance as one of the torques).

The relevance structures that come about through the evaluative re-interpretation illustrated here may to some extent remind us of Marton's response to diSessa's notion of p-prims. As seen in Chapter 2 (see section 2.4.3), p-prims (phenomenological primitives) refer to how students make sense of what they do in problem-solving. They constitute what diSessa refers to as "the interface between experience and formalizable physics" (diSessa, 1993:193). It may be tempting to look at the above descriptions with the aim to explore how this type of "interface" knowledge structure becomes constituted. Phenomenographic analysis, however, does not concern itself with questions of this nature: questions that seek to account for how the person-phenomenon relation is established. What is of significance is how this relation "changes as time passes" (Marton and Booth, 1997:139).

- **re-interpretation (ii): explorative re-interpretation**

As was the case with evaluative re-interpretation, explorative re-interpretation showed students questioning their interpretations or algorithms through a constant monitoring of the solution representation leading to a change in understanding. The crucial element missing in explorative re-interpretation, however, is the formulation – and imposition – of a knowledge structure against which to evaluate the change in understanding (shift in focus).

In the following description, the student is asked to explain how he worked out the forces acting on the cyclist. It is in the process of reflection upon this strategy that the student begins to realize that he did not include all the forces that are acting on the cyclist. He realizes that, since he has to work with the y-component of the weight, there should be an x-component as well - even though he cannot justify it formally.

R: *In the y-component … you say you used the forces acting in the y-direction to work out the acceleration, but earlier on you pointed out that acceleration in the y-direction is zero… Make me understand your reasoning here.*

S5: *What I meant here was the way in which I worked out N. This is the free-body diagram for N only and not for the whole system. And I took the whole:* $N = mg\cos\theta$ *(worked out from* $N - mg\cos\theta = 0$*). So, instead of substituting the normal force (N) into* $F_k = \mu_k N$. *I substituted it into* $F_k = \mu_k mg\cos\theta = ma$.

R: *Does what you have worked out make sense to you?*

S5: *(Pause) I substituted like that… but this is not a complete diagram because it is a diagram for the y-direction only, the guy has got the component in the x-direction, so* $mg\sin\theta$ *will have to be included … pause …*

R: *Do you think that you can take yourself a step further than you did in the test? As you were suggesting, maybe you should look at the forces that are acting in the x-direction as well?*

S5: *The application of Newton II should give me the solution… (continues writing on the board)… let me check this out … OK, this is* $mg\sin\theta$*… no, there is not just one force… the sum of forces in the x-direction is the frictional force which is always in the opposite direction of motion which is minus… and* $mg\sin\theta$ *is equal to ma:* $\sum F_x = -F_k + mg\sin\theta = ma$. *The cyclist is accelerating, meaning that it is not constant… its velocity is changing all the time.*

R: *Just explain what you are doing there on the board.*

S5: *I don't know how to go about solving the problem because I'm not confident. I do not know what to do. You see, these are the kinds of problems I was experiencing in the test. Like what I could not understand now was the way forward in solving this problem. (Module 1 problem).*

The student explores the forces that act in the x-direction on the cyclist. In his re-interpretation of the problem, S5 realizes that there is not just one force acting in the x-direction, but two. He identifies these forces as friction and the x-component of the weight ($mg\sin\theta$). He clearly has difficulty with the application of Newton's Second Law in component form, in that even though he has identified the forces acting in the y- and x-directions, he cannot proceed further to determine the magnitude of the cyclist's acceleration. Unlike the other students in Module 1, S5 is able to link the cyclist's acceleration to the change in velocity that the cyclist will undergo. However, his failure to go further (to determine the acceleration) points to the complex nature of how new experiences are made sense of in terms of what is already known. It is the articulation of this change in the students' relation to the phenomenon - which may appear to indicate a gap (a missing part in the relevance structure) with which S5 above can make sense of changes in his understanding of acceleration. This observation points to the complex nature of the evolution of understanding in learning through the medium of problem-solving (where there's a simultaneous interplay between conceptual understanding and the ability to apply it) (see Laurillard, 1984).

> *R:* *What about the next question, working out the current in the 6.0 Ω ?*
>
> *S13:* *I know that the current splits up here so we cannot use the current we calculated earlier. So... I think I was supposed to find the current through the 6.0 Ω resistor and the current through the 10.0 Ω resistor. We have these two resistors (4.0 Ω and 8.0 Ω) in parallel so the current through the 6.0 Ω resistor splits up again here... yes, the current in the 6 Ω resistor (laughs). I think I will have to work out the equivalent resistance of these three resistors (6.0 Ω, 4.0 Ω and 8.0 Ω) and then... I don't know... I'll have to find the current in the 6.0 Ω resistor 'cause the same current will go through the equivalent resistance of the 4.0 Ω and 8.0 Ω resistors because they are in series. (Module 3 problem)*

The focus on Kirchhoff's loop rule[xx] (see section 4.2.1.3.1 - translation moment (iii)) seems to have brought about a new way of looking at the problem. The student immediately realizes that she should have used Kirchhoff's second rule to work out the current through the 6.0 Ω resistor. She argues that the current splits into two (i.e. I_2 and I_3) when it enters the junction where the 10.0 Ω resistor lies into two (i.e. I_2 and I_3) when it enters the junction where the $10.0\,\Omega$ resistor lies parallel to the $6.0\,\Omega$ and $2.7\,\Omega$ resistors (from the positive terminal of the battery). Her understanding of the algorithm used to determine the resistance in series connection is useful in this regard. Although it follows from the student's reasoning that, once the equivalent resistance of the $4.0\,\Omega$ and $8.0\,\Omega$ resistors has been ascertained, the current passing through the $6.0\,\Omega$ resistor will be the same as that through the 4.0 and $8.0\,\Omega$ resistor combination, she is unable to represent this understanding mathematically. This difficulty is reflected below.

S13: *(T)he current that goes through the first one here, the internal resistance ($0.5\,\Omega$) is 18A...no... here I got 0.88A and that was the current in the simple circuit. Is the current in the simple circuit the equivalent current?*

R: *What do you think?*

S13: *I think yes it is... I have worked out the current in the first and found it to be 18A. This does not make sense, if 0.88 is the equivalent current, then how can the current here be more than 0.88?*

R: *Explain how you worked out the current through the internal resistance?*

S13: *I used I = V/R... I can see that it is wrong... I am expecting 0.88 A, because it is the current I got in the simple circuit, which means if we simplify these four resistors ($6.0\,\Omega$, $10.0\,\Omega$, $4.0\,\Omega$ and $8.0\,\Omega$), the current that goes through here will be the same as that through the internal resistance. Let me try something else here. (Works on her own for a while) I am lost now...*

R: *How far did you go? What is it that you find you no longer understand?*

S13: *I thought that the current through the four resistors, the $5.0\,\Omega$ and the $0.5\,\Omega$ is the same... because the current does not split... I just know that it has to be the same... I was just checking if I can get the current over the $0.5\,\Omega$ and the $5.0\,\Omega$ resistors but I can see that it is not the same. If I got the current over 0.5 to be the same as that over the $5.0\,\Omega$ resistor then I could have gotten the current over this $10.0\,\Omega$ resistor*

> *and the current over the combined four resistors. And if I add both currents then they should add up to 0.88 A. (Module 3).*

The student points out that the current running through the $0.5\,\Omega$ resistor should be the same as the one that runs through the $5.0\,\Omega$ resistor. The dilemma faced by the student is how to determine the current, using the knowledge that the resistors are in series. In confirming that the current is the same in all the resistors concerned, she assumes the voltage across each of the resistors in series to be the same. (In series combinations, the current through the resistors is the same but the voltage is different). This assumption explains her discrepant answer. Even though it is the result of an insufficient conceptual understanding of Ohm's law, the student is fully able to recognize the discrepancy in the answer she has obtained.

4.3 Summary of findings of Research Question 1

In responding to Research Question 1: what characterizes students' problem-solving strategies? three moments were identified: (i) scanning; (ii) translation; (iii) re-interpretation (explorative / evaluative).

Table 4.1 Summary of findings of Research Question 1

MOMENTS OF PROBLEM-SOLVING	STRATEGY A	STRATEGY B
SCANNING	Scanning (i) involves the simultaneous identification of problem-type as well as the algorithmic skill necessary for the application of the underlying concepts Scanning (ii): "mindful repetition" in attending to the perceived dominant features of the problem Scanning (iii) involves intuitive interpretation derived from the identification of a perceived difficulty with problem content	Scanning (iv) involves pattern recognition according to convention
TRANSLATION	Translation (i) involves simultaneous application of the underlying principles and the algorithm Translating (ii) involves "mindful repetition" in attending to the perceived dominant features of the problem Translation (iii) involves strategic application of intuitive interpretation	Translation (iv) involves application of the algorithmic requirements of the problem according to convention
RE-INTERPRETATION	Re-interpretation (i) involves a change in focus informed by a new relevance structure to evaluate solution representation (evaluative) Re-interpretation (ii) involves a change in focus remaining at an exploratory level (explorative)	No re-interpretation

The results obtained point to the following implications for physics learning. Students categorized as employing Strategy A (re-interpretation of the problem representation subsequent to scanning and translation) challenged their understanding of both the concepts and the algorithms they used. In this way, modifications of relevance structures / changes in understanding became possible, to which varied levels of commitment were expressed. The students categorized as using Strategy B (scanning and translation without re-interpretation), on the contrary, were more concerned with the formal requirements of the problem tasks than with their understanding of the content of the problem, and did not engage in a conceptual exploration during the solving of the problem task. The factors that were seen to bring about those two distinct strategies are the subject of Chapter 5, which explores Research Question 2.

CHAPTER 5

DATA ANALYSIS AND RESULTS OF RESEARCH QUESTION 2

5.1 Introduction: The importance of context

This chapter presents the results with regard to Research Question 2, which addresses the factors that influence what first year physics students do during problem-solving. An obvious point needs to be emphasised. This study's concern with physics learning through problem-solving is fundamentally a concern with physics learning / problem-solving *within a context*: the institutional context of a typical university department. Laurillard brings to our attention a very important aspect of the context of problem-solving. She highlights that, whilst with experimental studies the problem situation can be treated in isolation, the case is different for students solving problems as part of a physics course. In a physics course, "the problem is not an isolated event; it comes after a certain lecture ... it will be marked by a certain lecturer" (Laurillard, 1984:131). The solutions that students work towards will give account of one essential factor: *where* - under which conditions - do the students attempt the problems? "Each step and each strategic decision made", Laurillard tells us, "refers to the immediate *context of the problem* as it occurs in that course" (Laurillard, 1984:131). One can clearly recognize the phenomenographic perspective of this study in Laurillard's remarks. The intentionality central to the phenomenographic epistemology is *non-dualistic* – there is no specific divide between the act of knowing and the context in which it occurs. Marton and Booth make this point as follows:

> We cannot separate our understanding of the *situation* and our understanding of the *phenomena* that lend sense to the situation. Not only is the situation understood in terms of the phenomena involved, but we are aware of the phenomena from

> the point of view of the particular situation. (Marton and Booth, 1997:93. Emphasis theirs).

5.1.1 A brief description of context as used in this study: Institutional context

Research Question 1 (Chapter 4) explored the *content* (Laurillard, 1984) of the strategies that the students employed. This chapter, by contrast, explores what constitutes the *context* of these strategies. What do we mean by context? The notion of context is multi-faceted. Let it be stated at the outset that this study, being conducted within a university physics course, is obviously concerned with a certain type of *institutional* context. All the factors that influence the students' approaches to problem-solving – and the meaning they attach to physics learning – can *in some way* be said to derive from the fact that they are learning physics at an institution of higher education.

What this study is not concerned with, however, is the broader social (socio-political) "context" of the institution concerned. Situating itself within phenomenography, the object of the study is to show variation in ways of experiencing (of physics learning through problem-solving). The variation in experiencing which is our concern is regarded as non-dualistic; in other words, there is no projected "outside world" that would be a determining factor in its characterization (see Marton and Booth, 1997).

A certain type of institutional context – that of a first year physics course at an institution of higher learning – is, however, of significance. It is crucial to give recognition to the specificity of the disciplinary context and its implications for problem-solving. In other words, the discipline of physics constitutes the first and the principal context we are concerned with. The notion of enrolment is critical here. The outcome of learning is seen not only as the interaction between the students and the task, but, in fact, as a function of how students "enrol" themselves into the discipline of physics. Enrolment, as was discussed in Chapter 2, is closely linked to the notion of progress made by the students within a particular discipline. The two ways in which students insert themselves into "the disciplinary accumulation cycle of physics", highlighted by Nespor (1994:21), refer to "how students represent their experiences" in the ways of the discipline and "how they represent themselves and their own experience in stable mobile and combinable forms such as grades and transcripts" (see section 2.5.3). The idea of students representing themselves and their experience may be related to *personal context* (see section 5.1.3. below); the "forms" Nespor refers to offer a clear indication of the importance of the *setting* in which the learning takes place. This is discussed below.

Prosser and Millar clearly have a similar idea to Nespor's concept of enrolment when they state that to have learnt physics means to have acquired "the formal propositional structures of the discipline and the problem solving techniques that are appropriate to the discipline" (Prosser and Millar, 1989:526). It is precisely this *history* (background knowledge of problem-solving in physics) that distinguishes a physics learner from learners in other disciplines. It also follows that this (institutional) context refers to / gives rise to a variety of spatial *settings* (contexts) that are, in a sense, dependent on the institutional context. This study is particularly concerned with the implications of these settings, in that the students interviewed referred to them as specific spaces and opportunities for problem-solving. In fact, it is within these settings that the students' "history of problem-solving" is constituted: the lecture, the tutorial, the test, high school, etc.

5.1.2 Personal context

The idea that the physics discipline is a context can be taken further. We have already mentioned Nespor's reference to students' "enrolment" into the disciplinary accumulation cycle of physics. Indeed, apart from saying that the discipline-as-context refers to a number of physical *settings* (related to the institution in which the learning takes place), the discipline-as-context is also concomitant with how, in Nespor's words, students "represent themselves" in the discipline. In phenomenography the concepts of students' *intentions* and *conceptions* have been used in this regard. Gibbs *et al.* (1984) talk about "personal context". Personal context refers to those "attitudes and aims which express the student's (individual) relationship with a course of study and the university" (Gibbs *et al.*[xxi], 1984:165). It is through focusing on this personal context that "we can aim to present a more holistic description of students' experiences of learning" (Gibbs *et al.*, 1984:166).

Most studies concerned with the factors that influence students' approaches during problem-solving (see Laurillard, 1984; Prosser and Millar, 1989; Ramsden, 1984) bring to the fore the notions of intentions and conceptions of learning. In phenomenography "intention" is discussed in the phenomenological terms of intentionality, implying a unifying bond between the *psychic* and the *physical*. The term "conception" relates to "the meaning that people see in and ascribe to what they perceive" (Säljö, 1988:38-39). In this view the thought (conception) is never "merely" a thought, it is from its inception *intended towards something* (see Marton and Booth, 1997:84).

Obviously the intentions and conceptions of the students are as much constitutive of their history of problem-solving as the settings in which / through which the problem-solving occurs. In short, both intention / conception (personal context) and setting (physical context) influence what students do during problem-solving.

Rather than to establish a hierarchy between these two sets of factors (it would be impossible to argue that the one “precedes” the other), we may simply acknowledge the constant influence - and interaction - of both. Making essentially the same point, Laurillard states that students’ choice of approach does not “wholly” derive from their intentions, but also depends “on the nature of the problem-solving task itself and also on how the requirements are perceived” (Laurillard, 1984:143). Ramsden, for his part, sees the relationship between students’ approaches and their perceptions of the learning tasks to lie at a number of separate but interconnected levels (Ramsden, 1984:147). The two factors which he sees as having a major influence on students’ approaches are students’ “interest in the task” and their “previous experience of the area to which it relates”. He argues that these influences “are associated with” perceptions about how the work will be assessed as well as the range of choice of content and method of learning available in the situation.

5.1.3 A brief review of the interview setting

While students were attempting the given problems during the interviews, they continuously referred to the previous settings in which they had practiced problem-solving. In this way, different contexts of problem-solving (tests, homework / studying, lectures, tutorials) were at different times brought into the students’ focal awareness. The interview context can thus be seen as a problem-solving context through which other problem-solving contexts were “accessed”.

The main aim of the in-depth interview, as discussed in Chapter 3, was to provide for “simulated recall” – a mechanism through which the students could “relive” and recount their test problem-solving attempts. The interviews created a problem-solving setting in which not only the test problem-solving attempt was brought to the students’ focal awareness, but indeed, other problem-solving contexts (settings) meaningful to the student. The students’ descriptions illustrated which - and how -

specific aspects of the problem were focused upon. These descriptions were the subject of Chapter 4. In addition, their descriptions in many instances indicated the influence of various factors at work on their problem-solving. Of particular interest in Chapter 5, are the meanings (relating to their intentions and conceptions) the students attached to the various problem-solving settings to which they had been exposed.

5.2 ANALYSIS ACCORDING TO RESEARCH QUESTION 2

5.2.1 The meaning that the students attached to the different settings of problem-solving

A crucial concept for characterizing the meaning students attached to their various instances of problem-solving across different settings is the concept of *familiarity*. Before looking more closely at this concept and how it informed students' problem-solving strategies, we however need to describe in detail *from where this familiarity is derived*. Students' familiarity with the problem tasks was seen to stem from their exposure to the settings mentioned above (see section 5.1.1), specifically the settings of studying; the tutorial; the lecture; high school and the test.

The interview setting was discussed above (see section 5.1.3). It is not singled out as a separate setting here, seeing that it served as a mechanism of reflection through which the meanings of the different settings of problem-solving could be explored.

In the section below, descriptions are provided:

(i) of how students use particular settings (and – in the case of studying for example – the different means of studying at their disposal). How the setting is used is seen to reflect the influence of the physical context on problem-solving;

(ii) of how the students relate the physical context to their personal context – bringing to the fore their intentions and conceptions of problem-solving.

5.2.1.1 The setting of studying

Studying refers to how the disciplinary "tools" such as textbooks, lecture notes, study guides, problems (both lecture and tutorial problems) and equations were used by the students. It also brings to our attention the perceptions that students have of these means of studying. Studying not directed towards either test writing or homework assignments was rarely mentioned. Only a few cases of students studying for something other than the tests came to the fore, where students mentioned preparation for tutorials and lectures. Most students claimed to have studied in groups; the meaning attached to group versus individual problem-solving therefore became another interesting aspect of this setting.

(i) How students use the setting of studying

The analysis indicated that the students' use of the disciplinary tools, whether it be the textbook or the study guide, can be categorized as aimed at either reproducing or understanding the material learnt. The following descriptions provide a sample characterizing these two distinct ways of focusing on the disciplinary tools within the setting of studying.

> *S12: The study guide gives you a summary of what it is and it points you to a page in the textbook which you must concentrate on and then you read that part... There is a lot*

> *of…I can't say unnecessary information…but there is a lot of information that is not necessary in doing certain calculations, so you end up wasting time going through all that and you aren't going to remember anything. So, the study guide eliminates some of the unnecessary work in theory and it tells you exactly what you need to concentrate on (Module 3).*

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> *S15:* *I mainly use the tutorial manual for questions because they normally have questions that are not in our textbook, problems that are a bit difficult. They show you the calculations and explain carefully what you need to consider in working out the problems, so when it comes to the theoretical part you can relate it to what you saw in the manual. I find these two books very useful; I use it more than I use the textbook. The textbook's problem is that it does not provide answers to the most difficult problems. The study guide has the even numbered problems and it has the systematic problem solutions to these difficult problems (Module 4).*

The reader can see appreciation of the value of the study guide in both descriptions. The study guide helps in determining the critical aspects of the material covered. This is apparent in the lines: "it tells you exactly what you need to concentrate on" or "it explains carefully what you need to consider". The process of figuring out (or discerning) the most important parts of the material is made easier for the students in this regard. It allows better access to problem-solving techniques: - "there is a lot of information that is not necessary in doing certain calculations", and enables the students to better relate the theoretical aspect of the problem task to the problem-solving strategy: "when it comes to the theoretical part you can relate it to what you saw in the manual".

(ii) How the students relate the physical context to their personal context

Two distinct ways of relating the physical context to the students' personal context were identified. They respectively pointed to the process of repetition geared towards memorization and reproduction, and repetition geared toward understanding.

- **studying setting: repetition concerned with memory and reproduction**

> *S10:* *The lecturer did some problems with us; I went through those problems as a basis for my preparation for the test. The day before the test we had a tutorial and my friend said we must go over the problems we did in the tutorial (Module 3).*

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> *S7:* *...The lecturer did one example in class, I never wrote it down because I thought I would just memorize it ...(Module 2).*

******

> *S13:* *I decided I would do...I was like hopeless I didn't know what was happening; so I just thought I would memorize the stuff the lecturer might ask (Module 3).*

The above descriptions point to the importance the students attach to previous encounters with problem tasks: – "I went through those problems ... "; "I thought I would just memorize it ... ". These tasks were encountered in different settings, namely, the tutorial and the lecture. However, the way in which the students decide to treat the problem tasks in the setting of studying is characterized by memorization. The intention is clearly to reproduce them in a test setting, in response to the lecturer's hint that the particular problem tasks will be part of the test. The factors that play a role in the students' approach to the problem are clearly related to "external requirements" (Ramsden, 1984).

- **studying setting: repetition concerned with understanding**

> *S8:* *...(W)hen I studied, I did some of the problems relating to the ladder. I did the whole problem. I had to understand that when they say that the ladder is in equilibrium it means that it is not moving. One has to understand things like that (Module 2).*

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> *S2:* *I remember wondering how the tutors got the mg cos θ and so forth, but I think it helps to do more problems ... It gives one a better understanding. How does one know whether it is mg cos θ or mg sin θ? If you are only going to do one problem and go and write the test it will not be enough because you have not yet understood what you are doing. You have to go through quite a lot of textbooks that explain and tell you about the different component sets...(Module 1).*

As in the category of repetition concerned with memory and reproduction, the students in this category also claim to have had previous encounters with the problem tasks, in the lecture setting and the tutorial setting. What we observe, however, is an orientation aimed towards understanding the principles underlying the problems to be solved. This is apparent in the lines "when I studied I had to understand that when they say the ladder is in equilibrium it means it is not moving" and "I remember wondering how the tutors got the mg cos θ and so forth". The descriptions point to the students' awareness of the critical factors which need to be focused on when dealing with the problem task. It is through the process of exploration aimed at understanding the underlying structure of the problem tasks that these students' encounters with the solving of the tasks is repeated in a meaningful way - even though the students are motivated by the lecturer's hint about the problem tasks appearing in the test. Here there is little question of the external motivation seen in the previous category; the problem ta is done "for its own sake" (Ramsden, 1984).

5.2.1.2 The setting of the tutorial

At the University of the Western Cape collaborative work is encouraged amongst students. In small-group tutorial sessions (typically three students) aided by a tutor, students work through the tutorial problems. The collaboration encouraged in the tutorial is seen not only to promote student-to-student networking, but to link the students to the disciplinary tools they are supposed to master. Students are encouraged to bring their lecture notes and textbooks to the tutorial, the idea being to highlight and re-enforce the links between what students do in the various settings of first year problem-solving. The tutor's intervention is informed by the reflective practice espoused by Donald Schön (see conceptualization of the tutorial framework in Linder *et al.*, 1997). Although the tutorial setting as such was not referred to separately by the students interviewed, the problems encountered in tutorials and the manuals used were frequently mentioned in relation to other settings (studying and tests).

5.2.1.3 The setting of the lecture

Descriptions of the studying setting (see section 5.2.1.1) reveal the differences in how students interpreted the hint of the lecturer during a class (clearly related to the up-coming test) to "go over" the problem tasks in their preparation. As Roth and Roychoudhury (1994:5) point out, what happens in the classroom not only depends on how teachers conceptualize their roles, but also on how students perceive and conceptualize their learning as well as the (authoritative) role of the teacher.

(i) How students use the setting of the lecture

None of the students who referred to the lecture setting associated it with physics understanding. This does not necessarily mean, however, that the setting is not associated with learning (from the students' point of view at any rate); some students clearly appreciated the fact that they acquired algorithms during lectures (particularly in sections which they had never encountered at high school). One category was identified for this setting: the lecture as form of authority or convention.

- **the lecture as form of authority / convention**

S1: *I don't find class notes useful.*

R: *What do you find useful during the lecture?*

S1 : *Just listening in class. It is because I hardly ever take notes. I try to follow what the lecturer says (Module 1).*

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S8: *Like with this problem you need to know about the moment about a point, you need to know this. And this we learnt in class, it was the first time I came across this material. If I were given this problem without being taught how to work out the moment about a point I would surely be stuck (Module 2).*

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S14: *I go to lectures, but not always...I update myself on where they are...and try and read about it and so forth...*

R: *What made you decide to do that?*

S14: *You go to class, of course the lecturer will give you his understanding of how you should do it and he won't stress on some points...because there are small parts there that if you miss out on them you won't understand...but then he knows about it and he is good at it, but he won't go down ...this stuff*

> *is new to us...he won't go down to depth with it...like when you talk about the Doppler effect...it seems easy when you read it out and do it while you refer to your textbook, but when you have to put in the signs in the Doppler equation... to me it is very confusing (Module 4).*

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> *S13:* *With physics you go to class and you take notes, you do not have to understand the work. I mean you do nothing in class other than listen and take notes. When you hear that there is a test coming, you study maybe two days before the test. You go through your notes, mhhh...the formulas and that is it. Many people are doing it; most of us do it. We do not really understand it. Computer science is more practical you go to the lab all the time. It's continuous you have to know what happened yesterday in order to proceed to the next project (Module 3).*

The taken-for-granted view that you need to go to lectures in order to learn and understand physics is challenged in these descriptions. What is apparent in the above descriptions is the authority the students associate with the lecture setting, especially as represented by the lecturer and the physics discipline: "I try to follow what the lecturer says ..."; "The lecturer will *give you* his understanding ..."; "With physics you go to class ...". The setting of the lecture is strongly associated with the idea of enrolment (Nespor, 1994) into the physics discipline through acceptance of authority and convention – rather than understanding (see section 2.5.3). There is a clear conception of physics learning and problem-solving as "teacher-to-student transfer of algorithmic routines" (Linder, 1992:112).

This experience of the lecture is echoed in Nespor's findings, which shows physics instruction to be perceived as "feasible journeys" that a student can take through the "representational space" (of physics). The student has to "(know) which procedures [are] ... worth taking and how he could negotiate them." However, whether the student understands "why the routes exist and why one should want to go from one place to the next" (Nespor, 1994:61) is never explored during the lecture itself. Nersessian (1995) makes the same point, arguing that the process of meaning making during lectures is (regrettably) left to take place through "osmotic" means. In this way, the "discrepancy between the [students'] way of thinking about the subject matter and the new way desired by the teacher" may, indeed, never be confronted (Ramsden, 1988:22).

(ii) How the students relate the physical context to their personal context

The perception that the lecture setting does not promote understanding presents itself in two ways. Firstly, there is the identification of the settings that students *do* perceive to promote physics learning - the tutorial and the studying settings. Secondly, there is the passive role the students assume in the setting of the lecture. There seems to be the conception that "sitting in class and listening" is *not* active physics learning. Besides, active physics learning is not actually required, since "the lecturer will give you his understanding". The students do not participate, they receive. Active physics learning would refer to the ability to immediately apply the information "gathered" during lectures and be able to attend to the critical aspects of the principles covered, like the Doppler effect, for example: " ... there are small parts there that if you miss out on them you won't understand...". This type of learning for understanding seems, however, to be more strongly associated with the setting of studying.

5.2.1.4 The setting of the high school

This setting makes up the bulk of what constitutes the students' previous learning exposure to physics. It reveals the students' pre-university history of physics problem-solving. The role that previous knowledge plays in any new learning situation is acknowledged by most theorists, irrespective of their theoretical framework – whether it be cognitivists (the importance of background knowledge for task analysis), constructivist Ausubel's famous quote: "the most important single factor influencing learning is what the learner already knows; ascertain this and teach him accordingly."(Ausubel,1968, p. iv)) or phenomenography (Marton's notion of human understanding representing "culturally sedimented layers of experience" [xxii] (Marton, 1990: 45)).

(i) How students use the setting of previous learning experience - the high school

The students' reference to a previous learning encounter with the problem tasks at high school focused on representing the past learning experience in such a way as to acknowledge the "discipline trajectory" (Nespor, 1994) along which they had moved. In other words, it focused on how students had enrolled themselves into the discipline of physics. The students showed strong identification with the competencies gained through their history with physics through schooling. This was apparent, during the interview, in the many unelicited references to the school setting, which were, however, characterized by a rather impulsive (unreflective) use of this previous physics knowledge.

> *S4:* *Ay no, it isn't gravity…but its acceleration is in the opposite direction… Once I read a physics book - that was back in Matric, I have not read the one we are using now. Mostly these are the things that I learnt at high school, that when a body goes up an incline its acceleration is downward. So, as it goes up it decelerates, nah, nah … is it always? This one as it goes up its speed will be decreasing. What will cause the decrease in speed…? I think… it is friction …pause…I am not sure (Module 1).*

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> *S8:* *To find the magnitude of the reaction forces (on the ladder leaning against a frictionless wall) you have to consider the*

sum of the forces along the x-axis and along the y-axis, because not all these forces are on the same axis. It is a simple thing, and it will be difficult to explain to somebody who does not do physics. If you do physics you are supposed to know such things. At this level you are supposed to know it. I cannot even remember when it was the first time that I realized this is how it is done. I have always known this from school. At high school, we did not do problems like this, but we did do problems that included forces in the y-direction and the x-direction. I cannot remember whether we were told at high school why we had to do it like this, but for me this is obvious (Module 2).

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S10: *We did some of this stuff in Matric so it was easy for me. I knew how to do the series and the parallel connections. (Module 3).*

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S11: *What I know is that the terminal voltage is always less than the emf because you always subtract the product of the internal resistance and the current from the emf that is why it is less. The emf is the voltage that makes the battery to work and the terminal voltage is the voltage that destroys the battery. If you switch on your torch and it doesn't glow this is because of the terminal voltage being greater than the emf.*

R: *How did you come to that understanding?*

S11: *When we were in Standard Seven (Grade 9) we were told that the terminal voltage destroys light, that is the understanding I have always used in making sense of why a battery gets flat (Module 3).*

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S13: *To know what to do and understanding are the same, I think. If you understand you draw your sketch to see what is happening at this point and that point. There were stages when I really understood the work… When I was at school I did understand, I mean I had the time, but here things are hectic and you don't have the time. We have too many subjects we need to hand in assignments and you are not given enough time. I always feel I need to spend more time with computer science because I'm doing it for the first time.*

> *With physics one always thinks, one knows it because one did it at school (Module 3).*

The above descriptions give an idea of the meanings attached to being enroled in the discipline of physics through past experiences. According to the students, to have done physics means to have *accumulated* certain formal formulations and problem-solving techniques, which can be deployed - with or without understanding - in various situations depending on the demands of the problem tasks. It means being *au fait* with certain competencies, such as: "when a body goes up an incline its acceleration is downward"; "to find the magnitude of the reaction forces you have to consider the sum of the forces along the x-axis and along the y-axis"; "to do the series and the parallel connections"; "terminal voltage destroys light". Whereas past learning experiences seem to provide background knowledge necessary in the solving of the problem tasks, this background knowledge is presented as taken-for-granted; the students do not in any way question its conditions of application. Not unlike we noted in the setting of the lecture, we see a strong association of physics at high school with authority and convention.

(ii) How the students relate the physical context to their personal context

The taken-for-granted use of the previous learning experience points to the fundamental nature of enrolment which, in a sense, "precedes" personal context (see section 5.1.1). The students draw upon the various competencies mentioned above, but these have not been related to the students' personal contexts in terms of seeking meaning. This discrepancy between previous learning encounters and personal context is typified in the line: "With physics one always thinks, one knows it 'cause one did it at (high) school".

5.2.1.5 The setting of the test

In physics, tests fulfil the role of assessing knowledge acquisition, which includes problem-solving as a way of learning physics. From the point of view of the lecturer, tests are perceived to provide a setting in which students demonstrate their understanding through the application of concepts and principles to the problem tasks given in tests. According to Laurillard (1984:124), "knowing without the ability to apply is rightly seen as a poor commodity". In this sense, problem-solving tasks in the tests should be perceived as an important part of learning. Of significance to this study are the *students'* perceptions of the test setting. Is the test setting perceived as a setting conducive for testing physics understanding?

(i) How students use the setting of the test

In a test setting it would, of course, be highly unlikely that problem tasks are done "for their own sake" (Ramsden, 1984); the entire setting is structured in such a way as to emphasize factors strictly speaking extraneous to the problem tasks: mark allocation, time limit, the stress of "having to pass". In this sense, the students all "use" the test setting in the same way. All the students are to some extent influenced by the formal requirements of the test setting, which will also impact on what they do. Yet, within this set of formal requirements, there is some distinction noticeable between those students who almost exclusively attend to the demands of the task *as required by the test*, and those who extend their focus *beyond* these requirements.

(ii) How the students relate the physical context to their personal context

This question probes the link between successful problem-solving and "repetition" during the test. It was earlier pointed out that the students generally knew, as a result of the lecturer's "hints", that the problem tasks were going to appear in the test. The way they went about preparing themselves for the test differed, however, according to the intention either to reproduce / memorize or to explore meaningfully.

In the sections to follow descriptions are given with brief introductory explanations. A discussion highlighting the issues on which the students focused will be provided at the end of each section.

- **the test setting: attending to the problem at a test requirement level**

The issue of the reasonableness of the solutions arrived at during the test is emphasized in the first two descriptions given below. The time factor is an important influence.

> *S14:* *For me during assessment... when I read something and it seems right to me, I just carry on 'cause I am pressed for time. During assessment when you write the test you do not try to make sense of everything that you do, this you do only when you study (Module 4).*

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> S4: *First I thought I had to calculate the distance using the questions of motion using:* $v_f^2 = v_0^2 - 2as$. *I took this one because I had the velocity, the acceleration, and all I wanted was the distance (s), so I made (s) the subject of the formula. The distance at* t_0 *is zero so speed* $= \frac{0.4^2 - 40^2}{2 \times 4.4} = -181m$, *okay, distance is not negative so ignore the minus sign and get 181.8 m. So, I said how can he travel 181 m, it was too big because the river is just 20 m wide, so how can he travel 181.8 m, it is so big. I thought that the answer would be something like 30 or 40m, something close to 50 m not something greater than 100 m, but anyway I was running out of time so I had to stick to that answer (Module 1).*

In the two descriptions below the failure to explore questions of which the students are not sure, is related to their perception of authority. The descriptions illustrate how students' minds appear "constrained" (Marton, 1983:293) in trying to represent their experiences according to what the lecturer did in class.

> S10: *I think we did a problem like this in the tutorial. I know how to do a problem like this but I wasn't sure so I didn't do it. I didn't want to guess (Module 3).*

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> S7: *I do not think that I was trying to figure this thing out… When I came to question (d) I remembered the lecturer saying in class that you should remember you should make sure that you understand this problem. I think he said this a few days before we wrote the test. I remember the one about, what is the maximum distance he can climb up the ladder before he slides. I was thinking back to that… and I rather panicked because I did not do this particular problem (Module 2).*

In the following description the lecturer's authority extends to that of mark allocation. This influences the student's commitment to the exploration of the problem task.

R: *What is your understanding of the term internal resistance of the circuit?*

S10: *All the resistance… I should have included this $0.5\,\Omega$.*

R: *And why didn't you do that in the test?*

S10: *I thought that I would lose marks (Module 3).*

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S12: *Firstly I had to work out the current in the $6.0\,\Omega$ resistor (iv). I did not know whether I had to calculate all the resistance in here first that is why I say I did not know how to go about it from a simple circuit. I made this into the equivalent, but I was not sure whether I should make the whole circuit into a simple circuit and from there calculate the current. But then I thought it is only three marks so why go into that trouble? (Module 3).*

For the students who attended to the problem at a requirement level, the ability to transfer what they had done in the studying / tutorial / lecture settings to what they did in the test, was seen as the main issue in relating the physical context to their personal context. Even if they might have explored the problem task in one of the preceding settings, their "over awareness" (Ramsden, 1984) of the test requirement precluded them from attempting similar exploration during the test – at stake is merely the need to repeat what was done before. In this way the test limits the students' willingness to meaningfully engage with the problem task. Most of the students did not explore the more demanding parts of the problem tasks. Which aspects of the setting did the students consider in their decision to refrain from attempting these tasks? The reasons given included: "I did not want to guess"; "I was thinking back to that (what the lecturer said in class)"; "I thought it is only three marks so why go into that trouble".

It is evident that the problem tasks assumed that if the students could successfully do questions (a); (b) and (c), they would be able to "interconnect" the "understanding" required to do the last question – (d). In most instances, however, this was not the case. The students showed confidence in repeating the practices they had been exposed to in previous settings, but lacked the confidence in their own ability to interconnect these practices in such a way as to make sense of the difficulties encountered in the test setting. Problem-solving in a test setting is therefore conceived of as an activity in which students get to confirm the lecturer's approach - rather than to interconnect experiences in a meaningful way.

- **the test setting: attending primarily to the content of problem**

The following descriptions illustrate problem-solving that is primarily motivated by an understanding or at least an awareness of the critical aspects underlying the problem tasks.

S2: *It is all about understanding. It goes with practicing. Practicing everyday, like after the lecture, going over what was said, do some examples, do examples in the text and the tutorial manual and then you know that there is nothing that they can give you that you have not gone through... Now I understand when the lecturers used to say that the formulas are not so important because I mean you have to understand what you are doing. It's not about taking something and plugging it in there... When you look at it you must be able to think about it and draw a diagram that will show you exactly where everything is... Look at as he is moving what is happening to him, what forces are being applied and what effects do these forces have on him. (Module 1).*

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S8: *Yes, there are situations like that where the pictorial representation is not enough, maybe it is situations where I need something that would explain the question more. Like with this problem, you need to know about the moment about a point, you need to know this. And this we learnt in class, it was the first time I came across this material. If I were given this problem without being taught how to work out the moment about a point I would surely be stuck. You do the first*

> *part (working out the force) knowing that you are going to use it in calculating the moments. The ultimate goal is to work out the moment about a certain point. This is where conceptual understanding comes in. You do not memorize these things, you have to understand them. (Module 2).*

Even when they focus on the mark (and the authority of the lecturer), the students are still guided by the content of the problem tasks (the reasonableness of the solution), as is evident in the descriptions below:

> *S15* *:If I got a value that was bigger than 560 Hz I would have gone back to check where I went wrong. If time ran out, I would have written that the frequency calculated was supposed to be less than 560 Hz. That is what the lecturer told us; if you get an answer that you did not expect you should state that it was not an answer you expected and he'd give you a mark for that. (Module 4).*

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> *S1:* *The eleven marks… (Laughs) the eleven marks that is a lot to lose. If it was five marks I would have put more effort into other problems, but eleven marks is just too much to lose. The thing is I never understood these questions, never ever… and I never got a mark for this question whenever it came up. The first time we did it in class… I did not understand it. For the second test it came out with the physics professor crossing the river and I did not get it right. I thought this time I had to get it. So, I just thought… I had to think about it this time; today I just have to do it. I said whatever it takes I will think about it and then I thought deeply about it. I read over the question over and over again to try and make sense out of the question. I said in general the man had to have a greater velocity initially to be able to get to the other side of the river. And the distance that he'll have to cover will have to be greater than 20m horizontally and greater than 30m vertically and that is what I could come up with. (Module 1).*

For students attending primarily to the content of the problem, problem-solving in the test setting is seen as an indication of understanding. Emphasis is placed on the concepts that underlie the problem tasks. In cases where students ran into difficulty with the problem tasks, they were prepared to try to "reconstitute" their understanding in a systematic way, guided by the concepts and conditions of application peculiar to the tasks at hand. Problem-solving in the test setting is therefore perceived of as an activity by which the students interconnect their learning experiences in a meaningful way.

5.3 Summary of main findings of Research Question 2

In this Chapter, I set out to elicit students' intentions and conceptions of problem-solving through an exploration of both the physical and the personal context that constitute the students' problem-solving history (see section 5.1.2). Two qualitatively distinct intentions were seen to underpin the students' problem-solving strategies (see Chapter 4): intention to memorise and intention to understand. Furthermore, the analysis revealed two qualitatively different conceptions of problem-solving: problem-solving as "reproduction" and problem-solving as "meaning making". I can be argued further that these conceptions not only reflect how students perceive the process of problem-solving, but also highlight how students perceive the various settings within which problem-solving occurs. The students' perceptions of the various settings within which problem-solving occurs, seem to reflect the experience of learning physics through problem-solving. In this regard, physics learning is seen as either "constituting understanding" or "confirming convention". This observation is particularly significant to the study in that it provides the basis for addressing the overall aim of the study: the experience of learning physics through problem-solving. I take this discussion further in Chapter 6.

Table 5.1 Summary of Research Question 2 results

Settings of problem-solving	How do students use the setting	How do students relate the physical context to their personal context
studying	• to reproduce material under study • to understand material under study	• repetition concerned with memorization • repetition concerned with understanding
tutorial *	-	-
lecture	• lecture as form of authority / convention for teacher-to-student transfer of algorithmic routines	• physics learning associated with the setting of studying • students' role in lectures perceived as one of passive participants
high-school	• high school setting provides a taken-for-granted background knowledge to be used in problem-solving • physics at high school is associated with authority and convention	• enrolment precedes personal context
test	• attending to the task at a test requirement level • attending to the task at the level beyond the test requirements	• problem-solving is confirming the lecturer's / conventional approach • problem-solving is interconnecting learning experiences in a meaningful way

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* NB. the use of tutorial problems and manuals was not discussed under this section but was discussed in the other settings.

5.4 Focus on content versus focus on requirement: further factors to consider

My detailed overview of the various settings in which students are exposed to problem-solving served to provide a contextual framework for a notion generally regarded as crucial in successful problem-solving: familiarity. The research question on factors influencing what students do during problem-solving can therefore be seen as targeting exactly those *aspects of familiarity*[xxiii] the students "actualize" in their problem-solving. In short, students' familiarity with the problem task (acquired across a variety of settings) influenced what they did. Similar findings have been made by other researchers, who have observed successful resolutions of problems (see diSessa, 1986; Bodner, 1990).

It is necessary to make a subtle yet important distinction between two objects of focal awareness that play a role in students' focus on "requirements" or "content", and which are underscored by the students' intentions and conceptions during problem-solving.

5.4.1 The nature of the problem task

Motivated by certain intentions or conceptions, students focus in a particular way on a problem task within a given setting. Laurillard (1984) argues that the problem-solving task can influence the outcome of learning to the extent that the task is perceived to make certain demands on the students. A task may be perceived as making minimal demands on the part of the students even where the understanding of a fundamental concept is involved. When the demands are perceived as minimal, "operation learning" is the result (Laurillard, 1984:139 – the term is borrowed from Pask's conservation theory of learning). Laurillard argues that operation learning would come to the fore in any problem-solving situation where it is, perceived that a standard problem-solving procedure is called for. This type of situation will not necessarily "engage the students in thinking about the subject at a deeper level" (Laurillard, 1984:143).

5.4.2 The effect of learning experience

In Chapter 4 two strategies (A and B) were described which were distinguished from one another by what I called *different moments* of problem-solving: Strategy A involved a moment of re-interpretation of the problem task *in addition to* the moments of scanning and translation, while Strategy B included only the first two moments - see section 4.2.1.2.

Although the two strategies are qualitatively different, it was interesting to note that some students, having been categorized as predominantly Strategy A *exhibited characteristics* of Strategy B in certain sections of the problems. This phenomenon pointed to a certain fluctuation in focal awareness across problem tasks. As I pointed out in section 4.3 students categorized in Strategy A were primarily concerned with the questioning of their own understanding, while those of Strategy B preoccupied themselves with the formal requirements of the task. These different concerns could obviously be related to the main tendencies highlighted in this chapter, namely "focus on problem content" and "focus on problem requirement". Thus I shall reflect briefly on the reasons for fluctuation between focus on content and focus on requirement.

To do so it may be useful to briefly refer to descriptions from this study that seem to point to the factor of "learning experience" as a variable where a student, who initially focused on problem content, subsequently changes the focus to problem requirement – see section 4.2.1.2.1, scanning (iii).

S3 : *…it makes sense now, because... at the edge the velocity cannot be 40m/s. I had to assume that... here the speed is 40, I know that... this is where all the principles come in. Maybe it is because I knew that I was trying to find acceleration, and so I thought, let me just make this zero, and calculate the acceleration at this point... I know that this is wrong because when he has covered the distance of 100m, the speed has decreased already… when his speed is 40m; he has not completed the whole thing yet. (Module 1 problem).*

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S3: *I was stuck and I ended up doing the calculations for the sake of doing calculations, because I had the variables and I had the equations. I ended up substituting, because the equations... were there... I ended up doing something that I really did not know. I did not know how this was going to help me…I knew that the velocity was going to decrease... (Module 1 problem).*

The student is clearly focusing on the content of the problem, which makes it possible for her to rectify her assumption (in the test) about the initial velocity of the cyclist being zero. In trying to explain why she worked out the problem in the way she did ("maybe it is because I knew ..."), her response however comes to concentrate on the requirement of the problem: calculate the acceleration. The student no longer correlates her intuitive understanding of the problem (that the velocity does indeed decrease as the cyclist goes up the ramp) with the formal analytical representation of the problem (to determine how the net force affects the motion of the cyclist - "... this is where the principles come in ..."). In fact, her whole problem representation indicates that she not only has difficulties with the concept of acceleration, she also confuses velocity with position (a confusion also reported by, amongst others, Rosenquist and McDermott, 1987).

At issue is the absence of an interpretive framework within which the student can make sense of the problem. It would be dangerous to claim, however, that this failure is the result of the student *not* sufficiently focusing on the problem content. It is more likely the student's difficulties ("I was stuck ... ") stem from inadequate learning experience (Ramsden, 1984). The student lacks the appropriate physics descriptors against which to evaluate her intuition. In the end, the student turns to focus on problem requirement as a kind of coping strategy; she merely does what she perceives to be appropriate within the specific context of having to pass the test.

The student's (inadequate) learning experiences seem to be the main limiting factor in her way of focusing on the problem. Although she starts off by focusing on the content of the problem, she eventually resorts to a purely formulaic approach. In the absence of the necessary physics descriptors, it could be argued that students will in all probability focus on the problem requirement rather than the problem content.

5.4.3 To what extent do ways of focusing on the problem task match up to a particular strategy?

The factors we have considered in this section caution against a simplistic categorization of students according to how they focus on a given problem task. According to Ramsden, "what a student does should be understood in the context of the task... the effect of the conditions has to be understood in terms of the perception of the individual learner" (Ramsden, 1988:24). This caution is particularly appropriate in the discussion to follow in Chapter 6, which will further discuss the relation between the factors (influences) we have highlighted in this chapter and the problem-solving strategies analyzed in Chapter 4 (particularly in light of Ference Marton's deep versus surface dichotomy).

A direct "one-to-one" relation between students' intentions and their strategy could only be established in the descriptions of three students: S2, S8 and S15. The key factor seemed to be the awareness, by these students, of an underlying structure guiding physics knowledge. They were able to make sense of the lecturers' insistence on the importance of using diagrams in their representation of the problem, rather than merely to rely on memorized formulae. In addition, they were able to show this awareness across different settings (the setting of studying as well as the test). The descriptions of the students (see sections 5.2.1.1 (i) and (ii), and 5.2.1.5 (ii)) show clear evidence of such critical attributers in their awareness, which clearly guide the way they thematise the problem task.

It is interesting to note the metacognition, on the part of all three of these students, of the length of time it took them to reach their understanding. It took S2 (who was repeating the course) a full year to change her conception of the structure of physics knowledge from "one of pieces composed of formulae" to one that emphasizes the logic and the coherence inherent in the structure of physics knowledge. It took S8 "a term" to appreciate the complementary relation between concepts and equations in physics learning. In this period he seemed to become aware, not only of the continuation between school and university physics, but also of the need to interrelate the different modules, especially when dealing with new material. It is only in the last module that S15 gets to appreciate the role that visualization can play in constituting coherence in the structure of physics knowledge, especially when having to deal with effects that transcend common-sense perception: "(The lecturer)... told us about the importance of drawing diagrams, but I did not do it... I believed that I could solve the problems without them". (The significance of time as a factor in learning has been referred to as "temporal extension". This concept will be more fully dealt with in Chapter 6).

Marton and Booth argue that people can be aware of their own learning, but to talk about it, to describe it, takes another kind of awareness – an awareness of awareness (Marton and Booth, 1997:51). As Ramsden phrases it, this awareness "concerns changes in people's conceptions of certain aspects of reality" (Ramsden, 1988:26). It is significant to note that the change in the students' conception of learning could be intimately linked to their changing beliefs about how they think they are expected to go about their physics learning through problem-solving. These beliefs are, initially, strongly informed by the notion that problem-solving, somehow, does not require reasoning. Once they are able to appreciate the coherence of the underlying structure of physics, they gain confidence in their ability to reason their way through a problem task. It is clear, from the descriptions of the students, that they are acutely aware of an evolution in their own approach to physics learning. One may argue that it is at this point that some students adopt a deep approach to their learning. The deep approach that they are seen to adopt is therefore itself the result of their change of conception of their own learning. (The term "approach" as it applies in this study is fully discussed in Chapter 6).

As already observed, the majority of the descriptions point to a mismatch between ways of focusing and strategy, to the extent that there are significant fluctuations in students' focus and intentions / conceptions as they move through the different contexts of physics learning, as well as fluctuations in strategy (see the example of S3 in section 5.4.2). The interaction we noted at the beginning of this chapter between intention / conception (personal context) and setting (physical context) is again relevant in this regard.

This chapter has been about the meaning students attach to the context of problem-solving. Chapter 6 will carry this reflection further, by fully integrating the concept of learning into the students' problem-solving practice. The discussion in Chapter 6 will derive from the central notion of enrolment, the aim being to provide a "holistic view" (Entwistle and Marton, 1984) of the experiences of first year students' learning of physics through problem-solving.

CHAPTER 6

DISCUSSION ON THE MEANING OF THE EXPERIENCE OF LEARNING PHYSICS THROUGH PROBLEM-SOLVING IN LIGHT OF THE FINDINGS OF THE STUDY

6.1 Introduction

In this Chapter I will discuss the referential aspect of the experience of learning physics through problem-solving. In order to achieve this objective, I will first review the structural aspect of the students' experience of learning physics through problem-solving as discussed in Chapters 4 and 5. The two qualitatively distinct strategies identified in the study are reviewed in the light of the concept of familiarity, bringing to bear the students' intentions and conceptions of problem-solving. Part of this discussion will examine how these strategies can be related to the deep-surface characterization of students' approaches to learning. This discussion will provide the basis upon which to characterize the meaning that the students attach to physics learning through problem-solving.

Marton and Booth (1997) argue that the deep or surface approach to learning is rooted in a certain kind of *awareness*. To be able to describe something we have to be aware of it. They argue that people can be aware of their own learning, but to talk about it, to describe it, takes another kind of awareness (Marton and Booth, 1997:51). This kind of awareness lies in one being aware of one's own awareness. As it was pointed out in section 2.4, learning in a phenomenographic sense is fundamentally about *change (variation) in conceptions*. Learning is relational. It involves both *how* students learn and *what* students learn. Moreover, both "how" and "what" are embedded in a *context*. "How" (the approach) and "what" (the content) are, in this sense, both a function of "where" (the setting).

It is significant to note how "quality learning" (Entwistle, 1997) in a phenomenographic perspective resembles what Novak (1993; 1998) refers to as "human constructivism" (the capacity to make meaning) despite the differences between phenomenography and constructivism (regarding the role of internal schemata in the individual's ability to make sense of the world – see section 2.3). What Novak and the phenomenographic theorists have in common is the importance they attach to the learner's *capacity for meaning making*. Crucial to this capacity is the optimization of the learner's "phenomenal capacity" to make meaning, including her awareness of and confidence in the processes that are involved (Novak, 1993:190). In other words, the learner has to realise her responsibility as the key to determining quality outcomes. It is a similar view of "quality learning" that prompts Marton and Booth (1997) to challenge the "unreflective manner" in which students go about their learning, especially in higher education. Entwistle similarly argues that the unreflective manner in which students approach learning in higher education "seriously undermines the opportunities for developing conceptual understanding" (Entwistle, 1997:131).

In addition to the importance of the individual's capacity for meaning making, Ramsden highlights the *conditions under which people learn*. One way to improve learning would be to improve these conditions. Learning is multifaceted; the point is to look at what students do in the context of the task. The effects of the conditions of learning, he argues, should therefore be looked at in terms of the perceptions of the individual learner (Ramsden, 1988:24). Linder reflects similarly on the importance of the learning context as a factor to be considered concurrently with that of conceptual understanding:

> [It is] extremely important for science educators not only to focus on conceptual development but to provide students with opportunities to reshape their approaches to academic learning. Such opportunities can only manifest in an environment which enhances student trust and confidence in what we are trying to do (Linder, 1992:10).

Chapter 4 identified three different "moments" of problem-solving: scanning, translation and re-interpretation. While some variation *within* each of these moments was noted across the group of students, the most noticeable variation within the strategies employed was attributed to the fact that the moment of re-interpretation was apparent in only a limited number of problem-solving strategies. The relative presence or absence of the moment of re-interpretation – which was itself subject to internal variation – was the decisive factor in deriving two main strategies, qualified as Strategy A (which included a moment of re-interpretation) and Strategy B (strategy limited to moments of scanning and translation). The main *qualitative* difference between Strategies A and B could be described as follows: Strategy A *explored* the problem content with a view to achieving some form of personal understanding; strategy B was primarily concerned with *repeating* sets of algorithms.

Chapter 5 paid particular attention to the notion of context. Central in this regard was the students' *enrolment* into the discipline of physics, signifying the institutional context of tertiary learning. Enrolment was then interpreted within a dual contextual framework: *physical* context (the different settings of problem-solving / physics learning referred to during the interview: studying, the tutorial, the lecture, school and test) and *personal* context (students' intentions in physics learning and conceptions of problem-solving). *Both* physical and personal context were seen to constitute the students' history of problem-solving. Students were seen to use the different settings of problem-solving in two essential ways, which reflected the *meaning* (as informed by their personal context) they attached to these settings. The contexts were either spaces / opportunities for *(re)constituting understanding*, or spaces / opportunities for *confirming convention*.

The concern of this study with strategy (Chapter 4) brought into focus the question of conceptual understanding. In Chapter 5, which analyzed the factors influencing students' problem-solving strategies, the issue of context – closely tied up with familiarity – was dealt with extensively. In this way, the study attempted to place itself within the relational framework of the phenomenographic perspective on learning.

After the concern with "what students do" in Chapter 4 and "what influences what students do" in Chapter 5, Chapter 6 focuses on "what students think about". Before arriving at this point, however, Chapters 4 and 5 need to be considered collectively. This fusion of the students' problem-solving strategies and the factors influencing them will be achieved in our discussion of the implications of the findings of Chapters 4 and 5 (the two research questions). It is in this process that we will be able to derive the concept of *approach*, which is seen, in this study, as encompassing strategy on the one hand and influences (intention / conception) on the other. As such, the concept of approach will serve as basis for the aim of this chapter: to derive the meaning the students attach to learning physics through problem-solving (see section 1.1).

The strategies identified in this study can to some extent be argued to fall within the deep or surface approach categorization developed by Ference Marton. This chapter will offer a review of how the tendencies revealed in this study compare with the deep-surface characterization of students' approaches to learning.

6.2 The concept of familiarity in light of Strategy A and Strategy B

This study found that the strategies that students use are a function of various factors, which are combinations of content and context bound variables. Similar results have emerged in other studies conducted in a range of disciplines involving different learning tasks (see Biggs, 1993; Bowden *et al.*, 1992; Booth and Ingerman, 2000; Kember and Gow, 1989; Laurillard, 1984; Marshall, 1995; Prosser and Millar, 1989; Ramsden, 1984; Trigwell and Prosser, 1996).

The examination of the factors that influence what students do during problem-solving indicated that the key factor lies in the notion of *familiarity* – how familiar students were with the problem tasks. This point has been made by other researchers, who have observed that successful resolution of a problem is a function of familiarity with the problem rather than a question of difficulty or complexity (see diSessa, 1986; Bodner, 1990).

To different degrees, all fifteen students who took part in this study claimed to have been familiar with the problem through exposure in previous settings of learning. Based on this stated familiarity, it would be logical – especially in a test setting - to expect that the problem-solving strategies employed by the students would tend toward an archistic model (see section 2.5.1.1). In other words, familiarity gives rise to a strategy / model that, through its recourse to recall and repetition of algorithms, is fundamentally linear. *Both* archistic and anarchistic problem-solving models (the latter to a limited extent) were, however, observed in the strategies employed by the students in this study – even in the test setting. Faced with the Module 1 problem during the test, S1, for example, described how she "did… (the finding of the unknown variables) separately, one thing there and one thing here… I thought deeply about it. I read over the question over and over again to try and make sense out of the question" (see section 5.2.1.5 (ii)).

The different settings in which the students had encountered problem tasks before, collectively constitute what I have referred to as the students' "history"[xxiv] of problem-solving. Nespor in this regard talks about "different spatio-temporal distributions of knowing" (Nespor, 1994:11). Clearly this *history* (or "knowing") is a resource in problem-solving – it is familiarity. Yet, although all the students broadly speaking attributed the same importance to their familiarity with the problem tasks, this familiarity was "acted upon" in different ways, as will be shown in the following sections.

6.2.1 Strategy A

What distinguished Strategy A (re-interpretation of the problem representation subsequent to scanning and translation) from Strategy B (scanning and translation without re-interpretation) was the extent to which the students were prepared to reconstitute personal understandings to deal with the problem tasks. From the students' descriptions of the various moments characterizing Strategy A, we saw the expressed need among the students to formulate *personalized* forms of understanding in order to make sense of what they are learning through problem-solving. Trying to work out the acceleration of the cyclist going up an incline (Module 1 problem), S2, for example, stressed the need "... (to) be able to think about it ... (to) be able to understand what will happen as he moves from here to there ... " (section 4.2.1.2.1 - scanning (i)). We clearly see in this instance the interdependence between the student's personal context and the meaning attached to the physical context (section 5.1.2). The students' engagement with the problem at a personal level affected how the setting within which the problem is solved is perceived; situating herself *within* the content of the problem, the student is concerned with exploring the problem task *beyond* the requirement of the test, which now becomes secondary.

This personal engagement with the problem would clearly fall within Marton's deep approach to learning. The intention of students using Strategy A is to make a meaningful interpretation of the task as well as their role in bringing this meaning to the fore. In particular, we can be reminded of the points of focus in the moments of scanning (i) and scanning (ii) and translation. These are characterized by two elements: simultaneous identification of problem type and procedural skill necessary for the application of the underlying concepts, and "mindful repetition" in attending to the perceived dominant features of the problem.

The exploratory way of looking at the problem that characterizes Strategy A brings about a modified structure of relevance (the interpretive framework becomes refined). Once again, this feature clearly resembles the deep approach. Students using a deep approach to learning are consistently involved in a search for meaning in the presentation of their data (in this study: the solution representation), which results in them adopting a different view of the material studied. In this study the moment of re-interpretation (section 4.2.1.4) showed examples of this type of change. As new ways of seeing the problem are explored, there is an emphasis on the need to go beyond quantitative methods of analysis in the strategies and to move toward procedures that are guided by qualitative analysis - conceptual understanding. This was apparent during the interview, in which the students who in the setting of the test had strategically manipulated equations to fulfil the requirements of the test, were seen to come to terms with their understanding of the material by focusing on the task differently – on its critical aspects (section 4.2.1.3.1 translation (iii); see also the moment of re-interpretation - section 4.2.1.4). In this regard, personal involvement with the problem task appears to be crucial in bringing about variation in the way of looking at the problem.

We can say the following: students who were categorized as using strategy A, regarded familiarity with the problem to be an *added* advantage (but not the only one) in their problem-solving. A crucial point needs to be made here however, relating specifically to the role of repetition of learnt algorithms. As will be seen below, repetition plays a pivotal role in Strategy B. This does not imply, however, that repetition of learnt algorithms has no place in Strategy A. If Strategy A is essentially about exploration of understanding, it is about the willingness on the part of the student to interconnect different previous learning experiences, many of which will have come about through repetition (including of learnt algorithms). As S2 put it: "It is all about understanding. It goes with practicing. Practicing everyday, like after the lecture, going over what was said, do the examples, do the examples in the test, in the tutorial manual and then you know that there is nothing that they can give you that you haven't gone through... Now I understand when the lecturers used to say that the formulas are not so important, because I mean you have to understand what you are doing" (see section 5.2.1.5; see also section 4.2.1.3.1.). This view of repetition, moreover, corresponds to Marton and Trigwell's view of repetition as variation (Marton and Trigwell, 2000).

6.2.2 Strategy B

Strategy B was about the repetition of conventional procedures. Contrary to the observation, in Strategy A, that knowing is in the act of reconstituting – of *doing* (see Schön's 1987 idea of "knowing in action"), one observes in Strategy B a preoccupation with knowing as (re)*duplicating*. The students' problem-solving procedures (irrespective of the setting) are marked by the deliberate recall of the strategies employed during the test, which resemble the methods prescribed in the textbook or copied during the lecture. Strategy B therefore hinges on the students' ability to either duplicate: "You just follow the convention ... " – S7 (see section 4.2.1.2.2, scanning (iv)) or logically relate the strategies used to those of the lecturer or other authority: "You basically had to read the question and then apply ... choose the right formula and apply it" - S12 (see section 4.2.1.2.2, scanning (iv)).

Strategy B relied mainly on formal representations (authoritative representations) which were perceived to be self-explanatory. Rather than reconstituting the necessary experiences in the act of problem-solving, the students frequently opted not to do the problem at all. In Module 2, S7 does not attempt the last question of the problem because he could not remember the exact way in which the lecturer solved the problem. In Module 3, S10 recalls having done the problem in the tutorial, but when faced with it in the test, and upon realizing that he is not sure about the prescribed problem-solving method, he does not attempt it because he does not want to "guess" - see section 5.2.1.5 (ii). In these instances, guessing and conceptual exploration are not seen as useful practices. The impression is created that, within the test setting, thinking is not encouraged - only recollection. Could this be a manifestation of a particular "disciplinary accumulation cycle" (Nespor, 1994) through which students insert themselves into the power relations of the physics discipline?

To what extent does strategy B resemble Marton's surface approach? In Strategy B we see familiarity as the student's single resource. Despite the fact that the moment of re-interpretation is not present in their problem representation, the students categorized as using Strategy B have, on the whole, similar competence in the application of Newton's Second Law to the students in Strategy A (see in particular S4 and S7 –sections 4.2.1.2.2, scanning (iv) and 4.2.1.3.2, translation (iv)). Their "relevant knowledge structure" (Novak, 1993) seems, however, not to be reflected upon appropriately. They do not see themselves as meaning makers (Novak, 1993). This is apparent in their unwillingness to explore their understanding, because they see the knowledge structure they apply as resembling that of authority – the textbook or lecturer. In this way they fail to interconnect their learning experiences in a meaningful way.

In their focus on the problem tasks, the students using Strategy B bring to the fore the three elements (or what Marton calls "components of learning experience" - see Marton, 1983:293-295) used to describe the surface approach (see section 2.4.2). Certainly, some of the students in Strategy B clearly deal with the different parts of the problem in isolation, with little focus on the essence of the problem task. The moments of scanning are characterized by pattern recognition, while translation is little more than an application of algorithms (section 4.2.1.2.2, scanning (iv); section 4.2.1.3.2, translation (iv)).

What does this tell us about the students' conceptual understanding? This is a difficult question. What I can say is that in the setting of the test the students do not seem to be concerned with conceptual understanding, to the extent that they seem to take it for granted – it is not something to be "explored": "I was not thinking... but was constantly trying to remember how the lecturer would have solved it" - S7 (section 5.2.1.5 (ii)). Interestingly, in a different setting (studying at home) the same student *is* able to make sense of the problem: "... I don't know what the difference was between being in the classroom or at home because I myself was stunned, you know, when I got to the answer at home... ". Whether or not the students understand, what is clear is that understanding is so closely related to the authority of the lecturer (or the text book) as to be virtually indistinguishable from it. It may also – as this example illustrates – depend strongly on the students' perception of the setting.

According to Marton and Trigwell, "(w)ithout variation there is no discernment, no learning at all" (Marton and Trigwell, 2000). A similar statement could perhaps be made in this study with regard to the students categorized as using Strategy B - but nonetheless with certain reservations. Once again, we may reflect on the interdependence of the students' personal context and physical context – the question of enrolment, and the importance that some students attach to the importance of *imitating* the perceived authority, not to mention the influence of mark allocation (section 5.2.1.5, (ii)). It could also be that the students simply regarded the problem task as "easy" – as some of them indeed stated. Bowden *et al.* (1992) have pointed to the fact that differentiating amongst students on the basis of the level of understanding becomes problematic when the problem tasks are perceived as relatively easy.

In conclusion to our discussion of strategies A and B, we may further caution against an over-hasty fusion of these strategies with the deep and surface approaches. Other researchers also express similar concerns (see Biggs, 1993; Case 2000, Marshall, 1995). Biggs (1993) asserts that what is specifically meant by deep and surface approaches in any instance, depends on the context, the task and the individual's encoding of both. His argument is related to the association of rote learning with the surface approach. In this regard, he distinguishes between the students' decision to "reproduce without understanding" and the decision to "ensure accurate recall of already understood information" (Biggs, 1993:7). The former decision is regarded as depicting the surface approach whilst the latter - depending on the context – could represent a deep approach or, in fact, a third approach that Biggs identifies as an "achieving approach" or "strategic approach". According to Biggs, the achievement approach is based on the enhancement that comes out of visibly achieving (in the sense of receiving a reward). The focus is not task centred but on the recognition gained from performance. The strategy is to organize time, working space, and syllabus coverage cost-effectively, with cue-seeking, systematic use of study skills, planning ahead and allocation of time according to task importance (Biggs, 1993:7). Were these not, in fact, the very preoccupations of some of the students in this study, focusing on test requirement rather than content? This question will be returned to in the discussion on learning below. Of the three approaches, Biggs argues that it is only the deep approach that is task-focused (or natural) since both the surface and the achieving approaches are seen as dependent on "institutional creations, sanctions and rewards" (Biggs, 1993:7).

6.2.3 Two meanings of the experience of learning physics through problem-solving

The discussion in the section above explored the two qualitatively distinct strategies identified in the study in light of the conception of familiarity (bringing to bear students' intentions and conceptions of problem-solving). This discussion provides the basis upon which the students' experiences of learning physics through problem-solving can be inferred. In this way the overarching focus of the study, viz. the nature of first year undergraduate physics students' experience of learning physics through problem-solving, is addressed. The two qualitatively different meanings that students attach to physics learning through problem-solving are characterized as follows:

(i) **Physics learning as *(re)constituting understanding*;**

(ii) **Physics learning as *confirming convention*.**

These two meanings are related to the qualitatively different *approaches* (comprising strategies and influences) used by the students in problem-solving. Whereas in Strategy A knowing / understanding was perceived to be in the "act of reconstruction", Strategy B conceived of it to be embedded in the "act of repetition". The key word here is "embedded". We noted earlier in the section that repetition indeed played a significant part in students' attempts *to explore understanding* (Strategy A). In these cases, though, repetition is merely a *part* of the students' meaning making process. There is also a further element common to Strategy A and Strategy B. *All* the students in the study clearly had some concern with "confirming convention" (which is a factor of enrolment, as was illustrated in Chapter 5). In a way, familiarity can indeed be thought of as familiarity with convention. Once again though, the students categorized as using Strategy A were seen to go *beyond* convention - in both studying and test settings.

6.3 Concluding remarks and recommendations

As has been emphasized, a relational view guided our exploration of students' experiences of learning physics through problem-solving, pertaining to an "insider's perspective". It is the learning of physics *as experienced by first year physics students* that was reported on. The results of both research questions indicated the students in this study to regard problem-solving as a way of *learning* physics, even if the meanings they attached to the various settings of learning physics through problem-solving differed markedly.

What is foremost in approach (ii) in previous section above (physics learning as confirming convention) is the link between problem-solving and authority, indicating a particular preoccupation with *performance*. This "performance" is a particular function of problem-solving – or, rather, the physics problem, which *demands* to be solved. As argued by Laurillard, the demands of the physics problem are different from those of the (narrative) text. The text, while calling for interpretation (meaning), does not require of the reader to arrive at a *specific* meaning. It does not stipulate its purpose. By contrast, "(a) problem-solving task explicitly requires a student to solve it".

In this act of performance, the product (the solution) and the process (the search for the solution) take up different meanings in the students' focal awareness. The role of performance within meaning can be related to Marton *et al.*'s concept of temporal extension (Marton *et al.*, 1993:283). This concept refers to the fact that learning is to "become able" in time. Marton *et al.* see this "becoming able" as represented in different "phases": "When they think of learning, people think of an occasion which is the acquisition phase and another which is the application phase of learning" (Marton *et al.*, 1993:283). This view of the phases of learning is further refined when Marton and Booth derive three distinct temporal phases in the experience of learning – phases which may or may not appear in any one way of experiencing learning (Marton and Booth (1997:41). The temporal dimension incorporates an "acquisition phase", a "knowing phase" and an "application phase". Marton and Booth also use the term "depth dimension" to characterize variation in the temporal experience on the basis of the "intertwining" of the "agent of learning" the "act of learning" and the "object of learning" (Marton and Booth, 1997:42).

These three phases of the temporal extension of learning were strongly apparent in the students' descriptions, particularly in the way they talked about their experience (of learning physics) in the different settings. The preoccupation with performance is concretely cast in the terms of these phases – we saw the need for students to *apply*, to *remember*. The "performative act" of physics learning through problem-solving entails the very stages of acquiring concepts and formal procedures; it requires the act of application, as well as knowing and committing to memory (see Marton and Booth, 1997:43).

Depending on the conditions of the learning environment and the problem-task, any phase (or a combination of the phases) is actualized in the process of problem-solving - is actualized in the process of *learning*. On this basis we may argue that the variations identified in this thesis: in the strategies employed by the students, in the ways they focus on problems, in their perception of the problem-solving settings, in the meanings they attach to physics learning through problem-solving – call for a framework of learning that *is constituted in* this spatio-temporal complexity[xxv].

Such a framework of learning could have clear practical implications, relating to how the various settings of learning are used in instructional programmes. The findings of this study indicated that to a large extent, settings of problem-solving *other* than the lecture and the test settings were associated with the idea of (re)constituting understanding. The setting of studying was particularly salient in this regard. This finding has implications for further research on the impact of, for example, "take-home" assessment. Programmes aimed at encouraging students to learn physics (through problem-solving) would benefit from a stronger reliance on those settings that the *students* regard as conducive to learning, not only with regards to homework assignments, but also with regard to assessments that students *perceive* to count towards them "making the grade". Students, as Laurillard argues, are likely to be better than teachers in directing their learning. This means that they should be given "maximum control over learning strategy and manipulation of content" (Laurillard, 1988:231).

How do we talk about the experience of learning introductory physics through problem-solving? The main theoretical implication of this study lies in its merging of the perspectives of phenomenography and the actor-network theory. The emphasis of phenomenography on the variation of the experience of learning has clear benefits to the extent that it has enabled educational research to move beyond the psychology of the individual learner. Actor-network theory shares with phenomenography its view of the spatio-temporal distribution of knowing, but its notion of enrolment is particularly useful in studies – such as the present one – concerned with how learning takes place through a particular *medium with its own demands*. These demands have implications for understanding, *over and above* the understanding of the concepts of the discipline. What do we mean by conceptual understanding? Conceptual understanding (at least in physics), cannot be limited to an understanding of "concepts or principles". Whatever understanding students have of the *content* of physics, must be fully integrated into the demands of the medium (the *process* of problem-solving) through which undergraduate physics is learnt. This is a particular challenge for further research in physics education aimed at exploring the experience of learning physics at an undergraduate level.

ENDNOTES

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[i] According to Prosser and Millar (1989:513) from a relational view of student learning (as espoused in phenomenographic research), the "how" of learning is seen as a "relation betweenthe student and the learning task such that the approach students adopt to a particular task depends on an interaction between the nature of the task and on the student".

[ii] Operating within a relational perspective to learning, the "what" aspect of learning "is thought of as a conception which is defined as a qualitative relationship between an individual and some phenomenon" (Prosser and Millar, 1989:513).

[iii] I use the word "frozen" to bring attention to the presentation of the content as a set entity.

[iv] Cedric Linder, Delia Marshall and Rudolph Nchodu formed the "Physics Education Group" at UWC.

[vi] Callon, M. 1987. "Society in the making: The study of technology as a tool for sociological analysis", in Bijker, W., Hughes, T. and Pinch, T. (eds.).*The Social Construction of Technological Systems*, Cambridge, MA: The MIT Press, pp. 83-103.

[vii] See Marton and Booth's "paradox the first" as well as paradoxes four, five and six (Marton and Booth, 1997:23; 8-11). How is knowledge received from the outer world *meaningfully* integrated by the learner if that knowledge is not pre-possessed by the learner?

[viii] Again, see paradoxes four, five and six – the "cognitive present" (Marton and Booth, 1997:8-11).

[ix] Summary of the differences between expert and novice problem solvers in physics (UMPERG, 1998:2)

	Experts	Novices
Knowledge Characteristics	Large store of domain specific knowledge	Sparse knowledge set
	Knowledge is richly interconnected and hierarchically structured	Disconnected and amorphous structure
	Integrated multiple representations	Poorly formed and unrelated representations
Problem-solving Behaviour	Conceptual knowledge impacts on problem solving	Problem solving largely independent of concepts
	Perform qualitative analysis	Manipulate equations
	Use forward looking concept- based strategies	Use backward looking means-ends techniques

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[x] See paradoxes four, five and six relating to the "homunculus" (Marton and Booth, 1997:811).

[xi] Social space, is not seen as a "natural container of activity", but as socially produced and contested (Nespor, 1994:15).

[xii] Adopting a geographical view to learning or educational research means being acutely aware that the logic and sense of an event or a setting can never be found entirely within that particularsetting, because as Nespor argues (1994), we are continuously moving through different "spatio-temporal distributions of knowing" "If people are spatially and temporally distributed, and courses are the fluid intersections of elements stretching out acros and moving through space and time, then the problematic we have to make sense of is the network of relations that tie things together in space and time. To understand what is going on in one section we have to look at the mesh that connects it to other intersections" (Nespor, 1994:22).

[xiii] Berger, J. 1974. *The Look of Things*. New York: Viking, p.40.

[xiv] "Appresentation" refers to the fact that phenomena, even though only partially exposed, are not experienced as parts but as "wholes of which the parts are parts" (Marton and Booth, 1997:100).

[xv] The concept has been used somewhat differently in this study in order to meet its own analytical needs.

[xvi] The concept of familiarity is relevant to this study in that it highlights what is being "thematized" (Martonand Booth, 1997). It is fully discussed in Chapter 5.

[xvii] Ramsden is quoting Hewson: Hewson, M. (1987) The Restructuring of classical textbook knowledge for problem-solving: A conceptual change approach. Paper presented at the AERA Annual Meeting, Washngton DC.

[xviii] When learners encounter a novel, complex or confusing phenomenon they need to have a conception of learning which will facilitate the discernment of critical aspects of the phenomenon in order to make sense of it, solving the problem it presents, or conceptualizing what it represents. In other words, they need to confront those aspects of the phenomena, which are taken for granted to become invariant, and vary them. As such *reflective learning* is the exploration of *the object (the content)* of learning through a mindfulness of the*act* of learning.

[xix] By "reflective monitoring" I refer to the monitoringof students' understanding and conceptions during problem solving. This process of monitoring fulfils a diagnostic purpose. It draws the students' attention to the interpretative framework being used to solve or make sense of a particular aspect in the problem task. In other words, reflective monitoring reveals the "status" (Hewson and Thorley, 1989) of the students' understanding during problem-solving.

[xx] The loop rule is an expression of conservation of charge. It states that the algebraic sum of the potential differences in any loop must equal zero, $\sum(\varepsilon + IR) = 0$. Thus the potential differences associated with the *emf*'s and those of resistive elements must be included.

[xxi] Gibbs *et al.* are quoting Taylor *et al.*, 1981. Taylor, E., Morgan, A. R. and Gibbs, G. (1981). The orientations of Open University students to their studies. *Teaching at a distance*, 20, 3-12.

[xxii] It needs to be stated that phenomenography treats the notion of previous experience differently– see argument in Chapter 2, section 2.5.1.2.

[xxiii] From a phenomenographic perspective familiarity should be seen as the principle component of relevance structure. Relevance structure relates to what is called for to make sense of things, and to the criteria by which some parts of the problem are seen as more (or less) relevant.

[xxiv] I am indebted to Shirley Booth for the use of the term "history" of problem solving. She suggested it to me in one of our discussions through electronic correspondence.

[xxv] This thesis acknowledges the concern raised by Nespor (1994) that the question of how is one activity in one setting (such as a classroom) relates to another activity setting distant in space andtime remains one of the most fundamental questions that remains unexplored in educational practice and research. Nespor (1994) rightly points out that "space-time relations" influence all notions of learning, (whether it be development, teaching, curriculum planning or reproduction) and yet in practice, both educational practitioners and researchers tend to suppress the notion of spatiality.

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APPENDIX 1

INTERVIEW TRANSCRIPTS DESCRIPTION FORMAT

Fifteen interviews were conducted. The interview transcript descriptions are divided into three stages as indicated in Chapter 3 (see section 3.4.3, p.56-59). A brief remainder on what these three stages entail:

stage 1: explores the students' descriptions of the problem task at the beginning of the interview *before* attempting to solve it;
stage 2: focuses on the students' descriptions *during* the working out of the problem and,
stage 3: focuses on the students' descriptions at the end of the interview after the problem task has been attempted.

The problem solving activity is divided into three phases. Phase 1 indicates a stage in which the students work on the problem without referring to their test scripts. The interviews followed closely on the principle of a learning conversation in that, as the students were solving the problem on the board, the interviewer was able to compare notes (since a prior analysis of the students scripts was done) on the differences or similarities in the approaches employed. In Phase 2 the student refers to the test script either to verify or to clarify a particular way of working or reasoning. Phase 3 indicates a process of change (and implementation of the change) in which an approach or a concept is given meaning that is different to the one given in the test. the headings are numbered according to the individual questions asked in the problem. Note: Not all headings appear in the organization of the interview transcripts of each student, since some students might not have focused on the issues covered under a particular heading (e.g. "re-interpretation", "end-of-interview reflections", etc.)

Five students were interviewed in the first module. Four students were interviewed for the second and third modules. Two students were interviewed for the fourth module. It is not the number of students interviewed that matters, but the variation that exists in the ways of approaching the problem. The students interviewed are referred to as S1, S2, S3, S4 and S5 respectively.

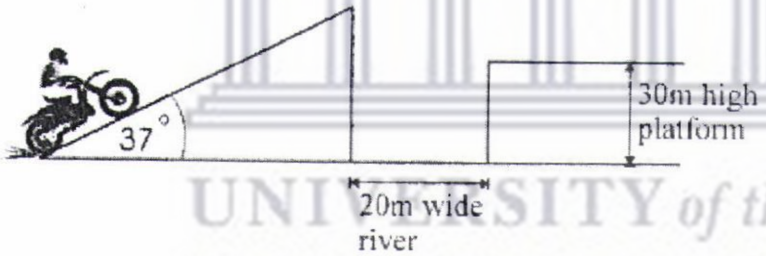
APPENDIX 2

Fifteen interview transcripts (including module problem tasks) organized according to the three stages of analysis of data

FIRST MODULE PROBLEM

TEST 3: APPLICATIONS OF NEWTON'S SECOND LAW

"In the sketch below a stunt driver approaches the ramp on his motorcycle at a speed of 40 m/s. The combined mass of the driver and the motorcycle is 200 kg and the ramp is 100 m long. The coefficient of friction between the tires and the road surface is 0.2. Use $g = 10\ m/s^2$. (11)



a) **Draw a free body diagram of the combined driver and motorcycle. (2)**

b) **How will the speed of the cyclist be affected as he travels up the ramp when the engine stalls at the bottom of the ramp? (2)**

c) **Confirm your answer in (b) by calculating this speed. {Hint: You first need to calculate the acceleration}. (4)**

d) **Will the cyclist make it to the other side of the river? Show your calculations. (3)"**

Student 1:

Stage 1

1.1 Beginning of the interview reflection

1. S1: *Reads the problem. (Pause)… I never know when to use the width of the river. Normally they say he jumps to the other side of the river which is 30m high or what …*

2. R: *You say you never know ...what I would like to know from you is whether you never know how to proceed or is it something else?*

3. S1: *I never know where to substitute…the 20m of the river and the height of the platform.*

4. S1: *Okay I know that you have to calculate the time that it takes for the man to get to the other side and the forces in the x direction and I think you get the time from working out the forces in the x direction and then you substitute the height that is given in to the forces in the y- direction.*

5. R: *How did you come to that understanding?*

6. S1: *Okay (Laughs) normally you look at the problem and work out the possible questions that they might ask.*

7. R: *This is interesting as I mentioned you are going to help me understand where the difficulty lies because many students come up with the same line…so you say that when you prepare for the exam you think about the possible questions that the lecturer might ask. Therefore, for this problem the things you need to know are the time…*

8. S1: *Yes, the time calculated from either the x or the y…I cannot remember. You'll see from the calculation. You will have to use the height to substitute in your forces in the y-direction and the width of the river…I do not know where it all fits but it fits somewhere…*

9. S1: *I think yesterday I read over the question I think yesterday I came up with a solution, but now when I read over it it's no longer there in my head. I cannot think. Okay, it hinted here calculate the acceleration, then I was stuck.*

Stage 2

1.2 Student's interpretation of the problem

Phase 1 (Interview without referring to test script)

10. R: *Take me through the problem itself so that I can get the feel of what you are saying. (S1 gets up and starts working on the board)*

11. S1: *Reads the problem.. (pause)… I never know when to use the width of the river. Normally they say he jumps to the other side of the river which is 30m high or what …*

12. R: *You say you never know ...what I would like to know from you is whether you never know how to proceed or is it something else?*

13. S1: *I never know where to substitute…the 20m of the river and the height of the platform.*

14. R: *This is interesting because a lot of students have in the past said they experience difficulties with these problems. You will have to help me figure out where the difficulty lies.*

15. S1: *Where the problem lies…?*

16. R: *Yesterday in the test you were confronted with the problem how did you go about it?*

17. S1: *The problem is that I don't know how to go about solving this. Okay I know that you have to calculate the time that it takes for the man to get to the other side and the forces in the x -direction and I think you get the time from working out the forces in the x -direction and then you substitute the height that is given in to the forces in the y-direction.*

18. R: *How did you come to that understanding?*

19. S1: *Okay (Laughs) normally you look at the problem and work out the possible questions that they might ask.*

20. R: *This is interesting as I mentioned you are going to help me understand where the difficulty lies because a lot of students come up with the same line…so you say that when you prepare for the exam you think about the possible questions that the lecturer might ask? So for this problem the things you need to know are the time…*

21. S1: *Yes, the time calculated either from the x or the y…I can't remember. You'll see from the calculation.*

You'll have to use the height to substitute in your forces in the y- direction and the width of the river…I do not know where it all fits but it fits somewhere…

22. S1: *I think yesterday I read over the question I think yesterday I came up with a solution, but now when I read over it it's no longer there in my head. I can't think. Okay, it hinted here calculate the acceleration, then I got stuck.*

1.3 The student's problem representation during the interview

1.3.1 Student's problem representation with regard to Question (a): What does the student focus on in drawing the body-diagram?

23. R: *Take me through what you have done on the board*

24. S1: *It says here for question a) draw all the forces acting on the driver plus the motorcycle. You indicate that on the incline, the driver and the motorcycle. Perpendicular to the incline you are going to have the normal force and the weight is going to be vertically downwards and it is going to form a certain angle* θ*. But it says the motorcycle is making an angle of 37 ° which is the same degree that the weight is going to make. You're going to have a friction force as the motorcycle moves upwards, friction is going to be in the opposite direction which is downwards.*

25. R: *How many forces do you think are acting on the motorcycle?*

26. S1: *Three, it's the normal force which is perpendicular to the incline, weight which is downwards and the frictional force which is opposite the motion.*

1.3.2 The student's problem representation during the interview with regard to Question (b): What does the student focus on in responding to how the motion of the cyclist will be affected if he stalls at the beginning of the ramp?

27. S1: *In responding to question b) I think the speed will decrease because the engine stalls at the bottom of the ramp. That means that the motorcycle has to start again and …okay…the initial velocity is going to be zero and as it goes up the…what …it has to increase and when it reaches the top the motorcycle will have to jump to the other side. It won't have enough power, so to say.*

28. R: *How did you come to decide that the initial velocity was zero…what I want to find out is… I'm not trying to find out whether you are doing it the right way or not…but I'm trying to figure out how do you get to decide …how do you come to a certain understanding at a particular time that the initial velocity is zero?*

29. S1: *Sigh…I don't know ..because the initial velocity has to be zero when the motion is started because it doesn't have a velocity.*

30. R: *Does the problem state that the initial velocity is zero ..where in the problem is it stated that the initial velocity is zero?*

31. S1: *It doesn't say. Okay, when an object starts its motion, it was at rest and when it is at rest it means that it doesn't have any velocity at all. That means that velocity it doesn't have it is its initial velocity is zero.*

32. R: *Does the problem say that the motorcycle is at rest.*

33. S1: *No it does not.*

34. R: *It does not ..now I am also confused, how do you then assume that the velocity is zero when the problem doesn't state that the initial velocity of the motorcycle is zero. How did you come to that conclusion?*

35. S1: *Laughs ..(can't figure out what R is going on about) I just assumed…*

36. R: *Based on what?*

37. S1: *Based on the fact that it is going up the ramp that means that it has to start its motion down here…*

38. R; *…Starting at zero and then..*

39. S1: *Its velocity increases…*

1.3.2.1 Re-interpretation of Question (b): Testing the plausibility of the new way of seeing the problem (Phase 3: Indicating process of change in

which an approach / concept is given meaning different to that given in the test)

40. R: *Why did you in the test respond by saying that the speed would decrease?*

41. S1: *Oh... yes, no it is supposed to increase x2!*

42. R: *You are changing your mind? Take me through your new thought?*

43. S1: *Because it was zero as it travels up the ramp...that velocity which was zero increases until it reaches the top of he incline.*

44. R: *Yesterday in the test what did you write, did you write it was going to increase or decrease?*

45. S1: *I wrote it will decrease because I thought as it is going up the ramp... because its up, the speed is supposed to decrease.*

46. R: *Why would the speed decrease, how did you reason it out?*

47. S1: *(No response).*

48. R: *So, now you are saying the motorcycle starts at zero the speed is increased until it gets to the edge of the ramp? And when you have to confirm you answer, how would you go about it?*

49. S1: *Okay about confirming the answer, as I said with these questions I always get stuck ..it says here calculate the acceleration. Yesterday, I calculated the acceleration but today I'm stuck.*

50. S1: *(Referring to what she has written on the board) As I said that the initial velocity is zero at the end the final velocity is 40m/s so I used that knowledge to calculate...the acceleration. I said that down here at the beginning of the incline the initial velocity is zero and then as it goes up the speed increases and here at the top it is going to be 40 m/s our final velocity. I squared the forty and substituted 0 for initial velocity and then got 8 for acceleration.*

Phase 2 (Referring to test script)

1.3.2.2 Comparing the two ways of seeing the problem

51. R: *Let's look at your test script and then you can explain what you did then.*

52. S1: *Pause... I calculated the sum of the forces ...in the x- direction. I took the direction to be negative because it is in the opposite direction and then I subtracted the weight which is another x-component sin 37 ○ s and I said it must be equal to ma (mass x acceleration) because the motorcycle was moving. Then... I solved for the frictional force. I did the same thing with the forces in the y- direction.*

53. R: *Explain why were you doing this?*

54. S1: *Here I was adding...remember the man and the motorcycle are travelling at an angle which means that they have both the x - and y-components. I then calculated the forces in the y and x- direction so that I can get the force on the motorcycle.*

55. R: *And what did you do next?*

56. S1: *From the y-component I calculated the normal force and I know that friction is the coefficient of friction multiplied by the normal force. For the x- direction I had the frictional force equal to...but then I substituted this from the normal force and I multiplied that by 0.2 and I substituted it into the frictional force and I equated the two and from there I could calculate the acceleration from here I could calculate the speed.*

57. R: *Can you see that what you did in the test is different from what you have on the board?*

58. S1: *Ya I see.*

59. R: *Can you explain, do you see that you initial velocity is 40m/s? Can you remember where you got this from?*

60. S1: *No, I can't remember but I think that the initial velocity has to be z ero.*

61. R: *So, you do not agree with what you wrote yesterday? Were you confident about it?*

62. S1: *Yes yesterday I was confident about it but today I'm not.*

63. R: *Why?*

64. S1: *Because I think the initial velocity has to be zero and the final velocity is the one that is supposed to be 40m/s.*

65. R: *If you go back to the problem and read it , what does it say?*

66. S1: *Reads quietly ..okay I get it now. It says here he approaches the ramp at the speed of 40m/s and I think that is where I took the initial velocity to be 40m/s because he approaches the ramp at that initial speed of 40m/s. when I looked at the problem today I thought that he started at the bottom of the incline from rest and the speed increased to 40m/s*

1.3.3 The student's problem representation during the test (Phase 2) with regard to Question (c): What does the student focus on in confirming the speed of the cyclist at the edge of the ramp?

67. R: *You mentioned earlier that when you did the problem yesterday you were confident, but why did you say at the beginning of the interview that these are the problems you struggle with? Make me understand that bit.*

68. S1: *No, I was confident in calculating the speed ...but here for calculating the acceleration I was only solving the problem and getting ...the whatever that I can substitute into something to finally get the a (acceleration)*

69. R: *Did you try to make sense of what you were doing in terms of what was happening?*

70. S1: *No. Even now it does not make sense…all these calculations ...they don't make sense to me.*

71. R: *Explain what is it that does not make sense.*

72. S1: *There are too many unknowns in every equation (pause)*

73. R: *Too many unknowns in the equation…?*

74. S1: *Ya because for the forces in the x.. the frictional force and the acceleration are unknown. And in the y - direction there is the normal force and the acceleration unknown ...pause but at least I managed to substitute the normal force into the friction and then I got to calculate my acceleration.*

75. R: *As you were working the solution to the problem did you at any stage try to get an overview of the whole problem to see what is happening from a bird's eye view to try and make sense of what you expected. Did you go back and check at what you were doing, like you did with the similar problem in section A?*

76. S1: *No I didn't… I ran out of time.*

77. R: *When you got the acceleration and saw that it was –6.3 m/s^2 what did you think?*

78. S1: *It made sense because as he was moving up the incline the acceleration had to be negative…as he was moving up.*

79. R: *Why, explain.*

80. S1: *I think as he moves up acceleration has to be negative ...why I don't know (said in a low harsh voice). I really do not know.*

81. R: *When you finally worked out your velocity to be 18.4 m/s, what did this result tell you?*

82. S1: *18.4m/s?..I think it says that the velocity decreased from what we had initially because we started off with 40m/s now we are getting 18.4m/s.*

83. R: *Did you use this result to determine whether or not the cyclist will make it to the other side?*

84. S1: *(laughs) ..no .. I just wrote that…but it is supposed to be he won't make it.*

85. R: *Why?*

86. S1: *Because the velocity decreased.*

1.3.4 The student's problem representation during the test (Phase 2) with regard to Question (d): What does the student focus on in determining whether the cyclist makes it safely to the other side of the river?

87. R: *(Looking at S1's script)… it says here that he will make it.*

88. S1: *I calculated the time using the formula $x_f-x_0=v_0t+1/2\ at^2$. I substituted the v that I got 18.4m/s for the initial velocity we know that the acceleration in the x-direction is equal to zero and I solved for time and I took this formula substituted the time that I got here into the formula $y_f-y_0=v_0t+1/2\ at^2$ I took my y_0 to be 30m and then I solved for y and I got 43m. And in conclusion I said he will make it because my y (vertical distance) is greater than 30m.*

89. R: *Tell me why you used the time it will take to cover the distance in the x-direction to find out the distance that will have to be covered in the y -direction?*

90. S1: *Because the same time it takes to cover the x- direction distance is the same time that it is going to take to cover the vertical distance.*

Stage 3

1.4 End-of-interview reflections in relation to the whole problem

91. R: *How was it possible for someone who claims not to understand a problem to get 8/11? How is that possible?*

92. S1: *I was only writing I mean ...okay ...I only did what I knew and I found that they could link to each other by calculating the forces in the x as well as y and after that I saw they could link and I could substitute these forces into the x and into the y. Well I didn't get 8/11 because I understood ..I got 8 because I made sense out of what I was doing (laughs). I substituted for every unknown. I just tried to find everything that I didn't know. I did them separately, one thing there one thing here and after that…the one thing that I didn't know and had to calculate was the acceleration. And for calculating acceleration friction was involved, the normal force was involved if there were other forces acting on it they would also have been involved. So, I looked at the acceleration and I took its branches, I solved for the frictional force that was unknown and put that aside and then I solved for the normal force and I put that aside and I looked at the coefficient of friction and the normal force and I asked myself what can I do to solve for friction. I then multiplied the* μ_k *by the normal force. There was acceleration unknown from both…and I thought I could solve these equations simultaneously to get acceleration.*

93. R: *Was this process as you described it to me clear to you as you were working through the problem? Or are you saying all this because you have been given the time to reflect on it?*

94. S1: *No, it was not clear .. I didn't have the idea of the sum of the forces in the x and y- direction. I had in mind the idea of normal and the friction forces. What was clear was that friction had to be calculated because it relates to the acceleration.. because as the thing is accelerating friction is acting downward and as they accelerate because they are on the ramp the normal force acts on them therefore I concluded that the friction and the normal forces had to be calculated and from there I calculated my things. I knew that to calculate the normal force I had to use the forces acting in the y-direction because the normal force is perpendicular to the incline and I knew that my frictional force was acting downwards in the opposite direction in the negative x-direction, so I had to calculate I had to calculate my forces in the x - direction.*

95. R: *This method that you used to solve this problem was it a method you learnt in class or was it a method that you devised as you were going along solving the problem?*

96. S1: *The method that I used I devised myself…,but based on what I learnt in class. `cause I learnt to identify the forces in the x-direction and calculate them like this, but for this particular problem the method I used I made it up myself.*

97. S1: *The thing is I never understood those questions, never ever and I never got a mark for this question whenever it came up. So, I just thought… I had to think about it this time, today I just have to do it. I said whatever it takes I'll think about it and then I thought deeply about it. I read over the question over and over again to try and make sense of the question.*

98. R: *So, what sense did you make of the question?*

99. S1: *I said in general the man had to have a greater velocity initially to be able to get to the other side of the river. And the distance that he'll have to cover will have to be greater than 20m horizontally and greater than 30m vertically and that is what I could come up with.*

100. R: *How different was this problem from the problems you might have done either in class or in the tutorial? Do you think that this problem was particularly different and difficult?*

101. S1: *I think it is difficult but not that different.*

102. R: *What are the difficulties that you picked that you think some other students would not have picked up?*

103. S1: *First, because it says here calculate the acceleration if you use the formulas of acc. as they are I think it is difficult to work it out.*

104. R: *Which formulae are you referring to?*

105. S1: *I mean using:* $v_f^2 = v_0^2 - 2as$*, it will be difficult to get the acc. If you use your knowledge of acc in general I think you can get it.*

106. R: *What general knowledge of acceleration would you use?*

107. S1: *That the forces in the x-direction that are acting on the man are equal to th e mass of the man multiplied by the acceleration because the man is moving.*

108. R: *Say more…*

109. S1: *The same can be said about the forces acting on the man in the y-direction they equal to (m x a) and then you work out your acc from there.*

110. R: *If you were placed in a position of teaching someone else about this problem, what are the things you would concentrate on?*

111. S1: *I would concentrate on the forces acting on the man.*

112. R: *Why?*

113. S1: *If you know that there are forces acting on the m an in this direction or that direction you can then calculate the sum of the forces acting on either direction.*

Student 2

Stage 1

2.1 Beginning of the interview reflections

106 S2: *I was really nervous, like the previous day I went through a lot of ex amples practicing, and I know that I know it, but once I'm inside an exam, once you are given the test, I always think what if I can't prove myself that I can do this, then I'm going to fail. it's like I don't know,… I think..I don't know…I get nervous. Cause I know I can do it. I attend the tutorials, they are really good they really helped me. I made sure that I understand everything in the tutorials, so I know that I'm prepared for the exam, but when I write it is quite stressful.*
107 R: *How did you find the test yesterday?*
108 S2: *Okay, but somehow….yes it was okay.*
114. R: *You were confident obviously..?*
115. S2: *I have to see the results.*
116. R: *Why are the results so important?*
117. S2: *Because I write to pass, right, but ..anyway..*
118. R: *You write to pass…?*
119. S2: *Yeeeesss! But no, no it's about knowing what you are writing. I know it but I think I can express myself better when I'm like talking to you. Like if you put something there and say right, Happy, what is happening there or what is this or what is that…other than writing it down. It all has to do with understanding, knowing what you are talking about … isolate the body and working out the forces and no matter what problem you get, the answer is like its just there and now I understand when the lecturers used to say that the formulas are not so important because I mean you have to understand what you are doing. It's not about talking something and plugging it in there, but I think that system that you have now is really working.*
120. R: *What do you mean, what system?*
121. S2: *The tutorials and stuff. You guys are always there to help us. Like for instance, …. when was it when we had a tut and you were there, just to make people understand why the example was on the board and you find that you are lost during the class and sometimes you might be scared to ask. But if there is somebody walking around and they quickly see when somebody is stuck.*
122. R: *Are we doing something different from last year?*
123. S2: *I don't know, but I think this year is… this year is…I think I like this year more. Maybe it's because I told myself that I can do this. This year I was just enjoying physics. I enjoyed it so much.*
124. R: *Let's talk about yesterday's test, how was it?*
125. S2: *I promise you yesterday I was stressed guess how many test I wrote, three. I had to write anatomy, it's like this big thing I had to write and I knew I had to write my physics and the other re- test. I didn't know whether I was going to make it. as I was studying this example and then jumping to the other going from this one to the other. But I said to myself I just have to go and prove to myself what I know and just write it down on the paper.*
126. R: *So you are saying passing a test, is all about understanding?*
127. S2: *It is all about understanding, yeah! Once you are confident, I promise you no matter what problem, you will be able to do it. It goes with practicing.*
128. R: *The confidence ..one gets it from ..practicing?*
129. S2: *Practicing everyday, like after the lecture going over what was said do some examples, do examples in the text and the tutorial manual and then you know that there is nothing that they can give you that you have not gone through. But if you haven't done that, obviously you'll go down and become stressed and you won't make it once you are stressed.*
130. R: *Are you talking from experience here?*
131. S2: *This is what I experienced last year.*
132. R: *So, when you started writing the test you were confident..?*
133. S2: *I was very confident 'cause I knew what I was writing. I was working out the problem and I was getting the answers and that boosted me. Previously I used to get the multiple choice questions wrong, work it out and not get it, I'll be so nervous that I won't be able to make it for the second section and I'm going to fail, you know, yeah. But yesterday, I was confident because I knew I had practiced.*
134. R: *And the long section, how did you find it?*
135. S2: *I was happy .. because this was exactly what he had showed us the day before yesterday about the incline when* something is going up.

Stage 2

2.2 Student's interpretation of the problem

The student's interpretation of the problem is covered in sections below.

2.3 The student's problem representation during the interview

2.3.1 Student's problem representation with regard to Question (a): What does the student focus on in drawing the body-diagram?

Phase 1 (without referring to test script)

136. R: *Do you mind taking me through how you solved that particular problem?*
137. S2: *(Drawing the body diagram) Okay the body is on an incline, you'll have the normal force, the weight (the x and y-components of the weight). This thing is supposed to be moving that way, so frictional force will be in the opposite direction, okay. Yeah! the mass is obviously ..mass is given 200kg.*

2.3.2 The student's problem representation during the interview with regard to Question (b): What does the student focus on in responding to how the motion of the cyclist will be affected if he stalls at the beginning of the ramp?

138. S2: *How will the speed of the motorcycle be affected as he travels up the ramp when the engine stalls at the bottom? (S2 reads from the question paper) Silence. This was a) and then b). Silence…reads the question again. We are given the initial velocity, obviously he has the initial force, he's got the initial force that pushed him up, and so he will be able to go up the incline.*
139. R: *And, how would the speed be affected?*
140. S2: *He will be going as fast as if the engine was still on.*

2.3.2.1 Re-interpretation of Question (b): Testing the plausibility of the new way of seeing the problem

141. R: *In terms of velocity would it increase, decrease or stay the sa me?*
142. S2: *The velocity will …..(silence).*
143. R: *How did you look at during the test?*
144. S2: *When I was answering I was actually …I was not specific, I didn't look at the change in speed as velocity. I just thought he will be able to go up. So, now if I have to consider that …he starts at* v_0 *which is equal to 0m/s.*
145. R: *Why?*
146. S2: *He starts from rest right…(awaiting my approval).*
147. R: *Assume that I don't know the problem and you were to explain to me how you went about it.*
148. S2: *Okay. Then I'll assume that the velocity.. the speed will increase … the speed will have to increase*

because he starts at a lower speed here at the bottom of the ramp and as he goes up it is going to increase, but somewhere he will have to stop (said softly). Oh no what did I say? (silence).

149. R: *Why do you say that the initial velocity has to be zero?*

150. S2: *Because he has to be starting somewhere from an initial position, i.e. from rest. Here we are given the speed when he's traveling upwards, so he still has to reach max velocity, that is what I'm thinking.*

151. R: *He has to reach max velocity?*

152. S2: *Yes!*

153. R: *How do you know that, … what are you basing this on?*

154. S2: *Mhhh, at the highest point he'll have to reach the max velocity ..where he can't go any further than that.*

155. R: *Where is your highest point in this situation?*

156. S2: *The highest point is right there at the edge ..(silence).*

157. S2: *If I can remember, okay …yes I used the equation: $v_f^2 = v_0^2 + 2as$, to find the acceleration …you first need to calculate the acceleration, yes ….so, I said that …$v_f^2 = v_0^2$ blah …blah ..blah … (referring to the formula on the board)… because now I've changed it so, I said that v_0^2 is zero and we are given the distance which he travels, it's 100m …and then we calculate v_f. Silence. Okay wait I didn't read the problem now, there is that 40m/s okay….so okay you are given v (the velocity) so I put v_f here…*

158. R: *So, you say v = (40m/s)2, what velocity is this, is it your initial or your final velocity?*

159. S2: *It is the final velocity …because I assumed that he must have started at zero.*

160. R: *And form there …what did you do?*

161. S2: *I then calculated my acceleration and then I had to find that v…*

162. R: *Which v did you have to work out?*

163. S2: *Oh no, no, no I didn't have to find that v because I already have the initial and the final v so I only had to find acceleration.*

164. R: *In question b) you were asked to work out the speed, what speed are they referring to in this case?*

165. S2: *(Reads the question) Confirm your answer by calculating the speed?*

166. R: *Which speed are they referring to here?*

167. S2: *They want the speed at which he will be travelling to go up this whole incline.*

168. R: *Is that what they want you to work out?*

169. S2: *(Silence) …..(Looks at the problem and reads something from the question paper) …Yes that speed …yes they want ….(reads the question again) Confirm …..by calculating the speed. No, I'm confused now, because we are given this one and that one, maybe I'm contradicting myself.*

Phase 2 (Referring to test script)

As mentioned earlier, Phase 2 is the exploration of the changes in the student's interpretation of the problem. It explores the differences in talking about the problem between the test and the interview contexts.

2.3.2.2 Comparing the two ways of seeing the problem

170. R: *Let's look at your script to see how you solved it. (Both R and S look at the script). In here you have something different, can you see that?*

171. S2: *No wait! Oh no ..no ways …no ways…*

172. R: *What?*

173. S2: *Okay , okay …I had to look at the sum of the forces mos, because this is Newton's law, now I was only thinking about the motion equations…*

2.3.3 The student's problem representation during the test (Phase 2) with regard to Question (c): What does the student focus on in confirming the speed of the cyclist at the edge of the ramp?

The student's understanding of the application of Newton II to the problem is explored below.

174. S2: *I had to find the sum of the forces in the x -direction for this body and then I had minus fk Frictional force); minus mg sin* θ. *we are given the angle it is 37 ° which is equal to ma, because the body has acceleration and then had to work out the sum of the forces in the y-direction. Since I took upwards as positive and downwards as negative, so my normal force will be positive and the component of the weight here will be negative, So I have* $N - mg\cos\theta = 0$ *because there is no motion in the y-direction and I ended up with* $N = mg\cos\theta$. *To work out N since we were given the coefficient of friction so I had to first solve for N and then proceed to working out fk. In the working out of the sum of the forces in the y and x I had to find fk here and then substitute it back there in order to find acceleration. Cause if you have got two equations you can find out the unknown.*

175. S2: *When you are looking at the body, you have to consider all the forces acting on the body, yes all the forces acting on the body. If the body is like this, then we divide it into different components, it is much easier to do this if the body is a point on an incline. In any body when you look at forces acting on it, you have to look at the y and x- directions.*

The following excerpt explores the student's understanding of negative acceleration.

176. R: *So, you used this knowledge to work out the acceleration?*
177. S2: *Yes, ..and it did make sense because it had to be negative.*
178. R: *What does it mean when you get a negative a?*
179. S2: *It means it's in the opposite direction.*
180. R: *Opposite to what?*
181. S2: *Since the motorcycle is going up an incline, as it goes up like this is in the negative direction er …(pause).*
182. R: *I don't understand.*
183. S2: *(Pause) ..you don't understand?….I don't know how I can explain this further, but I now that a is negative.*
184. R: *How do you know that?*
185. S2: *It's because I did so many problems like this and the acceleration came out to be negative, that's how I know.*
186. R: *If you were to explain this problem to someone who has never done physics before and you had to interpret the answer, how would you make that person understand what the negative a means. And your own response would be…?*
187. S2: *Not sure (pause).*

The following extract explores how the student confirms the decrease in speed of the cyclist going up the ramp.

2.2.3.1 Re-interpretation of Question (c): Substitution of magnitude of initial speed of cyclist (Phase 3)

188. R: *Okay, now that you've worked out a, how did you proceed from here?*
189. S2: *Instead of* $v_0 = 0m/s$ *I should have used 40m/s, obviously I understood it wrong, then I would have been*

able to calculate the final velocity. And with that v_f I should have been able to calculate the horizontal distance in the x - axis to see how far will he lend. I would then have been able to see if he was going to make it to the other side of the river or not, which is 20m away.

190. R: *And how would you have done that?*

191. S2: *It will make sense then to use the correct values of v initial (unlike the ones S used in her test). We will use the equation $v_f^2 = v_0^2 + 2as$, we will have $v_f^2 = (40m/s)^2 + 2as$ our acceleration is the one that I calculated and what did I get $-7.6m/s^2$. Forty squared is 1600 + 2(7.6) (100m) and for the acceleration, you don't have to put an negative sign if you are working it out, cause that just shows that it is in the opposite direction.*

192. S2: *Er ... because I'm looking at that 40 as my initial velocity so now I want to see at what speed will he be traveling at the here at the edge, ya. So, to work out the answer, (working on the computer), get the square root of everything and we get 58.8m/s. (writes it down) so that means....*

193. R: *Does it make sense?*

194. S2: *His final velocity is bigger than the initial one...? I was thinking it would be less because the speed will decrease and then I was going to use this final v to calculate the distance here.*

195. R: *Can I take you back to your acceleration, you said the minus sign does not have to be included, but you didn't offer a valid explanation.*

196. S2: *The minus sign just explains the situation here.*

197. R: *So, you are saying that the negative sign you got for the acc. doesn't influence your final result of the velocity....? Is that what you are saying?*

198. S2: *This confuses me sometimes .... but I think if we use it here it would make sense. My final v will be less, ya. Okay let's try it again let's put a negative sign. My answer doesn't make sense with positive acceleration. The final velocity can't be greater than the initial velocity in this case ..because when something starts at a certain point and then goes it will have the same velocity as that which it started with.*

199. R: *Are you expecting to get the same velocity as you initial velocity in this case. Is that what you are saying?*

200. S2: *(pause) Yes. like with projectile motion if a projectile starts at 40m/s it will end up at 40m/s, but looking at something on an incline. It is something like .....*

201. R: *So, what do you expect your final velocity to be?*

202. S2: *Less than forty.*

203. R: *Why?*

204. S2: *Because it is not on the same point as when it started ...(pause) ..the velocity has to decrease ... because the engine cuts out there, so obviously the speed will decrease as the motorcycle goes up.*

205. S2: *Yes, (S does the calculation) 8.9 m/s, but yesterday I didn't get something like this.*

206. R: *Let's look at what you got. (S and R look at S's script). Yes, yesterday you took our initial v to be 0m/s. Are you happy with your calculation today?*

207. S2: *Yes, because everything is right.*

2.3.4 The student's problem representation during the test (Phase 2) with regard to Question (d): What does the student focus on in determining whether or not the cyclist safely makes it to the other side of the river?

208. S2: *Looking at what we have to do now, work out whether the guy will make and show your calculations, I didn't know this one. I calculated roughly and just put the answer here.*

209. R: *Let's look at your script. Here you've got ...would you like to explain what you did?*

210. S2: *I calculated the time, cause I thought time will be important in working out the distance to be covered. Let me see ...Yes, I had to find the distance using the equations of motion $x_f - x_0 = v_0 t + \frac{1}{2} at^2$, yes that's another reason I thought I needed the time cause I thought in this equation you need to have the time. Your x_0 is 0 and you have to work out xf the distance from here to somewhere where he is going to land. This distance will then tell me whether he makes it or not. if it is more that 20m then we'll know that he makes and if it less we know that he would have landed in the river.*

Stage 3

2.4 End-of-interview reflections in relation to the whole problem

211. R: *How did you feel about working out this problem in the test?*

212. S2: *It was a nice problem, I understood it?*

213. R: *What do you think were the most important things to be kept in mind when working the problem?*

214. S2: *The first important thing is that when you first look at it, you must understand what the problem is all about.*

215. R: *What do you mean?*

185.S2: *When you look at it you must be able to think about it and draw a diagram that will show you exactly where everything is. Like this one, when you look at it you musty identify that yes this is the river this is the other side, just be able to understand what will happen as this person moves from here to there. Look at as he is moving what is happening to him, what forces are being applied and what effects do these forces have on him. Since this is a Newton type of a problem, so the forces are very important because … in order to work out your acceleration you need to know the forces acting and the role they play in the x and y-direction. You need to be excellent in identifying the forces, if you miss one force, then you get the whole thing wrong. This is what everybody should know on their fingertips, drawing free-body diagrams, isolating the body that is very important. You can't go through this problem without these steps. The next thing is knowing how to resolve your forces in the x- and y-direction because once they know that they will have a set of equations to use and from there is just mathematics.*

Student 3

Stage 1

3.1 Beginning of the interview reflections

216. R: *And the second one? How did you find the second one?*

217. S: *The second one was very challenging first of all, but then...*

218. R: *But it wasn't difficult, as difficult as this one, or would you say those are 2 completely different problems?*

219. S3: *The problem was very challenging ...It's very different. Okay here as well I've got an incline and they told us... here's the question, how would the speed of the motor cyclist be affected as he travels up the ramp when the engine stalls at the bottom of the ramp. And then I thought, the engine stalls at the bottom of the ramp, not up here. And then I got kind of... I didn't know what to say exactly, but then I knew that the speed would decrease, however... You see, now that's applying my own methods, that's not physics, because if I had to think about physics then I would have to analyse it, like know where exactly this whole thing happens..*

Stage 2

3.2 Student's interpretation of the problem

Phase 1 (Interview without referring to test script)

220. R: *What do you mean... I'm trying to understand when you say... you now have to use your own ideas and not physics. Take me through how you solved the problem and explain, where exactly did you sort of feel you were using physics and where were you not using physics...*

221. S3: *Well they ask this question about the speed of the motor cycle when... the engine stalls. Okay, I thought this was going to be really complicated physically, but as I understand it...*

222. R: *How did you understand it?*

223. S3: *As I understand it... I thought OK, if the engine is going to stall, but then the motion is going to continue, and I knew that it wasn't going to be fast, it couldn't be fast, I just thought so... I don't know what brought that to my mind but I knew the speed would have to decrease. That was my own thinking.*

224. S3: *Since I didn't know much about the physics.... The first thing that I thought about I knew it wasn't physics, so I thought I can't... just go and think about equations and everything, let me just try and... calculate this. So, I thought okay let me just find... because the second question says confirm your answer by calculating the speed.... I knew that I had to find the velocity obviously. And since I was given... the mass of... the motor cycle; the distance and the... speed.... the initial speed, so I thought I should use the principles of motion along the straight line..*

3.3 Student's problem representation during the interview

3.3.1 Student's problem representation with regard to Question (b)*: What does the student focus on in responding to how the motion of the cyclist will be affected if he stalls at the beginning of the ramp?

Note: The student didn't focus on Question (a) – body-diagram

225. R: *Take me through that?*

226. S3: *I don't... remember this, but... (pause)..I must... say I was not relaxed at all... with this paper, I was not relaxed. I thought it was just... it wasn't relaxing...*

227. R: *It was a trying experience... And the previous test...*

228. S3: *It was fine, I was enjoying the test, I was just writing, but this one I had to do a lot of thinking. (Pause). What did I do here? I used this equation. What did I do first, I didn't use the equation first. (Pause). I'm given the speed, 40 m/s, and the mass, the mass is 200 kg, and the distance is 100 m... They give us the coefficient of the friction...0,2. What I did here was... Oh I remember, I wrote something like this , I don't know what I was doing, but I wrote something like this. Force is equal to mass times acceleration, and then I realized... I'm getting away from what I'm supposed to do, but then I thought... Oh I had 2 things in mind, the equation of motion in a straight line, but then I thought if I have a thing about that, then I'm going to have to put this thing in component form, and that's going to very difficult for me, 'cause as I was trying to find the simplest thing, and I was... running out of time...I was saying that if I have to use the equations of motion and everything I have to put this in component form ,and I knew that I was running out of time so I was trying to find the simplest... method. So I said a force is equal to mass times acceleration... It looks simpler than the one where you have to say this squared minus that so I thought... let me just use this. So what I did was, I said the force here was 2000 Newtons, and then my mass was 200kg…I found the acceleration... here... I found it to be 10 m/s^2 . What else did I do? I wasn't confident about this. Because I had to think about… if... he was moving at 10 m/s^2 , how fast that was and everything, given this... distance. What else did I do? But I ended up using the other equation, where V squared is equal to V naught squared plus 2as. And I tried to find acceleration using this.*

229. R: *But then you had already got that acceleration there...*

230. S3: *I was just... trying to make sure that I'm doing the right thing. And so I said the speed was 40... and then the initial speed was zero, and the acceleration and the distance...*

231. R: *Just explain to me, why did you choose your initial speed to be zero?*

232. S3: *Because it says, he approaches the ramp on his motor cycle at a speed of 40 m/s. They don't say... he starts off at a speed of forty... It's like he's been moving already. So that's why I just said the speed was that...*

233. R: *But if it was moving already how can the speed be zero?*

234. S3: *I just thought maybe at the instant that he actually started moving, the time is equal to zero, I just assumed that he was not moving at all at time is equal to zero... And then maybe at time is equal to 1 second was moving at whatever speed...*

235. R: *I can see that you have used the equation V squared equal to V initial squared plus 2a (s final minus s initial), that's your distance, the s. For the second part I can see that you have substituted 40 for your final velocity, and at time t=0 you've indicated your initial velocity as zero, plus 2a, then in brackets you've got 100, which is the distance the motor cycle covers. And my question is: that 40 m/s that you have as final velocity, does it mean that the guy will be right at the edge...*

3.3.1.1 Re-interpretation of Question (b): Substitution of magnitude of initial speed of cyclist (Phase 3)

236. S3: *No.. This is not true. But I did something like this... I can't remember. Because... ya, it makes sense now, because... at the end... it can't be 40. But I think this is how I did it, because I had to assume that... here the speed is 40, I know that... this is where all the principles come in. Because... maybe it's because I knew that I was trying to find acceleration, and so I thought, let me just make this zero, and calculate the acceleration at this point... the distance I know...I know that this wrong because when he's covered the distance of 100 m, the speed has decreased already...Because at 100 m... the distance is 100 m long, so when his speed is 40 m, he hasn't completed the whole thing yet*

237. R: *But you said that whenever you solve a problem you like thinking through the problem first without using the formulae. From what you've explained to me…would you say you were thinking about it or what was happening?*

238. S3: *I'm thinking about the problem... in my mind, and then I try to use a lot of things that I think, like maybe... this equation for instance, I wasn't using the equation that we usually use, that's what I mean. 'Cause usually when we have these problems you know that you are going to use the equations of motion or the equations of Newton whatever... But then I tried to use... I used equations but the equations that... we don't usually use in class when dealing with these... problems.*

239. R: *How did you decide on that? Why did you say "I'm not going to use equations that we use in class, I'm*

going to use something else"?

240. S3: *First of all if I use 2 different equations... one that we always use in class and the one that I al ways think I could use... If I get a certain answer, then maybe I know that OK... it could be right...*

241. R: *But then you didn't first try out the equation you learnt in class?*

242. S3: *No...*

243. R: *How do you test, how do you check whether your answer is correct?*

244. S3: *I use the equation... first initially I use the equation that I'm thinking that... okay I could use this, and then I try to use the equation... done in class, and then compare the answers...*

3.3.2 Student's problem representation with regard to Question (c): What does the student focus on in confirming the speed of the cyclist at the edge of the ramp?

245. R: *Did you do it for this problem?*

246. S3: *Ya, we don't usually use these equations when dealing with this, because we've been using... the sum of the forces in the y-direction and the sum of the forces in the x -direction...*

247. R: *Why didn't you use that?*

248. S3: *I did use that.... because I had to... put this in component form... this is your angle and everything...*

249. R: *You didn't... Did you?*

250. S3: *Ya, I put this thing in component form... And here... I was without displacement, I had to... here as well, because I know the displacement is like 100 m, but for the whole thing. And then I used my x- and y-components to find the displacement in the x- direction and the displacement in the...y-direction.... I was just doing a lot of different calculations trying to find one thing. That's what I usually do...*

251. R: *And the final velocity? You ended up using your final velocity as what...? How did you work out your velocity? So eventually you conclude that the motorcyclist will make it to the other side?*

252. S3: *I said he would make it, but I don't know why I said so. I said he will be travelling at 35,8 m/s... How I found that, I don't know... Sometimes I think... I can't make out what I'm thinking. It was one of those moments... Sometimes physics makes you... think of things that you can't really make out when you're sitting in your room. Like no w, I didn't know this is what I wrote, I'm the one who wrote this but I can't remember it...*

3.3.3 Student's problem representation during the test with regard to Question (d): What does the student focus on in determining whether the cyclist safely makes it to the other side of the river?

253. R: *And then, what was the reason behind this (resolving the 100m into x - and y-components)?*

254. S3: *I was... going to find where this person would be... no..., if he would make it to the other side... Because I knew that I had to add 20 m in the x -direction... and then I forgot to add my 30 to the vertical displacement. Because here... this is 30 m high. I knew I had to put this in component form, but then I don't know really, maybe I was panicking, because here it says ya, I should have added this 20 to the x - and then this 30 to the y-, but then I did not do that...*

255. R: *But why would you have had to add the 20m to your x and the 30 to your y?*

256. S3: *Because I was trying to find if he would make it to the si de...I used my velocity in the x - direction which is the reason why I had to put this in component form. I was trying to find out where he would be if he moved... But I was supposed to calculate velocity first, the velocity at the final point. I think I did that. And then use that velocity and add this distance in the horizontal component, and find if he would make it to the other side at that speed. What I didn't know is that... if the speed, if he doesn't make it to the other side, the speed would decrea se, something like that. I know I had to find the distance, and if he doesn't make it, he would be here... somewhere here.*

257. S3: *I thought about the question and then I realized my equations, they're not helping me in any way. I tried to use the equations that we did in class, and I realized I was also stuck, 'cause now I had to find a lot of things, the velocity here for instance... I thought that would be easy, as we did problems like these in class. I got stuck somewhere however, and I ended up doing the calculations for the sake of doing calculations, because I had the variables and I had the equations. I ended up substituting, because the*

equations... were there... I ended up doing something that I really didn't know. I didn't know how this was going to help me...I knew that the velocity was going to decrease... and.... if he was to make it to the other side, I don't know if he was going to fly or whatever... I knew that if he makes it to the other side, he would be 30m above the ground, and he would be 79,9 m plus 20 m in the x-direction. That's the horizontal displacement, because horizontally we've got 20 m [the width of the river]. I knew that if I add the 30 m to this vertical distance I will get... 90,18 m, so I thought... no, this person won't be here, he would be there.

Stage 3

3.4 End-of-interview reflections in relation to the whole problem

258. S3: *I found the acceleration and I used this equation to find the velocity of the guy... here, and I think this is where I got stuck. I didn't know how this velocity... I didn't know whether it should increase or decrease... on his way to the other side. I saw this gap here, so I didn't know whether he was supposed to fly or what... That was my question.*

259. R: *Why was that question important at this point?*

260. S3: *Because we have an incline here, and then this space which is the river, and then the platform, where he is supposed to be. My problem is that... how is he supposed to get there? Is he supposed to fly?*

261. R: *Why was this particular thing so important? What is it that you thought was important to get the cyclist to the other side? I am trying to understand why was it a problem for you, that when the cyclist gets to the edge of the ramp, how was he going to get across?*

262. S3: *I knew that... the speed had to increase. Maybe he should accelerate... If he is moving very slowly, he's going to fall somewhere... here. I was thinking of a way to write this down, for someone to understand it. Maybe that's why I really struggl ed... 'Cause if the speed decreases, he is going to fall somewhere... here. And I was trying to write this down, using an equation and just putting in values... To someone else, especially if the answer is wrong, someone won't understand it... They won't un derstand what I'm trying to say, it will be like I don't understand what I'm doing, I'm just using the equations.... That was my problem.*

263. R: *So why didn't you use words then... to explain what you were doing?*

264. S3: *I just thought that it wasn't physics.*

265. R: *If you were to talk to somebody who has never done this problem before, what are some of the things that you would stress?*

266. S3: *I'll make it very clear that... you have to think. You can't just use the formula if you do not know what's going on. You can use the formula, but if you're just going to substitute in values, you might have a problem. To understand what is needed for the person to get to the other side, whether it is an increase in speed or whatever... I don't know...!*

Student 4

Stage 1

4.1 Beginning of the interview reflections

267. R: *How did you feel about the test that you wrote last week Thursday?*
268. S4: *I didn't practice much for the test you know, the only time I had for practicing was Wednesday round about 8 in the evening till 1 in the morning. What I didn't know I didn't care much about because it was just too late for me to practice , so I just went and wrote the test.*
269. R: *When you say you practice, what is it exactly that you do?*
270. S4: *Mostly, I look at the problems that I don't know ..like how to use an equation and when to use a certain equation.*
271. R: *Can you be more specific, can you think of concrete examples.*
272. S4: *Mostly I practiced problem related to circular motion because I didn't know how to calculate them.*
273. R: *How did you go about it? Were you using a textbook or notes …?*
274. S4: *I used the University Physics the latest edition. I did the problems involving circular motion.*
275. R: *How did you go about it, did you look at t he end of the chapter questions or did you do something else?*
276. S4: *The end of the chapter questions, …I didn't do the chapter, I didn't even read it. I just went and I did the problems because I got it when it was taught in the class. I just wanted to know how will I do if I do the problems.*
277. R: *Why did you concentrate on circular motion?*
278. S4: *It's because it's what I didn't know.*
279. R: *But the rest of the stuff … you were okay with it ?*
280. S4: *Not that ..but yes I can say that I was okay with it, that I knew it.*
281. R: *And when you got to the test…?*
282. S4: *I didn't see anything regarding circular motion (laughing) …*
283. R: *And then what?*
284. S4: *It was quite frustrating because I was expecting circular motion, but the test was fine it wasn't that hard because I could do most of the problem except for a few parts there and there.*
285. R: *I would like to take you to section b and focus on the second problem. Did you attempt it in the test?*
286. S4: *Yes I attempted it.*
287. R: *And how did you feel about it?*
288. S4: *I can't remember which one it was.*
289. R: *(Shows the student the problem)*

Stage 2

4.2 Student's interpretation of the problem

The interpretation of the problem is explored in the sections below.

4.3 The student's problem representation during the interview

4.3.1 Student's problem representation with regard to Question (a): What does the student focus on in drawing a body-diagram?

Phase 1 (without referring to test script)

290. R: *Do you mind showing me how you solved it?*

291. S4: *Ya , no problem. (Gets up to do it on the board) Reads the problem first. In the sketch below a stunt driver approaches a ramp on his motorcycle at a speed of 40m/s, at a speed …which means it's v0, I think. (Writes 40m/s on the board. Carries on reading.) The combined mass of the driver and the motorcycle is 200kg, writes on the board mass = 200kg and the ramp is 100m long, distance 100m. The coefficient of kinetic friction between the tires and the road is 0.2 which is friction, no this is* $\mu_k = 0.2$. *Then the first question says draw a body diagram of the combined driver and the motorcycle. You isolate the body there, the mc will look something like this I'm not good at drawing. we have the downward force which is the weight acting on the driver and the mc which is mg and then the upward force which is perpendicular to the surface and we call it N because the motion of the motorcycle is this way then you'll have friction in the opposite dire ction which is downward you have fk on this side. Ya what else. so these are the forces acting on the body. They are three.*

292. S4: *The second question asks how will the motion of the motorcycle be affected as he travels up the ramp if he stalls at the bottom of the ramp. Stalls at the bottom of the ramp.*

293. R: *What are you doing now on the board, is it what you did in the test yesterday?*

294. S4: *Actually this is what I do with most of the problems. I don't just have to think about the problem first and what the problem wants because that is going to waste me some time, so I have to pass do other problems and come back…*

4.3.2 Student's problem representation during the interview with regard to Question (b): What does the student focus on in responding to how the motion of he cyclist will be affected if he stalls at the beginning of the ramp?

295. S4: *If we go to the second question (reading the question again) I think this one does not need any calculations. The speed will be decreasing…*

296. R: *How do you know that?*

297. S4: *er … because (pause) as the motorcycle…if you initially give it; if you are initially traveling at 40m/s and then you'll be accelerating,.. no you won't be accelerating, as you go up the ramp your speed will be decreasing…*

298. R: *Yes, but why?*

299. S4: *Because you are going up.*

300. R: *So, do you mean that whenever you go up an incline your speed decreases?*

301. S4: *Not always.*

302. R: *Okay, in this situation why would the cyclist's speed decrease?*

303. S4: *(silence) Mhhh … why? (long pause) what I can say is.. you see with this motor cycle, I think there is no force applied on it, you see the initial force that pushes it to go up. I do not see that force. The only forces that are acting on the body are the ones I've already mentioned. I mean a force that will be initially given, let's say that this was not a motorcycle but a ball. You give a ball an initial velocity you push it up and it will go up the incline at a certain speed. Even the ball will decelerate ..because it'll have to overcome the incline.*

304. R: *What does it mean to overcome the incline?*

305. S4: *Er ..er how do I explain this? (pause) Okay, you see let's say that this ball is initially given a certain force, as it goes up the incline its acceleration is downward. It is being pulled on the negative side..*

306. R: *Pulled by what?*

307. S4: *I can say by gravity…(pause)*

308. R: *You are saying gravity pulls the ball sideways…?*

309. S4: *Ay no, it isn't gravity, ..but its acceleration is in the opposite direction…once I read a physics book that was back in matric, I haven't read the one we are using now. Mostly these are the things that I learnt at high school, that when a body goes up an incline its acceleration is downward. So, as it goes up it decelerates, nah, nah … is it always? This one as it goes up its speed will be decreasing …*

310. S4: *What will cause the decrease in speeeed…? I think ..er ..er its friction …pause…I am not sure.*

4.3.3 Student's problem representation during the interview with regard to Question (c): What does the student focus on in confirming the speed of the cyclist at he edge of the ramp?

311. S4: *And question c) says confirm your answer by calculating the speed (hint you first need to calculate the acceleration. Firstly, I asked myself how do I get acceleration and then I looked at the forces that I have. I've got one in the horizontal direction and then two forces oh I've got two … I've also being given an angle 37 °, I looked at that. This angle will be equal to this angle over this side… and how do I know this it's because this angle is 90 ° so for this triangle this is supposed to be 180 ° that is the sum of all the angles in a triangle. To get this angle I just add 90 plus 37 ° = 12 ° s and 180 -127 =53 °. Then this is 53 Ω and then you look at the bigger triangle this angle over , you see this is also a right angled triangle, so to get this angle over here, this is supposed to be 90 °, because it falls at 90 ° so to get this we've got to say 90 – 53 and we get 37 °. That is how I got this angle. And as I was saying we wanted acceleration as we were given a hint that we first have to calculate the acc. I said let's choose our direction and I chose my positive to be on my right and then I said on the horizontal axis I have fk. The sum of the forces acting along the x -axis = …*
312. R: *Why are you doing that…what was the reason thereof?*
313. S4: *That's because I want to find the sum of the forces .. the main thing I have to calculate is acceleration. To get acceleration we have to apply Newton's Second Law which is ..ya ..a body will remain in a state of uniform motion unless acted upon by an external or resultant force.*
314. R: *Is that NII?*
315. S4: *Yes (confidently) because this body is moving it is not at rest. So, we are going to apply NII which states F(resultant) = ma*
316. R: *Just explain what that notation stands for. Think of someone who has never done physics before and you had to explain to her what F (res) = ma means what would you say. Like what do you mean by a resultant force?*
317. S4: *To get the force acting on the body you have to find the mass and acc. How can I explain it er...resultant force …I think … the only situation in which I can explain the resultant force is that it is the force applied on this body.*
318. R: *The forces exerted on the body..?*
319. S4: *Not all the forces.*
320. R: *Make me understand that…*
321. S4: *Not all the forces.. I can say if this was a ball and it was given an initial force then I could say that that is the initial force … that is the resultant force, the force which is given to the body initially, that I can say is the resultant force (long pause).*
322. R: *You can try and unpack it for me as you take me through how you solved the problem, how is that?*
323. S4: *Okay.*

In the extract below, the student offers a mathematical representation of his application of Newton's Second Law in order to find acceleration for determining the cyclist's velocity.

324. S4: *… so we are finding the sum of the forces acting along the x- axis. We choose our x-axis to be horizontal, the sum of the forces acting along x-axis = then we have 37 deg. over here, the weight downwards, it has two components, this one and that one…You can see the body's acc is going this side. This is the side we want, this side we have the sum of forces acting on the x- axis = what is our weight, we have to know what mg is first, So, mg = 200kg x $10m/s^2$ yes that is mg = 2000N. Then I said, 2000N sin 37^0 minus… you subtract the frictional force because it is in the opposite direction, minus the frictional force and you equate it to mass times acceleration. The mass (m) is 200kg and a is …(pause) a is a, a is $10m/s^2$ Yes I think a is 10m/s2. No, this is what we want. Can I have a calculator. sin 37 deg x 2000 =1203 - divided by 200 = 6.018. I'm calculating the value of a …we said this was 1203 minus the frictional force equal 200 x a. We can't divide by 200 because we still have to get the value of fk. So we have to calculate the frictional force. There is something that I can't get quite yet. Let say 200 x sin37 = 120.3 okay in order to get fk we know that* $F_k = \mu_k \times N$ *where N is the normal force and is the coefficient of the frictional force. So we have to find N. To find N we have to calculate the sum of the forces acting along the y-direction, so the sum of the forces acting along the y -axis = let's put N which is acting upwar d and what is the other one, the other one is the weight, you see, ya it is the weight, so the weight is opposite N*

it is downwards. We subtract the weight from N. the weight is $2000\cos 37^{\circ}$ *and you see so we take it to the other side, we equate this to zero …neh…*

325. R: *Why?*

326. S4: *Er ..er …why do we equate to zero? Pause Okay if we were to say* $N - 2000\cos 37^{\circ} = ma$ *we couldn't have a… because we haven't got acc. in the y- direction we only have acc in the x-direction. So we say N is =2000 cos37* $^{\circ}$ *which equals 1597therefore fk will be equal to… we multiply 1597 by 0.2 = 319 so that's the value of fk. We go back to our first equation and find the value of a. We have 1203minus the value of fk which is 319 = 200 x acceleration. We make acc. the subject of the formula and say a = 1203 –319 divided by 200, you see we get a = 4.4 m/s* ^{2}*…*

327. S4: *We now have to work out the speed, speed is = distance traveled over the total time taken, we are given the distance 100m divided by the total time taken, ..no… no it seems like we don't have the time, this would then be hopeless. How do we work out the speed, ..okay this is how we do it. We need to get the time first in order to get going (he erases some stuff on the board.). What I though at that particular moment in the test was any equation that I could apply that would give me the time, I'm going to use it. So, I looked at my equations and I said the average a = change in velocity over change in time. Then make t the subject of the formula* $v_0 - v_f$ *no it is vf – vo over acc, which is 0 –40m/s..*

328. R: *Why is your final velocity zero?*

329. S4: *Because I'm not given the final velocity when I'm not given a variable I always put in zero then we say that divided by 4.4 and it equals to 9.09. So this will be minus –9.09 since we do not have negative time, we ignore the minus sign. So the speed will be equal to .. we will apply the equation of motion we say v 0 = 40m/s; a = 4.4 m/s* ^{2} *; t = 9.09s therefore v =79 m/s…79m/s?*

330. R; *Why do you look hesitant, is there something wrong?*

331. S4: *(long pause) No.*

332. R: *What do you make of your answer, what does that 79 m/s tell you?*

333. S4: *This tells us that the velocity of that motorcycle at the edge is 79 m/s. What came up on my mind was that how can he be travelling at 79 m/s when the acc. is 4.4 m/s2? So, I thought that velocity and acceleration are not the same thing, so I thought he could be travelling at 79m/s but accelerating at 4.4 m/s* ^{2}*.*

Phase 2 (referring to test script)

334. R: *Let me take you back to your script, you have acc. to be negative 4.4 m/s* ^{2} *. Can you explain that?*

335. S4: *I have it as minus 4.4m/s* ^{2} *? Okay let's go back and check… alright … alright … now I get it, it's my fault okay we look at this because here we are also dealing with …acc what is, it is a vector hey (says it softly unto himself) so we have to consider its direction as well because its direction is downward so it will have to be negative. Lets' do this part first. let's say 4.4m/s* ^{2} *x 9.09s and subtract this form 40m/s and our velocity will be 0.4m/s. What was required the speed, yes this will be the speed as it travels up the incline. So yes it will be travelling at 0.4 m/s*

336. R: *Does this calculation make sense to you?*

337. S4: *To me it didn't make sense because dropped drastically, so if it was travelling at 0.4 how will the motorcyclist make it to the other side of the river. When I looked at it I thought of a real life situation because he'll be risking his life so because I was running out of time so I went to d) anyway I couldn't change it because I knew that the speed had to decelerate.*

338. R: *What do you mean that the speed had to decelerate?*

339. S4: *It had to decrease, so I just moved on to (d).*

4.3.4 Student's problem representation during the interview with regard to Question (d): What does the student focus on in determining whether the cyclist makes it safely to the other side of the river?

340. S4: *(S4 reads question d) from the question paper) Show your calculation.*

341. R: *When you came across this question what did you, did you calculate or did you just think about it and inferred..*

342. S4: *First I thought about it,….will the cyclist make it to the other side. Ya… I thought I had to calculate the*

distance using the questions of motion using: $v_f^2 = v_0^2 - 2as$*. I took this one because I had the velocity the acc and all I wanted was the distance s, so I made s the subject of the formula. The distance at time o is zero so s is = 0.4squared – 40squares divided by 2 x 4.4 = -181.8, okay distance is not negative so ignore the minus sign and get 181.8 m. So, I said how can he travel 181 it was too big because the river is just 20 m wide, so how can he travel 181.8 it is so big. I thought that the answer would be something like 30 or 40 something close to 50m not something greater than 100m, but anyway I was running out of time so I had to stick to that answer.*

Student 5

Stage 1

5.1 Beginning of interview reflections

343. S5: *(Student worried about his mark) When I get below 65% I get worried, because I set a target for myself. I told myself that I'm not doing well.*

344. R: *You got 60% is this a big problem for you?*

345. 5: *Ya it is because you see it as being in between passing and failing. You can't rely on a percentage like 60% what happens if you drop and get 50% or even less. So, if I aim for 65% and above I know that even if I drop be 10% I'll still get above 50%. That is why I get worried whenever I get anything less than 65%.*

346. R: *You do not consider things like the difficulty of the problem…?*

347. S5: *I do not believe that anything can be difficult except being given enough time to do the problem and understanding the problem. I don't think that there's anything difficult, except if it isn't me that makes the problem difficult for myself because I'll tell myself that it is difficult I can't do it, my attitude will influence me.*

348. R: *Did you experience any of the things you've spoken about thus far yesterday in the test?*

349. S5: *(Hesitant) Ya…ya, , but ..ya I did experience it because when I told myself I can't do this automatically …I .. I… even though I was able to do it I knew that I wouldn't reach my target.*

350. R: *When you got the test , what did you do?*

351. S5: *I knew that I had problems with the application of Newton's laws, but I tried my best to answer some of the question althoug h I made mistakes here and there….but I realized that the way you interpret the questions could be problematic, for example interpreting the question the wrong way. Like not reading the whole statement correctly because I was rushing, that was one of the main issues. Sometimes you find you read the statement and find that don't understand the statement and you try and see that you can't do it and then you are in great difficulty. Let's say they say a car is sliding down an incline with a coefficient friction of whatever, if you don't know the meaning of sliding you even if you tell yourself that you can do it, you just can't..*

352. R: *Did you in particular come across a word in the test that you didn't understand which caused serious difficulty for you to interpret the question, can you give me an example?*

Stage 2

5.2 Student's interpretation of the problem

Phase 1 (without referring to test script)

353. S5: *Okay, there was this question, I think it was number 2 of section b, there is a guy with a motorbike and rides up an incline and they ask me what will his speed be if the motorbike stalls at the beginning of the incline. It was for the first time that I heard the word. I couldn't interpret the question because I didn't understand the word stall.*

354. R: *But Mr. Bantom explained what the word meant.*

355. S5: *Yes, he did ,but I had already gone past it, so …I ..did …so , I skipped it and went to another question.*

356. R: *So, are you saying that your difficulty was not the physics per say but the word that you didn't understand in this particular question?*

357. S5: *Except the way you interpret it ,..okay they write words and they write physics, but you find that the way you are interpreting the problem in a different fashion that the one that is given. That was one example where I experienced difficulty.*

358. R: *Let's be specific , let's talk about your difficulties with the question of the guy on the motorcycle…what do you say, let's be specific…how did you interpret this problem? What did you think was required of you to do in this problem?*

359. S5: *Firstly, they wanted to know ,..because they've given me the initial speed the next thing they wanted to know is after he has covered a distance of 100m what will his speed be then. Another issue is, ther e is a river on the other side of this 100m. And they ask me whether he'll be able to jump over or fall into the*

river. So I was supposed to work out the distance he will cover between the edge of the ramp and the 20m wide river.
360. R: *So, how did you go about it….?*
361. S5: *The way I read the statement, … like the application of motion on a plane, it involves Newton's laws but not that much. But mostly what I was thinking about was the … motion on the plane. If you go through the question … I think the only question that was for the Newton's law was the last question .*

5.3 Student's problem representation during the interview

5.3.1 Student's problem representation with regard to Question (c): What does the student focus on in confirming the speed of the cyclist at the edge of the ramp?

362. R: *Do you mind doing a bit of role playing here, you are now the tutor and I'm the student.*
363. S5: *Okay, about this problem … I was not confident in solving this one because they have given me the initial speed and the final velocity I have to find, they have given me an angle of 37 ° and I was also given acceleration.*
364. R: *No, you were not given the acceleration, you were supposed to work it out.*
365. S5: *Was I supposed to work it out..? I'm not confident with the way I solved it.*
366. R: *Just talk about what you did, that is all.*
367. S5: *(silence) No, I can't do it, I can't recall how I solved it, and no I can't.*

Phase 2

368. R: *Okay let's look at your script to remind us …. there… so you said for the first question he won't be able to go up the ramp because he is moving upwards. Can you explain what you were thinking o then.*
369. S5: *Tries to read the lecturer's comments on the script.*
370. R: *Do not read what the lecturer wrote, remember I'm interested in finding out how you solved the problem. I am not interested in the right way of solving the problem. You said you were not confident about his problem and yet you got 7 out of eleven for it?*
371. S5: *Well, like here, the mass is given, okay I think I can recall now, another given variable is the kinetic friction, I use the word kinetic instead of coefficient because I know that there is motion and using Newton's Second Law, i.e. the force is equal to* μ_k *multiplied by the normal force.*
372. R: *What force are you referring to?*
373. S5: *The frictional force,… so I can work out the normal force of the gentleman and try to find … because he is not a horizontal plane , he is at an angle meaning that my N will be mg cos* Ω*, the* θ *could have been beta or alpha and I'll be substituting it with the given angle. The reason why its a y mg cos* θ*, the motion is not vertical it is at an angle and this is to compensate for that …my vertical components are …*

5.3.2 Student's problem representation with regard to Question (a): What does the student focus on in drawing the body-diagram?

374. S5: *…can I draw the free-body diagram here…I have the gentleman here, this is my normal force, this is my weight my weight is always vertical this is the surface and the normal force is always perpendicular to the surface. Here the normal force is not perpendicular to the surface so I work out mg cos* θ*, my mg is against the normal force. Since I know that my normal force mg cos* Ω *must be equal to 0 because there is no vertical acceleration so my N equals mg cos* θ*. Since frictional force = the coefficient of friction multiplied by mg cos* θ*, then I'll substitute the answer back into Newton's Second Law formula.*
375. R: *The formula you've used states:* $\sum F = ma$ *(the summation of the forces equals ma)…what does*

this imply?

376. S5: *Yes, this is the acceleration due to the kinetic friction, but I don't think that I worked it out like that in my script. From here I'll substitute this one here and I know the mass is given and I can work out the acceleration by the guy through this distance and from there I can use:* $v_f^2 = v_0^2 - 2as$ *since I've worked out my acc. I have the distance and the initial velocity I can then work out the final velocity.*

377. R: *Just explain how you worked out the forces acting on the motorcyclist.*

378. S5: *Ya on the horizontal component...*

379. R: *On the y-component ... you say you used the forces acting in the y-direction to work out the acceleration, but earlier on you pointed out earlier that acceleration in the y-direction is zero... make me understand your reasoning here, I'm getting slightly confused.*

380. S5: *What I meant here was the way in which I worked out N. This is the free-body diagram for N only and not for the whole system. And I took the whole N= mg cos* θ *(worked out from N - mg cos* θ *=0) So instead of substituting the normal force (N) into (*$F_k = u_kN$*) I substituted it into*

$$F_k = \mu_k mg\cos\theta = ma.$$

381. R: *Does what you have worked out make sense to you?*

382. S5: *(pause) Yes, I think so, you know I'm not confident about it. I don't know whether I've used the right method or what...like in terms of using Newton' s law and substituting this one ... pause. When I was solving the problem I was not confident, that is why I say for N I substituted like that, this is not a complete diagram because it is a diagram for the y - direction only, but since the guy has got the component in the x -direction, so the mg sin* θ *will have to be included ... pause ...I don't know ... I do not know...*

Note: As a result of this insight, the student comes to re-interpret Question (c): Confirming the cyclist's speed at the end of the ramp. The section below should therefore be read in the light of 5.2.1 above.

5.2.2.1 Re-interpretation of Question (c): What does the student focus on in confirming the speed of the cyclist at the edge of the ramp?

Note: When interviewees were unable to continue with a problem I urged them to refer to their test scripts (move from Phase 1 to Phase 2). If, after having consulted with their scripts, the students still felt unable to proceed with the problem, the interview was terminated, as will be seen in the course of this description.

383. R: *Do you think that you can take yourself a step further than you did in the test. As you were suggesting now that maybe you should look at the forces that are acting in the x- direction as well how would you take this idea* ***forward?***

384. S5: *(pause) ...mhhh ...let me check this out ...(looking at his work on the board). I'm not confident about this hey, the force that act in the x-direction is mg sin* θ *it is accelerating meaning that it is not constant... it's velocity is changing all the time. The application of Newton II will give me the solution. This is mg sin* θ*, no there isn't just one force ... (talking to himself) can I say this is f1 for simplification (carries on writing on the board).*

385. R: *Just explain what you are doing there on the board.*

386. S5: *Okay the sum of forces in the x- direction it's the frictional force which is always in t he opposite direction of motion which is minus.. and mg sin* θ *= ma ... from here I don't know how to go about solving the problem because I'm not confident. I don't know what to do...You see, these are the kinds o f problems I was experiencing in the test. Like what I couldn't understand now was the way forward in solving this problem.*

The failure by the student to take himself further brings the interview to an end.

SECOND MODULE PROBLEM

TEST 3: EQUILIBRIUM OF A RIGID BODY

"A uniform ladder whose length is 10 m and whose mass is 50 kg rests against a frictionless wall. A man whose mass is 70 kg climbs 7.5m up the ladder.

a) **Draw the free diagram of the ladder and label the forces;**

b) **Calculate the reaction forces R_1 and R_2;**

c) **Check your result above, by taking the moment about another point;**

d) **If the maximum value of frictional force that would prevent the ladder from slipping is 700N, how much further can he climb before the ladder starts to slip?"**

Student 6

Stage 1

6.1 Beginning of interview reflections

1. R: *I will choose one problem from section B and then you take me through it. In general how did you find the test?*
2. S6: *Well I wasn't sure, x2 but apparently I did well.*
3. R: *You were not sure about what?*
4. S6: *Some of the things .....some of the questions*
5. R: *I remember the last time I interviewed you complained about section B saying that these are problems that you found difficult. So how did you find the problems in this particular test?*
6. S6: *This time around the problems were manageable, they were better, they were not that tricky. Do you remember that question three from the previous test, the one about the guy going up an incline...that was very tricky.*
7. R: *When you say you do not know how to approach a problem, what do you mean? This I picked up when I transcribed the interview I had with you I sort of remember I should have asked you what you meant when you say you do not know how to approach the problems.*
8. S6: *If a problem has to be done like this or like that , but you do not know where to start, how to proceed.*
9. R: *Are you referring to the problem that I interviewed you about last time or this one?*
10. S6: *One doesn't know how to go about through those steps . You find that you know those steps that you know what you need to do, calculate this or calculate that but you just do not know how to go about doing that!*
11. R: *What I want to find out from you, is what do you mean when you say you mean you know the problem but not how to go about it?*
12. S6: *Sometimes you find out that certain things are not given in a straight forward manner. and then you have to find one variable and substitute it into the equation and then solve for whatever is unknown and sometimes you do not see that You read the question and you expect all the variables to be there in the problem and then you find that you have too many variables that are unknown and then you get stuck.*
13. R: *So what you saying is that if one has the formulae and all the known variables then it will be easier for one to work out the problem?*
14. S6: *No, it's not about having all the known variables (Laughs) it is all about understanding*
15. R: *What does it mean to understand a problem?*
16. S6: *pause; I don't know how to put it!*

Stage 2

6.2 Student's interpretation of the problem

Phase 1 (Interview without referring to test script)

17. R: *Try and give me a concrete example, let's try and be specific. Let's look at the first problem for example...so you are telling me that when you answered this question in the test you understood it? Take me through what it meant to you to understand the problem and being able to work through it.*
18. S6: *...I think I understood the problem...*
19. R: *When you look at the problem and tell yourself that you understand it...what does that mean? Take me through what it meant for you to understand the problem and how you worked through it.*
20. S6: *When you read the question you imagine what you are going to do, how the graph would look like, that is, if you are given a problem that has something to do with a graph. You picture the graph and then think how you are going to do the calculations.*
21. R: *So, when you looked at this problem what did you picture?*
22. S6: *Something like a wall, vertical, and then a ladder, a ladder which is at an angle of 53 °, with a painter on the ladder ...(she's now working through the problem).*

6.3 Student's problem representation during the interview

6.3.1 The student's problem representation with regard to Question (a): What does the student focus on in drawing the body-diagram indicating all the forces that act on the ladder?

23. S6: *(Referring to the problem at hand). This is the frictional force, this is the ladder forming a triangle with the wall at an angle of 53 °, this is the ladder which is 500 Newtons …(.she carries on drawing the diagram)… there's' the painter at 7.5 m, the ladder is ten m long, and he weighs 700 Newtons. Well, this is the first part of the question, (S1 reads the question …and draws a free-body diagram to indicate all the forces acting on the ladder). There's the force that the wall exerts on the ladder, the normal force which is in the same direction as the ladder, I think, its can't be in the same direction as the ladder, the normal force has to act perpendicular to the wall, yes, I think this is the normal force, which is the force of the wall on the ladder…and the force that the ground exerts on the ladder.*
24. R: *Are these the only forces that are acting on the ladder?*
25. S6: *I think so.*
26. R: *And what about these lines of action that you have drawn here, going down?*
27. S6: *Oh! yes there is another force, the gravitational force acting downwards.*
28. R: *So, how many forces act on the ladder?*
29. S6: *Three!!*
30. R: *Why is it important that you to indicate the weights of the ladder and the man in your sketch?*
31. S6: *I'm going to use it in my calculation (She carries on working on the problem).*
32. S6: *No, I can't remember how I did it…*
33. R: *Do you want us to look at your script so that you can explain what you were doing then? But before we do that, just explain what you mean when you say you cannot remember, what is it that you cannot remember?*
34. S6: *I remember you have to calculate the force at the top, you take one point as the origin and you calculate the force at the top and at the bottom and then work out the torque. Then you are going to have two unknowns forming a simultaneous equation and then you use the torque to find the unknown force.*
35. R: *If you are giving me the procedure as you have done now, what did you mea when you said you couldn't remember?*
36. S6: *She laughs, I thought I had forgotten it. I can't remember exactly how I did it in the test but I know one has to choose a point as your origin and then calculate some forces and then one of the forces is going to be the unknown force and then you solve for the unknown force using the torque due to some point I cannot remember the exact details.*

6.3.2 The student's problem representation during the interview with regard to Question (b): What does the student focus on in calculating the reaction forces R_1 and R_2?

6.3.2.1 Student's interpretation of question (b)

Phase 2 (Referring to the test script)

37. R: *You told me in the beginning of the test in order to solve these problems one would have to understand them, so what understanding was there for you…in finding the forces? What is the point in doing all this? You say you know you have to do this and do that, you seem to know the procedure, but what is the ultimate goal in doing this problem? What is it that you are trying to work out?*
38. S6: *We were trying to find the force at the top and the force and at the bottom of the ladder. Once you've worked*
out the magnitude of the force that the wall exerts on the ladder you'll then be able to work out what the force at the bottom should be.
39. R: *Why do you have to work out these forces?*
40. S6: *`Cos I guess they are different, yes I think so, they should be…*

41. R: *Different in what way? what are the implications of this difference in magnitude. How does it affect this whole system that we are looking at?*

42. S6: *Because they are acting at different angles, different positions..*

43. R: *If the forces are different in magnitude what will happen to the ladder?*

44. S6: *It will remain standing, it won't fall. Assuming the forces are the same , the ladder would slide down , if they are different the ladder will keep still.*

The student's approach to this question touched on the following three aspects:

a) Applying the first condition of static equilibrium

This involved:

(i) Calculating the sum of the forces in the x-direction

45. R: *Explain what you were trying to do here. Please don't pay attention to the comments by the lecturer.*

46. S6: *Here I was calculating all the forces in the x -direction. I named the force at the top R_1 and the force at the bottom R_{2x}. R_1 is negative because it is pointing in the negative x- direction, I added R_1 to R_{2x} because the ladder is stable, there I made a sum to equal 0, and then I solved for R_1 which is equal to R_{2x}.*

$$\sum F_x = -R_1 + R_{2x} = 0$$

$$therefore\ R_1 = R_{2x}$$

47. R; *What does the above notation mean?*

48. S6: *I'm trying to calculate all the forces that are acting in the x-direction and after that I'm going to calculate all the forces acting in the y- direction and then add them to find the magnitude of the force (R_2).*

49. R: *Is this the force that you say cannot be equal to R_1?*

50. S6: *Yes!*

51. R: *Why do you say that some of the forces in the x -direction must be equal to 0?*

52. S6: *Because the ladder is stable its not moving .i.e. it is in equilibrium. All the forces that are acting on the ladder are balanced.*

(ii) Calculating the sum of the forces in the y-direction

53. S6: *In calculating the sum of the forces in the y- direction I said R_2 in the y-direction and I subtracted 700 Newtons which is the gravitational force acting downward minus 500 Newtons which is the weight of the ladder since the ladder is in equilibrium we say the summation is equal to 0.*

$$\sum F_y = R_{2y} - Mg - mg = 0$$

$$therefore\ R_{2y} = g(M + m) = 10(70 + 50) = 1200N$$

54. R: *So, when you finally got the magnitude of R_2y what did the result tell you?*

55. S6: *...that the y-component of R_2 is equal to 1200 Newtons.*

56. R: *Why is it important that you work out the forces in the y and x- directions?*

57. S6: *So that I can eventually calculate the magnitude of either R_1 or R_2 because they both have y and x-components.*

b) Applying the second condition of static equilibrium

This involved:

(i) Calculating the moment about point O to determine R_1

58. S6: *(Starts from R_2) From there I took R_2 as my fixed point, I made it the origin, I made it the fixed point. I am making R_2 to be the origin because I am calculating the torque.*
59. R: *What does it mean to say that you have to calculate the torque at this point?*
60. S6: *Oh God I don't know…(laughter)…I don't know!*
61. R: *But how do you know you have to calculate it if you don't know what it is?*
62. S6: *I just know it… because I was taught like that!*
63. R: *So, if you were not taught the procedure of how to calculate torque you wouldn't have known how to work it out?*
64. S6: *Yes, I wouldn't have known.*
65. R: *You never questioned it?*
66. S6: *I took it as it was. ..*
67. R: *Is it easier for you to take something as is and apply it?*
68. S6: *No, sometimes, not always.*
69. R: *Why did you do it in this particular case?*
70. S6: *I never really understood the concept of torque, so I had to take it as it was presented but for other things like the forces that I understand.*
71. R: *How do you know that you understand the other stuff?*
72. S6: *Because it makes sense to me. If the ladder is standing in that direction obviously it has a y - and an x - component and the forces acting on the ladder will differ and if it is stationery that means that all the forces acting on the ladder are in equilibrium.*
73. R: *If you say you never understood the concept of torque how were you able to remember all of this stuff during the test? If you say you never made sense of it how was it possible for you to remember it? Is it possible for someone not to understand something but be able remember it, just make me understand that bit?*
74. S6: *Sometimes we just have to know it by heart.*
75. R: *If they had changed the problem would you still have known what to do?*
76. S6: *Yes*
77. R: *But how?*
78. S6: *I know what to do, I know the steps (the procedure). It is just that I do not understand everything behind the concepts used.*

The student's mathematical representation of the calculation of $R_{1:}$

$$\sum \Gamma_{R_2} = R_1 10\sin 53^{\circ} - 500(10\sin 53^{\circ}) - 700(7.5\sin 53^{\circ}) = 0$$
$$= R_1.8 - 500.8 - 700.6 = 0$$
$$\therefore R_1 = 1023$$

c) Calculating R_2

79. S6: *R_1 is equal to R_{2X}. This comes from the sum of the forces in the x- direction. Because we calculated R_1 to be 1023 Newtons, therefore you say that R_2 in the x - component will be equal to R_1. And R_2 in the y - direction was calculated to be 1200 Newtons from working out the sum of the forces in the y- direction.*

since $R_1 = R_2x$ therefore R_2 equals:

$$R_2 = \sqrt{1200^2 + 1023^2}$$
$$= 1577N$$

6.3.3 Student's problem representation during the test with regard to question (c): Check your answer above by taking the moment about another point to prove that R_1 is equal to R_{2x}

6.3.3.1 Student's interpretation of question (c)

80. S6: *... remember the first time I took R_2 to be my point of origin, and then when they say: "take the moment of inertia about another point", you have to fix a different point. And then you calculate the torque.*
81. R: *If I can take you back to what you said at the beginning of the interview...that one has to conjure up a picture of what one is talking about...did you picture what was happening...?*
82. S6: *I was not thinking about in that was...I was thinking about this point here...and as you know that torque is the force going in or out a certain point. You do all the points by drawing the forces acting at certain distances*

The student's mathematical representation of the calculation of R_{2X}

$$\sum \Gamma_{R_1} = R_2(10\cos 53^\circ) - R_{2x}(10\sin 53^\circ) - mg(10\sin 53^\circ) - Mg(7.5\sin 53^\circ) = 0$$
$$8R_{2x} = 6(1577) - 5000(8) - 700(6)$$
$$R_{2x} = 158N$$

Phase 3 (indicates a process of change in which an approach / concept is given a meaning different to that given during the test)

83. S6: *The 6 is from... I think it is from the... (takes out calculator) I think it comes from working out the adjacent side (10 cos53^0). Okay, I told you that when we take the moment about a point, you fix that particular point, and the point about R_1 was the easiest. Because R_1 and this point, where the man is standing, have a distance.*
84. R: *So, you took R_1 as your point of origin, and here you have $6R_2$. 6, you say is the adjacent side, and R_2, is R_2 perpendicular to the adjacent side, is that what you are saying?*
85. S6: *No. It can't be perpendicular to 6.*
86. R: *So, which force would be perpendicular to 6, the adjacent side?*
87. S6: *I don't think that there's any force that is perpendicular to the adjacent side.*
88. R: *What about this R_{2Y}? Isn't it perpendicular to the adjacent side?*
89. S6: *Ya, could be. (Hesitates)*
90. R: *Could be?*
91. S6: *Ya... Well I think it might be at a certain angle, but not perpendicular. I don't think that it could be perpendicular.*
92. R: *Which force are you referring to? Is it R_2 or R_{2Y}?*
93. S6: *R_2. It doesn't make sense to say R_2 is perpendicular to the 6 m.*

94. R: *What do you mean when we say one thing is perpendicular to another?*
95. S6: *Usually a perpendicular force is the normal force. And there's no normal force in this case.*
96. R: *What do you regard as a normal force?*
97. S6: *It's a force acting perpendicular to the surface.*
98. R: *So, you're saying that there's no force acting perpendicular to the 6 m distance?*
99. S6: *It's going at an angle.*
100. R: *But here on your script you have $6R_2$ ...*

101. S6: *Well that was then…*
102. R: *Would you change it now? Would you look at it differently? Is that what you're saying?*
103. S6: *I think that it should be at an angle. Though I don't know what the magnitude of the angle is. That will be the problem So, I will just write it as R_2, because I won't know the magnitude of the angle, whether it is the y- component or the x-component…*
104. R: *When you were solving this problem, were you considering the fact that the force has to be perpendicular to the distance or not?*
105. S6: *I was just calculating. I didn't think about whether it was perpendicular or not.*
106. R: *My research tries to explore the different ways in which students look at the problem. That is why I am probing like this… I just want to find out what links you made, so that next year when the lecturer teaches this section, he pays particular attention to the fact that some students perceive the problem the way you do.*
107. S6: *I was just using what was given in the formula, what had to be done… Seriously, I didn't understand this work, I just felt OK, the one thing that I know is that you have to shift your fixed point and then calculate the torques according to that point. Obviously it had to be done the same way as in question (b),except that the distance had to change to 2.5 m for the 700 Newton force, because we're looking at it now from R_1. And the distance from R_1 to 500 Newton will still be 10 m.*

6.3.3 The student's problem representation during the test with regards to question (d): If the maximum value of frictional force that would prevent the ladder from slipping is 700N, how much further can he climb before the ladder starts to slip?

6.3.3.1 Student's interpretation of question (d)

108. R: *How did you interpret question (d)?*
109. S: *I think I had to find a force, and then from that force calculate a distance… A force that will overcome the frictional force… I think the same frictional force at the bottom will be the one at the top, on the wall.*
110. R: *Explain?*
111. S6: *Because… I think a frictional force will be here at the top of the ladder and down here at the bottom, but we know that frictional force is always in the negative x - direction, so I think we'll consider the force at the bottom only.*
112. R: *You said you would look for a force that was equal to the frictional force? Is that what you said?*
113. S6: *No. It would be a force that would overcome friction. And this force will be in an x- direction because the frictional force is in an x-direction. that is why I subtracted this 700 Newton which is the given.*

The student's mathematical representation of the solution to question (d)

$$\sum F_x = -R_{1N} + R_{2x} - F_s = 0$$
$$-R_{1N} = 700N - 1023N$$
$$R_{1N} = 323N \ \text{since} \ R_{1O} = 1023N$$
$$therefore \ \frac{R_{1N}}{R_{1O}} = \frac{323N}{1023N} = 0.3$$

114. R: *So, you say in the x- direction you'll have negative R_1… Just explain why you have used the negative sign?*
115. S6: *Because R_1 is towards the negative direction.*
116. R: ***And then you have positive R_{2X}? Why positive?***
117. S6: *Because I'm taking the x - component of R_2… My other forces are the 500 Newtons and the 700 Newtons, and they are in the y-direction. And the only force that's in the x- direction is R_1, R_{2X} and the frictional force. And then I said R_1 is equal to 323.I divided 323 by 1023, which is the R1 that I found initially (in part B) I don't know why I did this. And then I got 0.3 m.*

118. R: How did you interpret this result?
119. S6: I said 0.3 will be the distance that the man can climb before the ladder starts to slide.
120. R: The problem states that the man has already covered 7.5 m….?
121. S6: Which means… if he travels more than 7.8m the ladder will start sliding.
122. R: Make me understand that?
123. S6: If the man climbs any point beyond 7.8 m, the ladder will start sliding.
124. R: This is not what you wrote down here.
125. S6: I was running out of time. But this is what I meant with this 0.3 m result.

Student 7

Stage 1

7.1 Beginning of the interview reflections

The interview began with the exploration of the problem, as seen below.

Stage 2

7.2 Student's interpretation of the problem

Phase 1 (Interview without referring to test script)

NB. The student did not do questions (a), (b) and (c).

126. R: *What we will be discussing this afternoon is one of the problems that you did for your test. The problem that we will be doing today is problem No 1 from section B.*
127. S7 *I want to do 1d)…*
128. R: *You do not want to do a), b) and c)?*
129. S7: *I figured that if I can do d).it would be common sense that I would be able to do a), b) and c).*
130. R: *When you wrote the test did you start with d)?*
131. S7: *No, I never did d)… the same day I got home, I looked at the test saw that I could have done it if I …….*
132. R: *Why didn't you attempt it in the test?*
133. S7: *I don't know… He did one example I guess in class, I never wrote it down because I thought I'll just memorize it and then… my memory never served me well in the test. I couldn't remember but when I got home I saw that I could do it.*
134. R: *Why don't we then start with d) and then you can take me back to a), b) and c). Do you want us to read the problem together?*
135. S7: *No I am fine…*
136. R: *Do you prefer to talk while you are doing the problem or do you want to do it first and do the explaining later?*
137. S7: *I first want to do the pictorial representation!*
138. R: *Fine then I will leave everything to you, when you do feel like talking to m e then you can go ahead.*

7.3 The student's problem representation during the interview

7.3.1 Student's problem representation during the interview with regard to question (d): If the maximum value of frictional force that would prevent the ladder from slipping is 700N, how much further can he climb before the ladder starts to slip?

7.3.1.1 Student's interpretation of question (d)

139. S7: *(Draws a pictorial representation of the problem…) I want to talk now…they say it is a uniform ladder…that means its center of mass is in the middle,…when the balance is in the center. Its point of balance is in the center.*

140. R: *And for a non- uniform ladder, where would its point of balance be?*

141. S7: *They will say…like they will give it to you in the question.(after having worked on the problem for about 3 minutes) … here they tell you that ….they give you the maximum value of the frictional force which is 700 Newtons... erm..*

142. R: *So, what does that tell me?…if you say that you are given a maximum frictional force of 700 Newtons, what does that mean, why is that piece of information important?*

143. S7: *(He coughs) can I just carry on?….the system is in equilibrium, so I'm going to apply the two conditions of equilibrium*

144. R: *You will have to pretend that you are talking to someone who does not know any physics, like if you were explaining this to your little brother, how would you talk to him about this? So you need to explain, like when you say the system is in equilibrium, what does it mean to say that?*

145. S7: *OK, I will say that….can I just finish the problem please…..(laughter)…(after 2 minutes)…OK, I used the first condition of equilibrium to calculate R_1 …the reaction force, the force that the wall exerts on the ladder, and that's what I found, now, I'm going to use the second condition of equilibrium and I'm going to choose a point of origin. The point I choose is here at the bottom, …(laughter) (he works on the problem for 3 min's). After choosing a point of origin, I'm going to take the forces about this point i.e. torque and how is that going to help me? It will help me find, the distance that the man has to climb. When the ladder starts to slide the man will be some distance up the ladder, OK…I'm going to use his weight in calculating the sum of the torques.*

The student's mathematical representation of the solution to question (d)

$$\sum F_x = R_{2x} - R_1 = 0$$

$$R_1 = R_{2x} \ \sin ce \ R_{2x} = 700N \Rightarrow R_1 = 700N$$

$$\sum \Gamma_0 = -Mg(l\cos 53^\circ) - mg(5\cos 53^\circ) + R_1(10\cos 53^\circ) = 0$$

$$= -700(l\cos 53^\circ) - 500(3) + 700(8) = 0$$

$$= -420l - 1500 + 5600 = 0$$

146. S7: *…I've calculated R_1, when F_s is 700 Newtons he is somewhere up the ladder…I don't know where exactly but I know that his weight…I'm dealing with torques here so I need to have a perpendicular distance of the man but seeing that I do not know where he is, I'll have to give it an unknown value…right? Okay I named it L, it is L cos of 53 ○ because its on an incline. And the very same thing that I did with the man's weight I do it with the ladders weight, I know its perpendicular distance which is 5 cos of 53 ○ and ….you have to draw a line form the point of origin, perpendicular to the line of action of the force. So, force times that perpendicular distance gives us the torque.*

147. R: *…and what about this third part? Explain.*

148. S7: *It is because I chose the origin to be here at R_2, R_2 can't be a torque, R_2 as a whole can't be a torque, so its line of action runs through the origin, there can't be any perpendicular distance, I'm not saying that I'm not going to use it. I used it to calculate R_1, so it will be …erm... then used the first condition of equilibrium, so I have R_1 now this is going to cause a rotation about that point, so it will be part of the sum of the torques.*

149. R: *Just explain how would R_1 bring about the rotation of the ladder?*

150. S7: *It will be anti-clockwise rotation due to the 10 sin53^0 whose perpendicular line of action is R_1…R_1 is the line of action and this is its perpendicular distance.*

151. R: *Could you explain why is it 10sin53 ○ and not 10cos53 ○. If you were to explain this to a non-physics student how would you go about making them, understand what you've just done?*

152. S7: *It is 10sin53 ○ because it is not adjacent to the angle..*

153. R: *Is it that obvious, pretend you are a tutor and you had to explain this to a student, how would you go about it?.*

154. S7: *I used to tell people why we say 10 sin whatever angle, I used to know…the best that I can say is that this line is not adjacent to the angle…it's trigonometry!!!*

155. S7: *I'll tell you what the answer is as I remember it. I can't seem to calculate this but by ordinary algebra you will get to the answer L is equal to 10.*

156. R: *So, if you do work out L to equal 10 m, what does this result tell us?*

157. S7: *That…pause…10 m up the ladder …10 m is the distance that he can climb before the ladder starts to slip but he is already 7.5 m up the ladder. So, he only has 2.5 m to go.*

158. S7: *That's the right answer, right?*

159. R: Does it matter?

160. S7: (He doesn't respond)…shrugs his shoulders.

161. R: You said earlier on you were trying to remember, make me understand what you mean by "I was trying to remember". Is this what you always do or were you just applying this to this particular problem.

162. S7: At that time I was trying to remember.

163. R: When you write tests in general do you try to remember or do you try to make sense of the problem as you are solving it.

164. S7: Ja.

165. R: So, what was different about this question? Why did you have to try so hard to remember?

166. S7: When I came to d)I remembered the lecturer saying in class that you should remember , you should make sure that you understand this problem. I think he said this a few days before we wrote the test. I remember the one about, what's the maximum distance he can climb up the ladder before he slides? I was thinking back to that.

167. R: Did you panic since he told you to go and prepare this particu lar problem and there it was in the test?

168. S7: Sort of… I didn't do this particular problem.

169. R: So you didn't give yourself a chance in the test to think about it?

170. S7: aha …aha (No)

171. R: …but you said that you found a), b) and c) very easy .

172. S7: Yes…

173. R: Why, did they seem easier than d)?

174. S7: …because I know how to do it.

175. R: How do you know that you know how to do it?

176. S7: …pause…its…you just follow the convention, the two conditions for equilibrium, and then you first use the one to find unknown forces like using the reaction forces.

177. R: Do you mind taking me through a), b) and c) quickly?

178. S7: Okay!

179. R: We have to swop roles you have to talk to me as if you were tutoring me about this particular problem. you will start of with the two conditions of the equilibrium, you said they were important. why are they important? What do they tell me? How do the y help me in terms of taking the problem further

180. S7: Mhhh… when we dealt with…we dealt solely with …before we dealt with torques we did Newtons laws. Ask the question again please.

181. R: You seem to be very confident about these two conditions of equilibrium that need to be applied in this problem. you will have to make me understand what these two conditions of equilibrium communicate to the student. why are they significant in solving this problem and how are they going to be used?

182. S7: Ok, why do I think these two conditions are important? but I'll be saying the same thing as I did before. I'll have to apply Newton again meaning that the sum of the forces in the x-direction and like I said before… (after +/- 10 minutes the student fee ls uncomfortable and the student suggests that we stop the interview.)

Student 8

Stage 1

8.1 Beginning of the interview reflections

183. R: *Why did you choose to do physics?*
184. S8: *I wanted to do physics because I was doing Science at school. So I thought since I was doing it at school I might as well do it here.*
185. R: *How are you finding it so far?*
186. S8: *It's okay, it's interesting. It's coming along.*
187. R: *You told me that you didn't work that hard last term. But you managed to get the highest mark.*
188. S8: ***No I didn't, especially in the last test that we wrote. I studied the day before I wrote. I think I slept at about 3 in the morning.***
189. R: *So, at what time did you start studying?*
190. S8: *Around half past 8.*
191. R: *What did you do as you were studying?*
192. S8: *I went over the stuff we did in class. I did the problems, specifically the ones we did in class.*
193. R: *When you say you went through the problems, what exactly did you do? Give me an example.*
194. S8: *Firstly I looked at what the problem asked for, and then I looked at how we did it in class. Then I closed my book and did the problem myself. This meant if I was able to do it, then I know it.*
195. R: *If you can do a problem, then you know it.*
196. S8: *I think so.*
197. R: *Your study material... Did you use only the class notes or did you consult the text book?*
198. S8: *I used the text book here and there.*
199. R: *What did you use it for?*
200. S8: *To look up the equations. I never used the study manual, I only used the class notes and the text book. (University Physics). I don't use the prescribed text; I bought this one at the bookshop, it's an updated version.*
201. R: *To take you back to what you said earlier on... Why do you study the day before you write?*
202. S8: *I think it's because I had a lot of tests that week, and also I think I understand physics. So I didn't concentrate much on physics, I only concentrated on the work I didn't know. I could follow what was going on.*
203. R: *How do you know that you understand physics?*
204. S8: *Basically I know I understand it... We are given assignments and I can do them, and some of my friends come to me and ask for help. When I help them I can see that I have some understanding of the work.*
205. R: *Has it ever occurred that your friends come to you and you're not able to help them?*
206. S8: *It has happened once. Then that meant that I didn't understand the work well. (Pause) The problem was about a cup on a cloth, and then somebody has to pull the cloth, and we were supposed to calculate the distance the cup will move when it's pulled. What happens is that the cloth is pulled from underneath the cup without the cup falling.*
207. R: *So what difficulties did you encounter with this problem?*
208. S8: *I just couldn't calculate it.*
209. R: *So what did you do? Did you consult with the tutors?*
210. S8: *No I didn't. I didn't have the time. So I didn't do this problem but I attempted the others.*
211. R: *Getting back to your preparation for the test... Were you studying alone?*
212. S8: *No I studied with friends. We picked a problem and everybody did it, and we compared answers. If somebody got the answer wrong, we would show them how to do it. We stopped at 12, and when my friends left I carried on my own, and I concentrated more on the conceptual part of the problems.*
213. R: *What do you mean by the conceptual parts?*
214. S8: *Remember that there is also the multiple choice section, so one needs to understand the terms conceptually and not just concentrate on the calculations. This is one way of helping me answer the multiple choice questions.*
215. R: *When you started with the test, how did you feel about it?*
216. S8: *I felt like I hadn't studied, and it turned out that I passed the test. It's amazing. Maybe I went into the test thinking I was going to fail it. I was not relaxed. I kept on thinking that I only studied the day before and not more, because this is what I normally do, I study 3 days before and the night before I write I don't touch my books because I don't want to confuse myself.*

Stage 2

8.2 Student's interpretation of the problem

Phase 1 (Interview without referring to test script)

217. R: *Let us explore the idea that understanding means going through the conceptual part, by looking at section B, problem 1. The one about the ladder leaning against the wall.*

218. S8: *Yes, I remember that problem, and when I studied I did some of the problems relating to the ladder. Basically I did the whole problem. I had to understand that when they say that the ladder is in equilibrium it means that it's not moving. One has to understand things like that. if the ladder was not in equilibrium, then there would be a force added on top of the forces we work out. Friction would be added, because the ladder would be moving in a certain direction, and friction would be in the opposite direction. This brings in another force, which is going to create problems when we do the calculations. The thing is it's not stated anywhere in the question that the ladder is in equilibrium.*

219. R: *What clues are provided in the question to tell us that the ladder is in equilibrium?*

220. S8: *It is the first part which says a uniform ladder.*

221. R: *So, to you the word uniform means that the ladder is not moving?*

222. S8: *Yes, and if you didn't know this, you would be tempted to bring in an extra force. Friction in this problem is not included. Friction only comes in when something is moving.*

Stage 2

8.3 The student's problem representation during the interview

8.3.1 Student's problem representation with regard to Question (a): Draw the free-body diagram of the ladder and show all the forces that act on the system

223. S8: *(Reads the problem) It says "a uniform ladder of 500 Newtons and length 10 m leans against a frictionless wall". This is the ladder (draws), and this will be the wall. It leans against a frictionless wall, I can't remember how I explained that part to myself.*

224. R: *Do you want to look at your script so that you can see what you did?*

225. S8: *No. I think I can still remember. The weight of the ladder will be in the center because that is the balancing point of the ladder. Its length is 10 m. The foot of the ladder makes an angle of 53 ° with the ground. A painter weighing 700 Newton stands on a step 7.5 m up the ladder, and this is somewhere over here... And from here we are asked to draw the free diagram of the ladder and label the forces, and this is what I've been doing, but I haven't labeled all of them. You know that the ladder exerts a force on the ground, the ground will exert an equal but opposite force to balance it, and this (the force that the wall exerts on the ladder) we call the normal force. In this case we won't call it the normal force... it is sort of a normal force. We'll give it another name. The force that the wall exerts on the ladder will be called* R_1*.You can call it whatever you want. The force that the ground exerts on the ladder we call* R_2*. The force is at an angle, so it will have 2 components, which is the y - and the x- component. The normal force is going to be* R_{2Y}*, and this one in the horizontal direction will be* R_{2X}*. We now have 3 forces. These are forces in the y and x -axis.*

226. R: *When you are asked to draw a free body diagram, what exactly are you trying to do?*

227. S8: *We are trying to...It's a way of (pause)... specifying the forces. You see this one, the 500 Newton, it is the weight of the ladder. The 700 Newton force is the weight of the painter on the ladder.* R_1 *is the force that the wall exerts on the ladder, and* R_2 *is the force that the ground exerts on the ladder.*

228. R: *How does the drawing of the free body diagram help you? What's the aim of the free body diagram?*

229. S8: *It doesn't help me in solving the problem. I did it because I was asked to do it. If I wasn't asked I would have started with the problem straight away. I indicate the forces so that I can know that there is a force here and a force there. It helps in identifying the forces, you can't have weight being horizontal on your*

sketch, weight is always downward, gravity is downward, that is, the force of the earth pulling on the object.

8.3.2 The student's problem representation with regard to Question (b): Calculate the forces that the ground and the wall exert on the ladder

8.3.2.1 Student's interpretation of question (b)

230. S8: *To find the magnitude of the reaction forces you have to consider the sum of the forces along the x- axis and along the y- axis, because not all these forces are on the same axis.*
231. R: *Is it obvious that not all the forces are on the same axis?*
232. S8: *It's a simple thing, and it will be difficult to explain to somebody who doesn't do physics. If you do physics you are supposed to know such things.*
233. R: *But there are physics students to whom this doesn't seem obvious.*
234. S8: *At this level you're supposed to know it. I can't even remember when it was the first time that I realized this is how it's done. I've always known this from school....At school we didn't do problems like this, but we did do problems that included forces in the y-direction and the x - direction. I can't remember whether we were told at school why we had to do it like this, but for me this is obvious. At school we didn't do problems like this, but we did do problems that included forces in the y - direction and the x- direction. I can't remember whether we were told at school why we had to do it like this, but for me this is obvious.*

The student's approach to the question touched on the following three aspects:

a) Applying the first condition of static equilibrium

This involved:

(i) Calculating the sum of the forces in the x-direction

235. S8: *As I was saying, you look for the forces in the X-axis and we sum them up. You choose your direction because not all of them are going on the same direction. Some forces may be directed to the left or the right. There you have to know... I never thought about why we have to choose the direction. (Pause) We are working with vectors.*
236. R *So?*
237. S8: *The definition of a vector is that it is a physical quantity which has both magnitude and direction. And force is a vector, so that means if we consider the magnitude of these forces we have to consider the direction as well. We have R_1 which moves towards the left. I chose my -direction to be positive towards the right, so this means R1 is going in the opposite direction, which means it's negative. R_2 has two components, R_{2Y} and R_{2X}, the one that I am dealing with s R_{2X}, because I'm looking at some of the forces in the x-direction. Because R_2 is at an angle, then I have to consider the angle. R_{2X} is positive. Since there is no other force in the x -direction, I then do the same for the forces in the y- direction.*

$$\sum F_x = -R_1 + R_{2X} = 0$$
$$R_1 = R_{2X}$$

(ii) Calculating the sum of the forces in the y-direction

238. S8: *We have the weight of the ladder which is going downwards, which is opposite the direction I have chosen. We have the weight of the ladder and the weight of the man, which is 500 Newton and 700 Newton, and there's no other force acting in the Y- direction. What we do not know in this expression is* R_2*, but we can work out* R_{2Y}*.* R_{2Y} *will be equal to… We take negative 500 Newton and 700 Newton to the other side…remember this whole thing is equal to zero. To me this is one f the obvious things.*

239. R: *Can you explain why the sum of the forces in either Y or X has to equal to zero?*

240. S8: *This just means that the ladder is not moving, because it's stated that it's uniform, which means that the sum is equal to zero. The sum of* F_Y *is equal to negative* $W - mg + R_{2Y}$ *equal 0.* R_{2Y} *is equal to 500 + 700 Newton, equals 1200 Newton.*

$$\sum F_y = -Mg - mg + R_{2Y} = 0$$
$$R_{2Y} = g(M + m)$$
$$R_{2Y} = 10m.s^2(70kg + 50kg)$$
$$R_{2Y} = 1200N$$

b) Applying the second condition of equilibrium

This involved:

(i) Calculating the moment about point O to determine R_1

241. S8: *What we are required to do is to find* R_2 *and* R_1 *we still haven't found* R_2 *yet, we've only found its component in the y - direction. (Pause) I think now we have to find the moments about this point, working out the torque.*

242. R: *What's your understanding of torque?*

243. S8: *I can't remember what it means, but I have a picture… how can I explain this? I know that there's no way that I can find these unknown forces without taking their moments. If I take the moment about a certain point, I can eliminate some of the unknown forces. If I take the moment about a certain point, that particular point becomes zero, which means I eliminate the forces about that particular point, you see? Lets say I take the moment about* R_2 *at the bottom of the ladder, then I'll be eliminating* R_2 *and will only have to work out* R_1*. It becomes easier because I know the values of the other forces. The torque about* R_2 *will be equal to… We know that torque is equal to r x F.*

244. R: *Explain?*

245. S8: *This is an equation. I got from the text book. It tells me that torque is equal to… Let's say I take the moment about* R_2*, then the torque will be equal to the distance from* R_2 *to the force, that is, the line where the force acts. In this case torque will be the distance from this point to the weight. I first have to work out the distance and to do that… the weight is in the middle of the ladder and the ladder is 10 m long, which means it is 5 – 5. (Pause) The distance has to be perpendicular to the line of force, meaning that it has to fall at 90 °.*

246. R: *What if it falls at an angle other than 90 °, will we still be talking about torque?*

247. S8: *We'll be talking about something else, because as the definition says, it's from the point which is the line of force… the line of force is downwards…. I didn't really consider the question of what if it falls at a different angle.*

248. S8: *If we take the weight of the ladder, we work out the distance first… and the distance from this point to that point is given by… I stated that the length of the ladder is 10 m and the weight is in the middle, which means that either side is 5 –5, this side is 5, I've got the angle and the line of force of the weight forms a triangle, so it will be easier to work out the distance from the point to the weight. By saying that the distance is 5cos53 ° and this is the perpendicular distance to the line of force 500 Newton… Wait, I didn't consider the direction; it is going downwards, which means that it's negative. We now consider the weight of the painter, the distance from the moment from the point of the weight of the painter… It is* *stated in the question that from the bottom of the ladder to the point where the painter stands, the distance is 7.5 m. I can then work out the perpendicular distance by saying 7.5cos53 °, and then multiply this by the 700 Newton. The direction is downwards, meaning that it is negative. R_1 is going to the left, ya… (pause)… I am looking for the Y part, but in order to get it, I have to know the x. So the distance will be given by 10sin53 °, since the sin of an angle is given by the opposite side divided by the hypotenuse. Most of the people understand it as y/r. Sin53 ° is equal to y/10 and we will get - y equal to 10sin53 °, and this will give me the distance from the point to R_1. The torque will then be 10sin53 ° multiplied by R_1. All this will be equal to zero. There is something wrong with my signs, negative and positive… I don't know where exactly…Ya there is something wrong. The distance from here to there… (pause)… yes, this one is positive.*

The student's mathematical representation of the calculation of R_1

$$\sum \Gamma_{\circ} = -mg(5\cos 53^{\circ}) - Mg(7.5\cos 53^{\circ}) + R_1.(10\sin 53^{\circ}) = 0$$
$$= -500(3) - 700(4.5) + R\ .8 = 0$$
$$R_1 = 580N$$

249. S8: *We've now got the moment about point O, which is the bottom of the ladder, being equal to negative of 5cos53 ° multiplied by 500 Newton −7.5 cos53 ° multiplied by 700 Newton + 10sin53 ° multiplied by R_1, and all this is equal to zero.*
250. R: *Why must it be equal to zero?*
251. S8: *(Pause)… Why? Maybe it is because the sum of the torques about a point is equal to zero. The point is not moving, and I'm not sure what will make it equal to zero. I also need to understand this, I' m not sure about it. I know that the whole thing has to be equated to zero in order to work out R_1.*

c) Calculating R_2

252. S8: *You take R_1 and substitute it back into the expression.. The sum of the forces in the x- axis is equal to negative R_1 plus R_{2X} equal to zero. Since we know R_1 we can now get R_{2X}. We get R_{2X} the subject of the formula, and R_{2X} is equal to R_1. We have worked out R_1 which is what the question wanted us to do. We're not finished yet because we still haven't worked out R_2.*

$$\sum F_x = -R_1 + R_{2X} = 0$$
$$R_1 = R_{2X}$$
$$R_{2X} = 580N$$

Phase 3 (Indicating a process of change in which an approach / concept is given a meaning different to that given in the test)

253. S8: *We know R_{2Y} and R_{2X}; R_{2X} and R_{2Y} together form R_2, since they are the components of R_2. (Pause)…*
254. R *What's happening now?*
255. S8: *I'm thinking of another way of getting R_2. I think there are 2 ways of working out R_2. Lets make a triangle. This is R_2, this is R_{2X}, and that is R_{2Y}. These are all vectors. I know the value of R_{2X} and R_{2Y}. I can substitute those values and use Pythagoras' theorem to work out R_2.*
256. R *Did you work it out like this in the test?*
257. S8: *No I didn't. I didn't use the Pythagoras theorem, and I didn't include R_{2X}.*
258. R: *Did you check your answers as you were working?*

259. S8: *No, I didn't check. I do not think we are going to have the same value.*

260. R: *Why?*

261. S8: *It is because we didn't use R_{2X} which id another component of R_2. In order to get R_2 we need to sum those two up. I do not think that the way in which I did it is correct because as I said I didn't include R_{2X} in getting R_2.*

As performed in the test	As performed in the interview
$\sin 53^\circ = \frac{R_{2y}}{R_2}$ $R_2 = \frac{R_{2y}}{\sin 53^\circ}$ $R_2 = 1503N$	$R_2 = \sqrt{(R_{2y})^2 + (R_{2x})^2}$ $R_2 = \sqrt{1200^2 + 580^2}$ $R_2 = 1333N$

8.3.3 The student's problem representation with regard to Question (c): Confirm your result above that $R_1 = R_{2X}$ by taking the moment about another point

8.3.3.1 Student's interpretation of question (c)

262. S8: *(Reading)...Check your result above by taking another moment about a point...about another point, hey, let us see...I took the moment about R_2 I will now take the moment about R_1 now and I'll use the same strategy.*

263. R: *When you take the moment about a certain point what is it that you are trying to do?*

264. S8: *I'm eliminating that point...we now have to check whether the answer we get will be the same as the one we got for R_{2X}.*

265. R: *From looking at your script it does not seem you got to proving that $R_1 = R_{2X}$...why what happened?*

266. S8: *Ya...I skipped that part.*

The student's mathematical representation of question (c)

Phase 2 (referring to test script)

267. R: *You do have something interesting here...you have the moment about this new point to be R_2.8m...is that so?...What you were trying to do here?*

$$\sum \Gamma_{R_1} = -mg(5\cos 53^\circ) - Mg(2.5\cos 53^\circ) + R_2(10\sin 53^\circ) = 0$$
$$\sum \Gamma_{R_1} = -500(5\cos 53^\circ) - 700(2.5\cos 53^\circ) + 8R_2 = 0$$
$$= -500.3 - 700.15 + 8R_2 = 0$$
$$R_2 = 319N$$

268. S8: *Ya...I put the moment about R_1. I was supposed to have used R_{2x} and R_{2y}...why did I use R_2 that was a*

stupid thing to do...

8.3.3.2 Re-interpretation of question (c): Testing the new way of seeing the problem (Phase 3: Indicating process of change in which an approach / concept is given meaning different to that given in the test)

The student's mathematical representation of the new way of calculating R_{2X}

$$\sum \Gamma_{R_1} = R_{2X}(10\sin 53^\circ) - R_{2Y}(10\cos 53^\circ) - 700(2.5)\ldots - 500(?) = 0$$

269. R: *Why do you think you should have used R_{2Y} and R_{2X}..and not R_2. And how would you have used R_{2Y} and R_{2X} ?*

270. S8: *R_{2Y} and R_{2X} are components of R_2..that is why...I would have said the moment about the point = distance from the point where R_{2X} originates to R_1...yes that is what I was supposed to have done. R_{2Y} and R_{2X} are forces, hey...then the distance from the point would be 8 times R_1 (because $R_{2X} = R_1$). this would be positive. The distance from the point to R_{2Y} ...wait a minute ...how do I get the distance using R_{2Y}...?. The distance would be would minus10 cos53 °. I've got the weights as well, the distance from the point to the weight of the painter will be 2.5m, they say that the painter is 7.5 m from the top of the ladder, we know that the length of the ladder is 10 so you just subtract 7.5 from 10m*

271. R: *You said we have to look for perpendicular distance to the line of force, is this 2.5m perpendicular to the weight of the man?*

272. S8: *No, it is not, you see this is what I said we have to come back to...(pause)...what I know is that it has to be the line from the point to the force...here I am not really sure how I worked it out...*

Phase 2 (Referring to test script)

273. R: ***In your script you have 1.5m how did you get that?***

274. S8: *I got 1.5 and not 2.5...I think I meant 2.5...(pause)...how did I get 1.5m?*

275. R: *If you are considering the distance to that line of force how will it look like...show me how this line is drawn.*

276. S8: *Still no response*

277. R: ***You went on to say –500N multiplied by 3m how did you work that out?***

278. S8: *I can't remember how I got this distance...*

279. R: *Why is it difficult for you now to show me how you did it...where is the difficulty at the moment...?*

280. S8: *I can't seem to get the line from the point to the force, the force is going downward, I can't choose another vertical distance because the distance has to be perpendicular and not parallel to the line of force...because they say that the moment is calculated from that point to the line of the force and this is not the line of the force...*

Stage 3

8.4 End of interview reflections

281. R: *If we were to consider a line that is drawn from A (the new moment) down the 8m and then left to the weights would that be acceptable to you?*

282. S8: *No...no because it is not directly from the point to the force...*

283. R: *How are we going to move forward from here?*

284. S8: *We will have to change it and take the moment about another point…because I can't find the perpendicular line from the moment to the force.*

285. R: *When you study and you come across a hurdle like this what do you normally do?*

286. S8: *I would have skipped the problem and come back to it later, which is exactly what I normally do in the test…cause as I stop to think time is ticking, remember I still have to finish the test there might be problems that I would still haven't worked and for which I can collect more marks, you see…but when I study if I come back and still can't do it and then I go for help…*

287. R: *You wouldn't use a text to check how they do it?*

288. S8: *I would do but if I still can't solve it I'll ask some body to assist me*

289. R: *The problems that you are able to do swiftly, you do not do any thinking when solving them?*

290. S8: *No, it does not mean that I do not think at all, but it means that I don't have to stop and ask myself by the way how do I do this, I just know that I have to do this and do that…*

291. R: *How do you know that you have to do this and not that, where does that knowing come from?*

292. S8: *With these questions you are supposed to know the procedure because there is n o way to get R1 without knowing* R_{2X} *so firstly you have to link things up.*

293. R: *If you were to talk to somebody who has been struggling with these problems what advise would you give the person.*

294. S8: *You'll have to understand the question first, y ou'll have to make your own sketch of the problem, and if you can't draw the sketch then you'll have difficulties in understanding the problem…*

295. R: *How does the sketch help you in understanding the problem?*

296. S8: *It helps in identifying the forces, you can't have weight being horizontal on your sketch, weight is always downward, gravity is downward, it is the force of the earth pulling on the object.*

297. R: *If you have someone who would say I can draw the sketch, but I just do not know what to do next, how to move from there on.*

298. S8: *Yes there are situations like that where the pictorial representation is not enough, maybe it is situations where I need something that would explain the question more. Like with this problem you need to know about the moment about a point, you need to know this. And this we learnt in class, it was the first time I came across this material. if I were given this problem without being taught how to work out the moment about a point I would surely be stuck. You do the first part (working out the force) knowing that you are going to use it in calculating the moments. The ultimate goal is to work out the moment about a certain point. This is where conceptual understanding comes in. You do not memorize these things you have to understand them.*

299. R; *What do you regard as conceptual understanding?*

300. S8: *For me it is the part that does not include the calculations, it just expla ins what happens in problems in cases like this.*

301. R: *If somebody looks at your work, they may argue that all they see is mathematical representations and calculations, where is the conceptual part?*

302. S8: *It is behind the calculation. I mean for yo u to understand that force = ma it is not just put there, you need to understand that a force is a pull or a push and what does it push? it pushes this mass causing it to accelerate, you've got to understand that. We use the equation for the calculations, but to understand the equation you'll have to go through the conceptual part. And you get it from the textbooks…*

303. R: *What about the lectures?*

304. S8: *What I did last semester I went to class to listen and not to write and this semester I am doing much listening but I'm writing most of the times because I think the part we are doing now needs to be understood conceptually first. Previously it was mainly calculations there were a lot of calculations to be done. I had to work out for myself when you are given a problem like this, this is how you should attack it. This semester, it seems to include a lot of conceptual part.*

305. R: *It sounded as if you value the conceptual approach to learning physics…but now…you sound like you do not enjoy it…?*

306. S8: *We did not only do the problems last term…but mostly we concentrated on the calculations and not the conceptual stuff. yes, I used it there and there to understand I didn't use it that much…and this semester it seems I'll have to use it. I'll have to read to understand what we are being taught, it is too conceptual.*

307. R: *How are you seeing your progress so far?*

308. S8: *I got a D symbol for the first module my practical mark brought everything down, it was okay I passed but is was not wonderful, the second module I got a B which meant to me that maybe in the first module I didn't concentrate that much on my work. There has been an improvement in my understanding of physics; I feel I can now apply it. You apply it as you solver those problems. Now I understand that you are given the equations and you take the values and plug them in, it is not like that at all. You have to understand physics and I like it. It is interesting and challenging, you have to think. Let say you have to work out a problem involving forces, Here you are not always given the variables where you know the mass and the acceleration to work out the force. Even if the equation seems easy, but it is not always like that, you struggle sometimes to find the acceleration.*

309. R: *Has this changed the way you look at physics?*

310. S8: *Yes it did, I didn't like physics last year. We were failing. When I was at high school the whole class*

would fail, 60 percent of the tests we wrote during the year and then they'll pass at the end of the year. They didn't concentrate that much on continuous evaluation, what mattered was the last test we wrote at the end of the year.

Student 9

Stage 1

9.1 Beginning of interview reflection

311. R: *How did you go about answering this section?*

312. S9: *I read question 1 and checked out which one do I feel confident in , so that I do not waste time. So, I started with one since I had more information about that one.*

313. R: *What do you mean when you say you had more information about number 1?*

314. S9: *I mean…I could analyze the problem and from there on I could answer the questions asked. I then went to number 2 which was more complicated than number 1and then moved on to number 3. I didn't want to waste time.. I found that numbers 2 and 3 were almost the same.*

Stage 2

9.2 Student's interpretation of the problem

The student's interpretation of the problem forms part of his problem representation given below.

9.3 The student's problem representation during the interview

9.3.1 The student's problem representation during the interview with regard to Question (a): Draw a free body diagram indicating all the forces acting on the ladder

315. R: *Do you mind taking me through how went about solving number 1?*

316. S9: *For 13 marks …let us see…*

317. R: *Do you always look at the mark before you do a problem?*

318. S9: *Ya…*

319. R: *Why?…What role does the mark play?*

320. S9: *It sorts of guides me. I know that I need to spend about 13 minutes on it (reads the problem) …from the given information I'm told tha t the ladder is 50kg and it is uniform…*

321. R: *And what does that mean?*

322. S9: *If it is not uniform it would look like this: draws two pictures the first one is of a triangle focusing on the fact that it's center of mass is not in the middle, the word center of mass is not used by the student)….I am told that the wall is frictionless, meaning that there is no friction which implies that the x- component is the only force that is present. the y-component will be zero. The foot of the ladder makes a 53 ○ angle with the ground (Indicates this on his sketch)…I am given that the length is 10m and I'm told that the man is already 7.5m up the ladder. I am looking at both the y and x-components because the ladder is at an angle. Thus the force of the man in the x- component is 700N (10cos53^0). And in working out the x and y distances we know that cos 53^0 = x/r thus x = r cos53^0 = 10 cos53^0 = 6m and for the y-component sin53^0 = y/r which means that y = r sin53^0 = 10 sin53^0 = 8m. Now I know my x and y. The ladder is said to be uniform, meaning that its center of mass is between A and B and hence the horizontal distance will be half of 6m which is 3m.*

323. R: *What do you understand by the term: the center of mass?*

324. S9: *It is the balancing point (Uses a pen to demonstrate this). Now that I have all this, when I take the torque about this point, O, the horizontal distance will be 3m…*

325. R; *Do you care to explain…how do you know that it has to be half and not a quarter or some other value?*

326. S9: *Since we have chosen the moment to be about this point, (pause)…I do not know why we have to use half of the horizontal distance…I am not sure…*

327. R: *OK...you carry on…*

9.3.2 The student's problem representation with regard to Question (b): Calculate the forces that the ground and the wall exert on the ladder

9.3.2.1 Student's interpretation of question (b)

328. S9: *Since we are concerned with torques we will first have to use the condition of equilibrium and Newton's First Law in order to work out the forces along the x- component. Newton's First Law tells me about the first condition of equilibrium. I have to prove that the total force of the system is = zero meaning it is in equilibrium. that is why I have to use N1 and torque.*

329. R: *How do you know that you have to use these ideas and what is your understanding of torque?*

330. S9: *Torque has to do with the second condition of equilibrium…pause.. in order for the ladder not to slip the forces acting must be balanced. The total force must equal zero, these are forces acting in both the x and y-directions their sum total must be equal to zero…I am not sure about the reason for using the second condition of equilibrium…*

The student's to this question touched on the following two aspects (the student doesn't calculate R_2):

a) Applying the first condition of static equilibrium

This involved:

(i) Calculating the sum of the forces acting in the x-direction

331. S9: *>From here I worked out the summation of the forces acting in the x- direction. the ladder is leaning against a frictionless wall, there is no y- component of the force being applied. At the bottom of the ladder we have both x and y-components. if there was no y-component here the ladder wouldn't have been in equilibrium. there has to be a force acting downward to counter the force of the ground on the ladder, thus the summation of the forces acting in the x -direction is given as follows:*

$$\sum F_x = F_{2X} - F_1 - F_{man}\cos 53^\circ = 0$$

332. R: *You told me that F_1 is the force that the wall exerts on the ladder what about F_{2X} and the rest…?*

333. S9: *I do not fully understand this…I am not sure whether these forces are the forces exerted by the ground or the ladder…I am not sure…but what I understand is that in order for this ladder to be balanced here at the bottom we must have the x and the y -components…the point here is to calculate F_{2X} …F_1 and F_{man} are negative because I have chosen my coordinate axes such that downward and the left hand side of the point of origin are negative.*

334. R: *I wanted to ask you about the and F_{man} cos 53^0 …explain where does this force come from and who exerts it.*

335. S9: *I was trying to work out the forces that would balance the ladder…*

336. R: *Does the above equation about the forces acting in the x-direction being equal to zero make sense to you?*

337. S9: *The problem is that I can't solve this expression because I have two unknowns, F_1 and F_{2X}..*

(ii) Calculating the forces acting in the y-direction

$$\sum F_y = F_{2Y} - mg - Mg = 0$$
$$F_{2Y} = 1200N$$

338. S9: *Once we've worked out F_{2Y} we can calculate the torque in order to get F_1,*

b) Applying the second condition of static equilibrium

This involved:

(i) Calculating the moment about point O to determine R_1

339. S9: *We choose the moment about point O. According to the second condition of equilibrium the total torque must be equal to zero: This is where physics and maths go hand in hand, when you draw the line of action and the perpendicular distance.*

The student's mathematical representation of the calculation of R_1

$$\sum \Gamma_\circ = F_1.h - 500.3m - 700(7.5\cos 53^\circ) = 0$$
$$F_1 = 581N$$

340. R: *What is your understanding of the second condition of equilibrium, that is the total torque should equal zero? What is your understanding of the statement?*

341. S9: *(Pause)...What I can say is...a torque is like a circle...I can be a distance away from the center (i.e. radius) that is 2m and still have some displacement around the circle.*

9.3.3 The student's problem representation with regard to Question (c): Confirm your result above that $R_1 = R_{2X}$ by taking the moment about another point

9.3.3.1 Student's interpretation of question (c)

342. S9: *They wanted me to check out my solution. if it isn't the same as the one I got earlier then I'll know that I had left something out. If my F_1 does not equal F_{2X} then it means that something is incorrect...I made an error somewhere. If I substitute F_1 into the above equation I get:*

$$\sum F_X = F_{2X} - F_1 - 700\cos 53^\circ = 0$$
$$F_{2X} = 582N + 421.27N$$
$$F_{2X} = 1003.3N$$

343. S9: *>From here I then moved on to working out the moment about another point. I took the moment about A (the student's point A is at F_1)*

The student's mathematical representation of question (c)

$$\sum \Gamma_A = F_{2X}.h - W_{man}(7.5\cos53^\circ) - w_{ladder}(5\cos53^\circ) = 0$$
$$F_{2X} = 582.3N$$

344. R: *Make me understand how you can have two forces F_{2X} that are not the same. Over there you have F_{2X} = 1003.3N and here it is 582.3N, how do you explain this? Do you understand my question?*

345. S9: *Wow…I can see what you are saying…I am not sure…I didn't notice that in the test…I was not aware of it…*

346. R: *But you said the main thing here was to check whether you get the same answer or not…*

347. S9: *I was not aware of that during the test.*

9.3.4 The student's problem representation with regard to Question (d): If the maximum value of frictional force that would prevent the ladder from slipping is 700N, how much further can he climb before the ladder starts to slip?

348. R: *What about the last question, did you attempt it?*

349. S9: *I did try it out..(looking at his script)….but it gave me a hard time…*

The student's mathematical representation of question (d)

$$F_S = \mu_S N$$
$$700N = \mu_S 1200N$$
$$\mu_s = 0.6$$

350. S4: *This is all I could come up with…I didn't know how to do it…my textbook didn't have these type of problems with the man going up the ladder. The problems that I did were just about the ladder and I only touched on them in my prepar ation of the test…*

351. R: *When we started with the interview you said you felt confident about this problem because you had more "information" on it…*

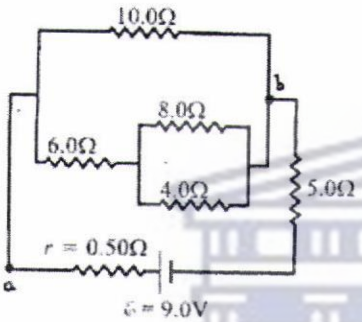
352. S4: *Yes, I was…but sometimes you can never know whether what you know is right or wrong. Like…even now I'm not sure whether or not I was supposed to have included the $F\cos53^0$ in calculating the forces in the x-direction…I know that there was something wrong with the expression but I do not know what…I can't explain this…*

The interview was ended at this point due to the student expressing difficulty in elaborating on the problem any further.

THIRD MODULE

TEST 3: ELECTRICTY

"A 9.0 V battery whose internal resistance r is 0.5 Ω is connected in the circuit shown below: (23)



Determine:

a) **The equivalent resistance of the circuit. (8)**

b) **The current drawn from the battery, i.e. the current in the simple circuit. (2)**

c) **The terminal voltage of the battery. (2)**

d) **The current in the 6 Ω resistor. (3)**

e) **The potential difference between point a and b. (4)**

f) **Assuming that the 10 Ω resistor is a heater, calculate the power it uses and how much does it cost per month (30 days) if it operates 3.0 hours per day and the electric company charges 10.5 cents per kilowatt-hour (kWh). (4)"**

Student 10

Stage 1

10.1 Beginning of interview reflections

1. *R:* *In general how was test?*
2. *S10:* *It was not that difficult, you just had to apply everything that the lecturer taught you. He did some problems with us, I went through those problems as a basis for my preparation for the test.*
3. *R:* *Did you talk to the other students, do they also think that it wasn't that difficult?*
4. *S10:* *I only spoke to my friend Ali (Mr. Pillay) he said it was not that difficult. The day before the test we had a tutorial and he said we must just go through the problems we did in the tut.*
5. *R:* *What would you regard as a difficult test, how do you judge the difficulty of a test?*
6. *S10:* *Say for instance you have not studied your work or you did not go through your problems. That's when the test becomes difficult. Then you just sit there and wait for the time to pass by.*
7. *R:* *When you got the test script how did you proceed, where did you begin with the test and why/*
8. *S10:* *At school our teachers told us never to start with multiple choice questions because it is like a file where you store all the information. You first start with the stuff that you know and then move on to the other stuff. When you are able to work out a long question problem then you have a basis for answering the multiple choice questions. And it works. Our Biology teacher told us that when you do the M. C questions you are searching for information, it's like the brain is filing all the necessary information in order. So when you start off with M. C. which requires that you look for various pieces of information. This throws all your information out of proportion. That is what he told us and I'm applying that.*
9. *R:* *How do you determine which problem to do first?*
10. *S10:* *You start with question 1 and if you cannot do it you move on to the next one so that you don't waste time. after you've done all the questions you can do you go back to the ones that you can't do.*
11. *R:* *So which one did you start with?*
11. *S10:* *Question 1…I enjoyed doing this problem.*
12. *R:* *Why?*
13. *S10:* *Because I know electricity and I just applied my information that I studied. We did some of this stuff in Matric so it was easy for me I knew how to do the series and the parallel connections.*

Stage 2

10.2 Student's interpretation of the problem

The interpretation of the problem formed part of the student's problem representation for question (a) in section 10.3 below.

10.3 The student's problem representation during the interview

10.3.1 Student's problem representation with regard to Question (a): Determine the equivalent resistance of the circuit.

Phase 1 (Interview without referring to test script)

14. *R:* *Do you mind then taking me through Question 1, explaining how you solved it?*
15. *S10:* *In the lectures The lecturer told us that we have to simplify the circuit first before answering any*

questions. The 4.0 Ω and 8.0 Ω resistors are in parallel so I simplified them first and I got 2.7 Ω. Since the 2.7 Ω and 6.0 Ω are in series I just added them up to give me 8.7 Ω. This 8.7 Ω becomes parallel with the 10.0 Ω. The answer here is in series with the 5.0 Ω. I was not sure whether I should include the internal resistance in working out the equivalent resistance. I just left it out and I got 9.6 Ω.

16. R: *What is your understanding of the term internal resistance of the circuit?*
17. S10: *All the resistance…I should have included this 0.5 Ω.*
18. R: *And why didn't you do that in the test?*
19. S10: *I thought that I would lose marks. At school we were told that the internal resistance is usually very small and we don't have to consider it at all.*

10.3.2 Student's problem representation during the interview with regard to Question (b): determine the current drawn from the battery

20. S10: *And the next question, i.e. working out the current drawn from the battery. That is the current of the simple circuit. Current is equal to the volts over the resistance. So, I took the 9V and divided it with 9.6 Ω and got 0.9A..*

10.3.3 Student's problem representation during the interview with regard to Question (c): Determine the terminal voltage of the battery

21. S10: *The third question required me to work out the terminal voltage of the battery, what I had to here was just to multiply the current with….I calculated the current in the second question and it was 0.9 A so I multiplied the resistance 0.5 Ω by the 0.9 A that I got. And subtracted this …the resistance times the current minus the 9.0V the e.m.f. that we are given.*
22. R: *What is your understanding of the terminal voltage of the battery?*
23. S10: *The voltage goes through the circuit if you include the 0.5 Ω resistance…*
24. R: *Make me understand what you are saying, I'm not with you…*
25. S10: *They tell you that there is a 9.0V running through the circuit, but if you calculate the terminal voltage…it is like…at school they only told us that we must neglect the internal resistance, but now we have to consider it when we work out the terminal voltage.*

10.3.4 Student's problem representation during the interview with regard to Question (d): Determine the current in the 6 Ω resistor

26. S10: *The next question: determine the current in the 6.0 Ω resistor. The current is voltage over resistance, this becomes 9/6 which is equal to 1.5.*
27. R: *Make me understand what you are saying, I'm not with you …to work out the current in the 6.0 Ω resistor you used the formula:* $I = {}^{V}\!/_{R}$ *, why?*
28. S10: *I thought then that was how I should have worked it out, but now I see that I was wrong.*
29. R: *Why do you think it is wrong?*
30. S10: *Because I did not get marks for it.*
31. R: *Where do you think you went wrong?*
32. S10: *(Pause)…I do not know.*

33. R: *What does the formula I = V/R tell you, how would you explain the use of this formula?*
34. S10: *It is part of Ohm's law, if you want to calculate the current you have to divide V by R.*

35. R: *Are there any conditions for the application of Ohm's law?*
36. S10: *You have to simplify the diagram you are given. It means to make it simpler to understand because there are other resistors in the circuit.*
37. R: *Could they affect the current in the 6 resistor?*
38. S10: *Maybe we should have taken the other resistors into consideration…they will also have an effect on the circuit.*
39. R: *How?*
40. S10: *(Silence).*
41. R: *Did you do a similar problem in class?*
42. S10: *Yes, I think so.*
43. R: *Do you have your notes with you, you can use your notes…*
44. S10: *I cannot remember how to approach it, but I know that there is another way of solving it.*

10.3.5 Student's problem representation during the interview with regard to Question (e): Determine the potential difference between point (a) and point (b)

45. R: *What about question (e) did you do it?*
46. S10: *I did not do it.*
47. R: *How come?*
48. S10: *I think we did a problem like this in the tutorial. I know how to do a problem like this but I wasn't sure so I did not do it. I didn't want to guess.*

10.3.6 Student's problem representation during the interview with regard to Question (f): Assuming that the 10 Ω resistor is a heater, calculate the power it uses and how much it costs per month if it operates 3.0 hours per day and the electric company charges 10.5 cents per kWh

The student at this point in the interview expressed great discomfort and the question wasn't further pursued.

Stage 3

10.4 End of interview reflections in relation to the whole problem

49. S10: *At school I never paid much attention to this section, I did not like this section.*
50. R: *How do you feel about it now?*
51. S10: *Now I like it.*
52. R: *What has changed?*
53. S10: *Here we have tutorial we go to lectures, we get assignments…at school we just had one period and everything was covered within that period we didn't get extra time to work out the problems and it school it wasn't like that.*
54. R: *Who did the problems for you then?*
55. S10: *The teacher.*
56. R: *Were you never given the chance to do the problems yourselves?*
57. S10: *You had to do the problems but if you did not the teacher did it for you. Here you have to do it yourself so that you can understand it. They try to make you understand that in order to understand the work you'll have to do the problems yourself.*

58. R: How do you find that?
59. S10: I like it.

Student 11

Stage 1

11.1 Beginning of interview reflections

60. R: How did you find the term?
61. S11: I really liked it, I have always loved electricity, it is fun. I' ve always wanted to know more about the subject.
62. R: Do you mind taking me through how you solved question 1 b. But before we do that how did you feel about the test?
63. S11: About the last test...it was tough, but I managed to make it. I was hoping for a higher mark than this.

Stage 2

11.2 Student's interpretation of the problem

The student's interpretation of the problem was not explored. The student wanted to do the problem immediately.

11.3 Student's problem representation during the interview

11.3.1 Student's problem representation with regard to Question (a): Determine the equivalent resistance of the circuit.

Phase 1 (interview without referring to test script)

64. S11: The first question requires that we calculate the equivalent resistance ...So, for this circuit I'll start with the resistors that are in parallel (4 and 8). This combination will be in series with the 6.0 Ω resistor. The combination of the 6.0 Ω and the resistance from the 4 and 8 resistors is in parallel with the 10.0 Ω. I work this parallel combination and get one resistance which is in series with the 5.0 Ω resistor . When I add the resistance two, I get the equivalent of the circuit.
65. R: What about the internal resistance, you won't include it?
66. S11: No...
67. R: Why not?
68. S11: I do not know...(laughs).
69. R: How did you know that you are not supposed to include it?
70. S11: I did a couple of examples from the textbook and saw that they never include it, so I came to that conclusion myself that it is not necessary to include it when working out the equivalent resistance.
71. R: What is your understanding of internal resistance why can't it form part of the equivalent resistance.
72. S11: I do not know.

11.3.2 Student's problem representation during the interview with regard to Question (b): Determine the current drawn from the battery

73. S11: *I had problems here; I did not understand what they meant by a simple circuit.*
74. R: *So, how did you interpret it in the test?*
75. S11: *I interpreted it as the total combination of all the resistances, the emf as well as the internal resistance. This is how I worked out the current in the simple circuit (pointing to her script).*
76. R: *Do you mind showing me how you did it? You can take me through what you have on your script, you must explain what you were doing.*

Phase 2 (Referring to test script)

77. S11: *I used the formula:* $I = \dfrac{\varepsilon}{r + R}$
78. R: *What does this formula mean…?*
79. S11: *(Silence)*
80. R: *How did you know that this was the formula you had to use?*
81. S11: *Firstly, I know that because I have the emf and I have calculated the resistance and I'm given the internal resistance so…*
82. R: *Does it mean that if you were not given maybe two variables you wouldn't have used that formula…you were matching the givens to an appropriate formula?*
83. S11: *Yes.*
84. R: *So…so when you finally worked out the current and found it to be 0.89A, how did you interpret it?*
85. S11: *I said this is the current that flows through the circuit…*

11.3.3 Student's problem representation during the interview with regard to Question (c): Determine the terminal voltage of the battery

86. S11: *The third question wants me to determine the terminal voltage…the first thing that I understand about terminal voltage is that it is the voltage at the end of the battery. The positive and the negative ends of the battery.*
87. R: *How does the terminal voltage differ from the emf?*
88. S11: *What I know is that the terminal voltage is always less than the emf.*
89. R: *Why is it less?*
90. S11: *Because you always subtract the product of the internal resistance and the current from the emf that is why it is less…the emf is the voltage that makes the battery to work and the terminal voltage is the voltage that destroys the battery. If you switch on your torch and it doesn't glow this is because of the terminal voltage being greater than the emf (laughs).*
91. R: *How did you come to that understanding?*
92. S11: *When we were in Standard seven we were told that the terminal voltage destroys light, that is the understanding I've used in making sense of why the battery becomes flat.*
93. R: *Do you still think that is a valid way of talking about why batteries run down?*
94. S11: *I think I'll have to find out exactly how it works because I'm no longer convinced*

11.3.4 Student's problem representation during the interview with regard to Question (d): Determine the current in the 6 Ω resistor

Phase 3 (Indicating a process of change in which an approach / concept is given a meaning different to that given during the test)

95. S11: *I can see now that I made a mistake in number four in determining the current in the 6.0 Ω resistor. I should have used the formula I used in number (ii). For the voltage I used the 9V which is given for the e.m.f. The big R instead of substituting the equivalent resistance, I will substitute this 6.0 Ω s and then add it to the small r. The e.m.f. will then be divided by the 6.0 Ω resistance and the internal resistance.*
96. R: *Why would you proceed this way?*
97. S11: *I just thought that this would be the case.*
98. R: *Now if you look at the diagram that's given and you have to work out the current in the 6.0 Ω resistor, how would you justify the use of the formula you have chosen?*
99. S11: *(pause)…I do not know…*

11.3.5 Student's problem representation during the interview with regard to Question (e): Determine the potential difference between point (a) and point (b)

100. R: *Okay, and what about number (v)…determining the potential between points a and b?*
101. S11: *I do not understand something clearly. If I move from left to right or from right to left we still have a and b…*
102. R: *So…where is your problem?*
103. S11: *It means I have to calculate both and add them…*
104. R: *Explain…Say more…*
105. S11: *I do not have anything more to say.*
106. R: *What is your understanding of having to work out the potential difference between points a and b? I need your understanding of the question…*
107. S11: *Silence (looks at her script)…*
108. R: *I can see that you did try out something in the test. Do you mind telling me what you did.*
109. S11: *I used e.m.f. = potential between a and b. The e.m.f. we are given by current x internal resistance…(long pause) it is getting hard. I think we should stop here.*

The interview was ended at this point due to the student expressing discomfort. The last two sections, 11.3.6 and 11.4 are therefore not covered.

Student 12

Stage 1

12.1 Beginning of interview reflections

110. R: How did you feel about the test?
111. S12: It was quite easy because they gave you all the formulas on a page. You basically had to read the question and then apply…choose the right formula and apply it.
112. R: Was it really that simple? Just choosing the formula and applying it?
113. S12: Except for the theory part which you obviously had to know...like the definitions that you had to give.
114. R: If the test was that simple why do you think most students did so badly in it?
115. S12: It is because we do not do enough applications…in class we concentrate on the theory.
116. R: But what about you…how was it possible for you to do so well?
117. S10: In the first test I wasn't used to the way The lecturer was teaching, as I said it was first theory then application that's why it was a bit confusing , because I did study for all my tests just because of the application part… I failed my first test and for the second test I got 50 %.
118. R: What is it that changed this time around?
119. S12: I know that he likes asking a lot of theory questions so I knew that I could score marks in the theory part…the tutorials…I also went through a couple of tut questions for the application part and through the study guide.
120. R: Quickly take me through how you prepared for the test...how did you actually use the study guide, the tut manual etc…?
121. S12: Firstly if I did not know for example what the photoelectric effect was I would go and read up on it. The study guide gives you a summary of what it is and it points you to a page in the textbook which you must concentrate on and then you read that part…there is a lot of...I can't say unnecessary information…but there is a lot of information that is not necessary in doing certain calculations, so you end up wasting time going through all that and you aren't going to remember anything. So, the study guide eliminates some of the unnecessary work in theory and it tells you exactly what you need to concentrate on.
122. R: Did you use the study guide in the previous terms?
123. S12: No I did not use it.
124. R: Why not?
125. S12: I do not know why I never used it…but I used it for the last test.
126. R: What prompted you into using it this term?
127. S12: I decided to go through all the information, the study guide and all that. I thought if I go through everything maybe I'll be able to pick up on something I might have missed, like provide an easier explanation or so…

Stage 2

12.2 Student's interpretation of the problem

Phase 1 (Without referring to test script)

128. R: Okay, let's look at some of the problems you were given in the test.. do you mind taking me through how you solved number 1(b)…how did you feel about that one?
129. S12: I was a bit confused…I don't think that electricity is one of my strong points
130. R: Everybody says that why…?
131. S12: …because I get confused when it comes to series and parallel. Section (b) question 1(b) number 4 gave me trouble…where I had to work out the current through the 6.0 Ω resistor .When I was writing in the test I knew that the current is the same in a series connection but not in a parallel one…but I didn't know how to go about in finding the current in this combination

12.3 The student's problem representation during the interview

12.3.1 Student's problem representation during the interview with regard to Question (d): Determine the current in the 6 Ω resistor

Phase 2 (Referring to test script)

132. R: *In your script you used the equation: Ω , do you want to explain that?*
133. S12: *You can't use that formula because you have a combination of parallel and series connection. I know that the current is the same in a series connection but not in a parallel one. When I was writing in the test I knew that but I didn't know how to go about in finding the current in this combination.*
134. R: *What do you mean, explain?*
135. S12: *Firstly I had to work out the current in the 6.0 Ω s resistor (iv) I didn't know whether I had to calculate all the resistance in here first that is why I say I didn't know how to go about it from a simple circuit., I made this into the equivalent....but I wasn't sure whether I should make the whole circuit into a simple circuit and from there calculate the current ...but then I thought it is only three marks so...go into that trouble.*
136. R: *You didn't do such a problem in class?*
137. S12: *I can't remember...I can't recall...I thought you had to do it like V= IR (equivalent) you just add the resistors since the current is the same...so many things were running through my mind there just wasn't enough time. I basically left it lik e that then I went to the other questions...there were just so many possibilities...I just left it like that. They give you (V) and they give you (R) which you have worked out then you basically collect terms with (I)...*
138. R: *What are you saying...you would do this after you have simplified the circuit or what?*
139. S12: *I thought it would be easier if I simplified it first and then use V = IR and consider the various resistors...because...the combined R is the equivalent of the separate ones so you could use it both ways because it would still yield the same answer that is what I think...it is basically easier because you are going to have fractions and you're going to have 1/R because it is in parallel...so I would rather simplify it first.*
140. R: *Why would you use V = IR how do you know that the current going through all these resistors is the same?*
141. S12: *Because it is in series with the rest, that is the 10;4;8 combination is in series with 5.0 Ω and 0.5 Ω .*

12.3.2 Student's problem representation during the interview with regard to Question (e): Determine the potential difference between point (a) and point (b)

142. R: *Did you attempt working out (v) i.e. the potential difference between points a and b?*
143. S12: *Yes...but you had to have the first answer there on top, i.e. the current drawn from the battery.*
144. R: *What understanding did you use to work it out?*
145. S12: *You could use Kirchoff's loop rule, i.e. potential drop is equal to potential rise...you can work it the same way...but I think for series the voltage will be the same. If you take it from a to b there is two ways of doing it, but they don't specify which way so I didn't know whether I had to do it the one way or both ways.*

12.3.3 Student's problem representation during the interview with regard to Question (f): Assuming that the 10 Ω resistor is a heater, calculate the

power it uses and how much it costs per month if it operates 3.0 hours per day and the electric company charges 10.5 cents per kWh

This problem was attempted in neither the test nor the interview.

Student 13

Stage 1

13.1 Beginning of interview reflections

The student's reflections form part of the interpretation of the problem below.

Stage 2

13.2 Student's interpretation of the problem

Phase 1 (Without referring to test script)

146. R: The problem I want us to discuss is number 1 (b) in section b. How did you find it?
147. S13: I thought it was okay. I knew that I wasn't going to get everything right because I always have problems with this voltage, like working it out at this point or that point, like in number (vi).

13.3 The student's problem representation during the interview

13.3.1 Student's problem representation with regard to Question (a): Determine the equivalent resistance of the circuit.

148. S13: The first question was okay because I know how to add resistors in parallel and in series
149. R: What was your understanding of having to determine the equivalent resistance?
150. S13: It is the sum total of all the resistance in the circuit.
151. R: Some students said that it wasn't necessary to include the internal resistance when working out the equivalent resistance...
152. S13: I do not know...but I included it.... I did think about whether I should include it or not I don't know why but I included it.

13.3.2 Student's problem representation during the interview with regard to Question (b): Determine the current drawn from the battery

153. S13: And the second one, you just use the equivalent resistance and the voltage given.
154. R: How do you know that?
155. S13: (laughs) The current that runs in the battery is the current that is in the simple circuit. That is how I worked it out. I took the equivalent resistance and the voltage here.

13.2.3 Student's problem representation during the interview with regard to Question (c): Determine the terminal voltage of the battery

Phase 2 (Referring to test script)

156. S13: *Working out the terminal voltage of the battery there, I do not know what I did.*

157. R: *Do you want to have a look at your script?*

158. S13: *Yes…there it was wrong…(laughs)…I don't know … there was something about…should we have used that Kirchhoff's loop rule or whatever…to work out the terminal voltage?*

159. R: *What is your understanding of terminal voltage?*

160. S13: *Isn't it the voltage across the terminals…I don't know…*

161. R: *Explain…how would you have used Kirchoff's law to work out the terminal voltage of the battery?*

162. S13: *I don't know, but they say something like…if you go across a resistor from positive to negative then this side is positive and that one is negative, it is like going down mean ing it(electric potential) goes down. IR becomes negative, that's what I did. So I took… I didn't know how to go about it. I used the equivalent resistance…and the current…!*

163. R: *On your script you have V = IR and the next step you have the e.m.f. – IR =V, just explain that to me.*

164. S13: *Here I was using Kirchoff's rule…I didn't know how to work out for the parallel ones on the side so I took the resistance as the equivalent resistance and the current as the equivalent current that is how I did it!*

165. S13: *…but tell me was I supposed to have used Kirchhoff's law?*

166. R: *Remember as I explained earlier the aim of the interview is for me to find out how you solved the problem in the test. At present I am not your tutor, we are two people who are discussing a physics problem. Why do you think that Kirchhoff's law would have been appropriate to use in this particular scenario to work out the terminal voltage? What is your understanding of Kirchhoff's law?*

167. S13: *I do not know but I know that it is useful in finding out the voltage and that it is positive here and negative there. Sometimes they give you the e.m.f. and the terminal voltage as well so I don't know whether they are the same or not..*

168. R: *So, as you were working out the problem in t he test, what did you think?*

169. S13: *I did not think that the terminal voltage and the e.m.f. are the same why would they ask us to work out the terminal voltage if it was the same as the e.m.f.?*

13.2.4 Student's problem representation during the interview with regard to Question (d): Determine the current in the 6 Ω resistor

Phase 3 (Indicates a process of change in which an approach / concept is given a meaning different to that given in the test)

170. R: *What about the next question, working out the current in the 6.0 Ω ?*

171. S13: *I can see that I got it wrong…*

172. R: *Don't you worry about the mark you got just try and expl ain to me what you were doing because that is what I'm interested in finding out....*

173. S13: *I know that the current splits up here so we cannot use the current we calculated earlier. So…I think I was supposed to find the current through the 6.0 Ω resistor and the current through the 10.0 Ω resistor. We have these two resistors (4.0 Ω and 8.0 Ω) in parallel so the current through the 6.0 Ω resistor splits up again here….yes, the current in the 6.0 Ω resistor (laughs). I think I will have to work out the equivalent resistance of these three resistors (6, 4 and 8) and then…I don't know…I'll have to find the current in the 6.0 Ω resistor cause the same current will go through the equivalent resistance of the 4.0 Ω and 8.0 Ω resistors because they are in series.*

174. R: *Do you mind showing me how you would do it?*
175. S13: *The current is equal to 0.88A hey, and then what…help me out here…The current that goes through the first one here, the internal resistance (0.5 Ω) is 18Amperes...no… here I got 0.88Amperes and that was the current in the simple circuit. Is the current…there I go again asking you a question…*
176. R: *No, go ahead ask the question maybe you can try and answer it yourself.*
177. S13: *Is the current in the simple circuit the equivalent current?*
178. R: *What do you think? How did you interpret that in the test?*
179. S13: *I thought yes it was.*
180. R: *What seems to be the problem now?*
181. S13: *Now I have worked out the current in the first and found it to be 18A. This does not make sense, if 0.88 is the equivalent current, then how can the current here be more than 0.88?*
182. R: *Explain how you worked out the current through the internal resistance?*
183. S13: *I just used I = V/R…It is wrong…I can see that it is wrong…I am expecting 0.88 A.*
184. R: *Why would it be wrong?*
185. S13: *Because it is the current I got in the simple circuit, which means if we simplify these four resistors (6,10 4 and 8). The current that goes through here will be the same as that through the internal resistance. Let me try something else here. (Works on her own for a while) I am lost now…*
186. R: *How far did you go…what is it that you find you no longer understand?*
187. S13: *I thought that the current through the four resistors, the 5.0 Ω and the 0.5 Ω is the same…because the current does not split…I just know that it has to be the same.*
188. S13: *I was just checking if I can get the current over the 0.5 Ω and the 5.0 Ω resistors but I can see that it is not the same. If I got the current over 0.5 to be the same as that over the 5.0 Ω resistor then I…I could have gotten the* ***current*** *over this* ***10.0 Ω resistor and the current over*** *the* ***combined four resistors. And if I add both currents then they should add up to 0.88 A.***
189. R: *If you work it out what do you get for the current in the 5.0 Ω ?*
190. S13: *I got 1.8 A.*

191. R: *Is your V = 9 across the0.5 and 5.0 Ω resistors?*
192. S13: *Over here…no it cannot be…yes some voltage will be lost here…across here in all these combined resistors…*
193. R: *Explain…*
194. S13: *If you make these three (6,4,8) into one resistor, some voltage is going to be lost and if you get to the 5.0 Ω one the voltage will be less than 9 V…!*
195. R: *What do you mean by "lost voltage"?*
196. S13: *(Pause)…(laughter) I think …this is just not my section…I just do not like electricity…*
197. R: *You are not the first to say this…why don't you like the section.*
198. S13: *I do not know…maybe it is because I was not there at the beginning of this section. I really wanted to pay attention during lectures…but because I started it so late and there was a lot of work to be covered so I just went for the formulas…not even formulas…I just studied the stuff we did at school…*
199. R: *What do you mean?*
200. S13: *I wanted to pay attention…I was late…there was just so much to be covered…and I had a lot of work to do…*

201. R: *How did you prepare yourself for the test?*
202. S13: *I went through…in the textbook there's always some easy examples…so I just went through these you know simple series and parallel combinations. I didn't…I don't know…also this internal resistance…I really do not understand this section.…*
203. R: *What do you mean you do not understand this section…?*
204. S13: *I mean even now I cannot even do these things again…(laughs)…*
205. R: *Are you saying that if you were able to do them that would have proven that you understand the section?*
206. S13: *Ya…ya…after a while you can still do the things that you understand…so I was just lucky…because…I knew that I could get the first three questions but the rest…*

13.2.5 Student's problem representation during the interview with regard to Question (e): Determine the potential difference between point (a) and point (b)

207. R: *How did you fare with question (v)?*

208. S13: *I knew I would not get it right. This whole thing…I'm just lost…*

209. R: *People mean different things about their status of being lost, what do you mean by being lost and why do you think that?*

210. S13: *I am lost because I know nothing…(laughs)…about this whole thing…this circuit…(pause)…I would say…that the potential difference would be more at point a than at point b.*

211. R: *Explain how and why.*

212. S13: *Because potential is lost as you move through the various resistors.*

213. R: *What is your understanding of the term "potential difference".*

214. S13: *(Silence)… I'm hopeless…*

13.2.6 Student's problem representation during the interview with regard to Question (f): Assuming that the 10 Ω resistor is a heater, calculate the power it uses and how much does it cost per month if it operates 3.0 hours per day and the electric company charges 10.5 cents per kWh

215. R: *What about the rest …?*

216. S13: *Oh no!*

217. R: *Okay.*

218. S13: *Like the rest of the question I was doing them for the moment if someone were to ask me what happened I wouldn't know. I memorized it…as I said it is just for the moment after a while it is gone…it is gone…*

Stage 3

13.4 End of interview reflections in relation to the whole problem

219. R: *You have come to the end of the third module and you've made it.*

220. S13: *I just made it…(laughs)…just, just made it, but I will be back next term. This term I didn't understand the work.*

221. R: *But you got a C for the module how is that possible? What does the symbol mean to you?*

222. S13: *I don't know…I didn't understand…I was so lost …even the test I wrote yesterday, it was just application of formulas. At least with last module's work after having written the test I could like talk about it.*

223. R: *What changed?*

224. S13: *This term I joined the class late and it was a bit too much so I said I was just going to go for formulas… I didn't really understand the work.*

225. R: *And, the previous module, did you try to understand the work?*

226. S13: *I tried to...but…when I got to lectures, I felt I wanted to understand…this time around I just went for formulas. When you understand your work you don't have to study hard for the test because you understand what's going on. you don't have to be able to answer all the questions about the work, but you do not just run into formulas, oh no, at least if you know what to do, that is what I think.*

227. R: *What is the difference between running into formulas, knowing what to do and understanding your work?*

228. S13: *Running into a formula, you sit with a lot of formulas and you figure out which variable is missing, that is what we do (laughs)…everybody does it. To know what to do and understanding are the same…I think. If you understand you draw your sketch to see what is happening at this point and that point. There was a stage when I really understood the work…when I was at school I did understand…I mean I had the time…but here things are hectic and you don't have the time.*

229. S13: *Or you study the night before, then you are forced to go to your formulas…because it is going to take you the whole night to try and understand and more especially if you are alone and there is no one to help you. You need time and people to help you. We have too many subjects we need to hand in assignment and you are not given enough time. You end up spending more time with one subject and totally neglecting the others and y ou end up studying only when you have a test coming up…something like that. I always feel I need to spend more time with computer science because I'm doing it for the first time. With physics one always thinks, I know it cause I did it at school .*

230. R: *When you study for a test in Computer science do you use the same method as you do with physics?*

231. S13: *Yes, the theory you can memorize, but it is more practical you go to the lab all the time. It's continuous you have to know what happened yesterday in order to proceed to the next project. When you study for the test you just cover the theory because you know what is cutting with the programs because you work with it everyday.*

232. R: *And with physics?*

233. S13: *With physics you go to class and you take notes you do not have to understand the work. I mean you do nothing in class other than listen and take notes. And when you hear that there is test coming you study maybe two days before the test. You go through your notes, mhhh…the formulas and that' s it. A lot of people are doing it, most of us do it. We do not really understand it.*

234. R: *But would you really like to understand what you do in class?*

235. S13: *physics is a subject that one would like to understand…to really understand. If an accident happens you can use physics to explain what is happening. I would really like to understand it.*

236. R: *When?*

237. S13: *Even now I would really like to do this electricity section again. But I know that it won't happen. I would really like to be there and not just take down notes. The lecturer does ask us if we understand but most of us never say anything if we don't understand because we first want to figure it out on our own. The problem is when we get home we never try to figure it out and we never go back to the lecturer or friends to discuss what's happening. We just want to figure these things out only a day before we write the test. After the test we don't care about it anymore. If you didn't get a question correctly, we never go back and ask the lecturer how to solve it. We just do not bother. We right it off because we think we are not going to meet it again, but you know deep down that somewhere along the line you are going to meet it again. Like with this nuclear physics I didn't touch it at all, and I know this is going to pose a problem for me in the future..*

FOURTH MODULE

TEST 4: DOPPLER EFFECT

"The driver of car A is travelling at 20.0 m/s and sees a distant car B travelling directly toward him. He sounds his horn, which has frequency of 500 Hz. The driver of car B hears a frequency of 560 Hz.

a) **Show diagrams to describe the above stated problem.** (3)

b) **Use the diagrams in a) to obtain the expression for the speed at which car B is traveling.** NO CALCULATIONS (3)

c) **Calculate the speed at which car B is travelling.** (4)

d) **Calculate the wavelength of the sound waves observed by the driver of car B.** (2)

e) **Calculate the frequency that will be heard by the driver of car B after he has passed car A at the speed calculated in c).** (6)"

Student 14

Stage 1

14.1 Begin of interview reflections in relation to the test

1. R: *We are going to go though one problem and you can take me through how you solved it. Before we do that how did you find the test?*
2. S14: *It was okay…the problems were solvable, it wasn't that bad.*
3. R: *And, your preparation for the test, how did that go? How long ago before the test did you start preparing?*
4. S14: *Actually it was two days before the test.*
5. R: *How did you go about preparing for the test?*
6. S14: *It was first doing the conceptual part, that is understanding how do we go about doing the problem and then secondly learning the equations.*
7. R: *I'll have to ask what you mean by "doing the problems conceptually"?*
8. S14: *Okay...can I give you an example of what I'm talking about?*
9. R; *Yes, sure why don't we choose a problem and then you can explain using that particular problem.*

Stage 2

14.2 Student's interpretation of the problem

Phase 1 (Without referring to test script)

10. S14: *It is like…with this problem one needs to identify the velocity, that is the velocities and directions of car A and B and understand what happens as car A approaches car B. (draws the diagrams). Firstly it is understanding the question itself, understanding in which direction does either car travel and which car horns the frequency and which one hears the frequency…*
11. R: *Why is identifying that information important?*
12. S14: *It is important because in your calculations you have to indicate the direction by assigning either a negative or a positive sign for the velocities. When a car moves towards you, you know that its velocity is positive.*
13. R: *I would like you to explain clearly to me how do you know this, you have to assume that I am someone who has never done physics before and you are trying to explain the reason why – and + signs are assigned for velocities.*
14. S14: *When an object or a person moves toward object B…how do I explain this…I do not know how to explain it…*
15. R: *It is okay you can slowly unpack it for me as we go along…*
16. S14: *Okay, I will try to get it done first and then explain it to you.*
17. R: *Okay.*
18. S14: *(Works silently for about five minutes) …let's start with the first part where you have two objects and you have to find out in which direction they move. Secondly you have to identify which one emits the sound and which car receives the frequency and the value of the frequency heard...find out the velocities…you know that the velocity of sound is 345 m/s … you find out the velocities of the two cars according to the direction in which they…when you come to the equation it gives you the frequency heard and the frequency of the sound itself. You don't just slot the velocities as they are. You find out whether car B moves towards car A or what. If it moves toward car A then…okay…pause…then the velocity is positive because it moves towards the …pause*
19. R: *Make me understand what you have sketched he re. You have car B moving toward car A and this arrow…showing car A moving away from car B… what does it mean?*
20. S14: *Car B moves toward car A…both cars are in motion…A is moving at a velocity of 20 m/s and car B is*

travelling toward car A. We have to find the velocity of car B as it moves toward car A. We have both frequencies.

Re-interpretation of Question (a)

Phase 3 (Indicates a process of change in which an approach / concept is given a meaning different to that given during the test)

21. R: *In which direction is car A moving?*
22. S14: *(Pause)...I think in the test I thought they were moving in the same direction, car B follows car A...but now when I look at it again it seems that car A is moving towards car B. If I saw this in the test I would have interpreted it differently...because the velocity of car A will be negative...this concept is very tricky because there are parts where you get confused... like to identify a + or – velocity you get confused on directions. It is easier when you are dealing with a velocity of an object moving towards an initial object because we will have only one velocity to consider.*

23. S14: *>From my understanding if you look at the equation itself you get v +/- the velocity of the listener...which I think if you are going to add the velocity of sound to the velocity of the object itself...if the source emits a sound then the sound has its own velocity and the whole point is the listener, because this is what you want to get...if the source gives out a sound and moves away from the listener then the sound would...be less meaning the frequency will be less a well.*
24. R: *In the problem we have a situation where both cars are in motion, i.e. the source is moving towards the listener, but in the test you interpreted it differently...is that what you are saying?*
25. S14: *I was given that car A travels at 20m/s...it emits a sound with 560 Hz and we have car B moving in the opposite direction moving directly toward car A and car B hears a frequency but that frequency is 560 Hz.*
26. R: *Is that possible...from what you told me earlier if car B moves toward car A and car emits a sound while driving away from car B, the sound that car B will hear will be less. But here in your sketch you have indicated the frequency heard which is greater than 560 Hz, how was that possible? Did you pick it up as you were working on the problem?*
27. S14: *No, I did not. But now I can see it...I just saw it now that I made a mistake... 'cause if you were to have a high frequency like I did that means that car A is mo ving towards car B. The frequency that is heard is the frequency of the source itself and then we have the velocity of car A moving towards car B while car B moves towards car A and the velocity of car B is unknown...which we have to find out...*

14.3. The student's problem representation during the interview

14.3.1 The student's problem solving representation with regard to Question (a): Show diagrams to describe the above stated problem

28. R: *Let's first work out the first part... i.e. use the diagram to obtain the expression for working out the speed of car B without using calculations. How did you go about answering that one? What was your understanding of it?*
29. S14: *I draw diagrams without them asking for representation...cause it is easier to get all the information and know every bit about the problem. If I hadn't drawn the diagram then when I work it out I'll forget which car moves which direction and the respective velocities at which the vehicles are moving.*
30. R: *In a situation where from the on- set the problem is misinterpreted is there a possibility of understanding what the problem is about?*
31. S14: *You can...if I interpreted it this way then my answer will be informed by my interpretation. If I misinterpreted the direction in which car A was moving there is no way my answer can reflect a situation whereby my answer will match the correct one...it is two different things it shows that there was no understanding.*
32. R: *When you wrote down 560 and 500 Hz didn't you quest ion yourself...if your understanding from the*

beginning was if the source moves away from the listener then the frequency decreases, how come did you keep the frequency at 560 and not at something less. What I'm trying to get at here is that there seems to be a discrepancy between the drawing of the diagram and your interpretation of the problem.

33. *S14:* *For me during assessment ...when I read something...and it seems right to me I just carry on cause I'm pressed for time.*

34. *R:* *In your opinion what's the us efulness of diagrams?*

35. *S14:* *It is the understanding of the question ...*

14.3.2 The student's problem representation with regard to Questions (b) and (c): Use the diagram in (a) to obtain the expression for the speed at which car B is traveling (no calculations); Calculate the speed at which car B is traveling

36. *R:* *When you had to obtain the expression for working out the speed at which car B is moving, how did you do that?*

37. *S14:* *You have the frequency heard = frequency of the source multiplied by the velocity of sound either plus or minus the velocity of the listener divided by the velocity plus or minus the velocity of the source. we use this expression because we have both cars moving...both cars have velocities...then you make the velocity of the listener the subject of the formula...in this situation both cars are moving towards each other and the textbook it states that when a car moves toward another object the velocity becomes positive...*

38. *R:* *Which velocity are you talking about* v_l *or* v_s *...?*

39. *S14:* *Okay...wait... it goes like this (trying hard to recall)...when car listener moves toward car source the velocity is regarded as positive and when it moves away the velocity is regarded to be negative. There is way in which works this out...but now I can't remember exactly how it works.*

40. *R:* *What do you base your strategy on, do you make use of a diagram to know whether a – or positive sigh has to be assigned or what?*

41. *S14:* *When they give me the velocity of listener and the direction, so I know if it moves towards the source the velocity is positive and when it moves away the velocity is negative. Then I'd look at the velocity of the source and compare it to the velocity of listener and try to understand how...if the velocity of the listener will be + or –*

14.3.3 The student's problem representation during the interview with regard to Question (d): Calculate the wavelength of the sound waves observed by the driver of car B

42. *R:* *What about the next question: determining the wavelength of the frequency as observed by the driver of car B, do you mind drawing a diagram first to show me how you'd work it out?*

43. *S14:* *In the waves I wasn't good at all...when I saw this I thought of the wavelength...first of all I knew that it had to be observed by driver B because it is the listener and after that I just calculated the wavelength...I didn't actually have an overview of the question.*

44. *R:* *Why do you stress the fact that you had to use the wavelength of car B only, what about the fact that the sound is emitted from a moving source?*

45. *S14:* *...the whole point here is car B as the listener...at what velocity was he moving when he heard the sound and when you come to the wavelength of the sound that is observed by the driver of car B (which is the listener); that is why you'll have to use car B. The waves move toward him, car A is just the source and the waves are heard by car B and...I don't think the waves stick around car A they move on, therefore car B would observe sound wave. So we use car B instead of car A.*

46. *R:* *And that is your understanding of the question?*

47. *S14:* *Yes!*

14.3.4 The student's problem representation during the interview with regard to Question (e): Calculate the frequency that will be heard by the driver of car B after he has passed car A at the speed calculated in (c)

Phase 3 (Indicates a process of change in which an approach / concept is given a meaning different to that given during the test)

48. R: How did you interpret the last one, the frequency that will be heard by the driver of car B after he has passed car A at the speed calculated in (iii)?

49. S14: I assumed that since on the third question we calculated the speed of car B therefore if they move in the same direction it is going to be positive and since car B has a velocity we'll then have to find the frequency heard.

50. R: And this interpretation is according to your initial interpretation of the problem?

51. S14: According to what I did in the test?

52. R: Yes.

53. S14: That would mean that car B has a higher frequency than car A and that is what I got there a higher frequency. I got the velocity of car B which was higher than car A. So, I thought if car b has a higher velocity he will pass car A which brings us to the question of the frequency heard by the driver of car B. Thus he passes car A and the frequency heard has to be higher.

54. R: But in your script I see you have 485 Hz…and not a frequency higher than 500Hz?

55. S14: Ya I see…at that point he is closer to the source so the frequency that he hears has to be higher.

Phase 4: Re-interpretation of the re-interpretation of Question (e)

56. R: If we use the new interpretation of the problem, that is, both cars approach each other, how do we talk about the frequency heard by the driver of car B after he has passed car A at the speed calculated in (c)?

57. S14: That would depend on what velocity car B is travelling.

58. R: How would the velocity of car B affect the frequency heard?

59. S14: (Pause)...I think its position is actually…(pause)…frequency and velocity go together… depending on the direction of both cars…you find the velocity of each car, for example if car B moves toward car A…I can't put it in words…

60. R: Do you mind drawing it, draw it first …take your time and when you feel you are ready to talk to me just let me know.

61. S14: Okay it comes to whatever object that emits the sound, we know that sound has a velocity of itself so it would matter if wherever it comes out from, and if it is in motion its sound would be affected. Sound has a velocity of its own therefore frequency, as we know it has to do with waves okay if the source is at rest for us to hear it its frequency and velocity of sound would have to be considered…because to hear the frequency of the sound it depends on the speed at which the sound is travelling. For one to hear the frequency of a sound they need to know the velocity of the sound… my understanding of frequency is…. no I'm not that very clear about it…I do not know how to explain it but when it comes to velocity of car A…as you hear something you obviously hear sound and if a car is moving and it emits a sound, the wave speed is affected by the motion of the car…the closer car B gets to car A you add the velocities which leads to the increment of the frequency?

Stage 3

14.4 End of interview reflection in relation to the whole problem

62. R: *We do this type of research to find out where the difficulties lie…lecturers always argue that students are lazy to learn because all the information they need is either given in class notes or is in the textbook…*

63. S14: *During assessment when you write the test you do not try to make sense of everything that you do, this you do only when you study. It comes to appoint that when you get stuck…and from what I try to understand you refer to the book to find out…try and get your way correct rather than trying to grasp what is in the book. It is easy to remember after you've done something like this and you check in the textbook where you know it is right and then jot down some hints on how to do it and then you work out your way of how you would solve it. You do get situations in which how you thought about it and what is in the textbook do not correspond…and the way you are lectured is totally different to what you think. So you end up taking what is there but also giving your own way of seeing it..*

64. R: *You did physics last year and you got 49% for this section, how was it last year?*

65. S14: *I think I learnt more this year because the group was small, last year the whole lecture hall was full. It fine you go to lecturers you try and understand what is happening but you can't grasp everything. basically I study for myself…*

66. R: *What do you mean?*

67. S14: *I go to lectures, but not always…I updated myself on where they are…and try and read about it and so forth…*

68. R; *What made you decide to do that?*

69. S14: *You go to class…of course he will give you his understanding of how you should do it and he won't stress on some points…because there are small parts there that if you miss out on them you won't understand...but then he knows about it and he is good at it, but he won't go down…this stuff is new to us…he won't go down to depth with…like when you talk about the car thingie…it seems easy when you read it out and do it while you refer to your text, but when you have to put it in…it is...to me it is very confusing. It all comes back to one's understanding of directions, velocities…like you said "didn't I think about the 560 Hz"…most people just pass…they learn to pass and not to understand. To me physics is interesting, but you know the part that one doesn't understand…like now you showing me that I didn't think about the frequency heard…(referring to not checking up ones answer)…to identify such things you are actually…to me it is interesting because you begin to understand how come you got a particular answer and how was it possible to get that particular answer. When you write a test that understanding will come…when you study in a way to know and understand…*

70. R; *I would liken you to explain what you mean by studying in a way to know and understand…?*

71. S14: *I mean doing something and you feel it, you actually feel you know it even if you get it wrong but you understood what was going on…you saw it in a different way…other than just slotting in the frequencies and getting the answer. It is knowing without even looking …before you look at the formula and you know that you have to use a formula that has the frequency with both velocities and you notice where you go wrong in terms of determining whether the frequency has to decrease or increase and only then do you refer to formulas…*

72. R: *How does that understanding come about?*

73. S14: *I also do not know…it is through trying and trying…I guess!*

74. R: *It is interesting to hear that there ate still students who love physics…especially with this being the end of the year…do you actually enjoy problem solving?*

75. S14: *That is the part I love …especially problems like this without a lot of calculations where you are actually trying to figure something out. I love it more than Life Science, here there are various ways in which you can solve a problem, you do not just have to follow what other people say and have done.*

Student 15

Stage 1

15.1 Begin of interview reflections in relation to the test

76. R: *I'm going chose one problem from the test and I would like you to explain how you went about solving it. I might ask you to elaborate further on certain aspects of the problem> Also if something isn't clear I will ask you to repeat it or say it differently. So take your time and remember I am not interested in finding out the right way of doing the problem, but finding out what you did during the test. If you do not understand my questions please do stop me and ask me to explain. So do not feel over awed by all these questions, it is a way of finding out what you are saying. I do not want to assume that this is what you wanted to say later on when I sit to transcribe that interview. Here is a sheet of paper in case you need to jot something down. I'll also be making my own notes as we go along. While I still look for your script you can tell me how you found the test.*

77. S15: *I do not think that is was difficult, like the self-study chapters -36, 37, 38. I didn't understand them well. We didn't have much time to cover all theses chapters during the vacation. And the mistakes that I made must have brought my mark down.*

78. R: *But the tuff you covered in class, did you understand it?*

79. S15: *Yes, I did…but the sign convention gave me trouble even though The lecturer tried to explain it. I just couldn't understand it.*

80. R: *What exactly gave you trouble?*

81. S15: *The focal length being negative and determining where the image is supposed to be formed, all that I didn't understand.*

Stage 2

15.2 Student's interpretation of the problem

Phase 1

82. R: *Without wasting time, let us look at section b number 2 b, how did you go ab out solving that problem?*

83. S15: *Okay…she reads the problem…they say that the driver of car a is driving at 20m/s and sees a distant car, car B travelling towards him, he sounds his horn which is 500 Hz and the driver of car b hears a frequency of 560 Hz. So, I took car B to be the listener and car A to be the source. the reason that I say car B is the listener is because its frequency is higher than that of car A. If two cars are travelling towards each other the listener is supposed to hear a higher fr equency than the source…*

84. R: *Why is that…*

85. S15: *It is because the source travels towards the listener it is unlike a situation where you have the source is travelling away from the listener… We use the listener as a reference point…and ask is he moving toward or away from the source…if it's towards the source the listener hears a higher frequency and if it is away from the source the listener hears a lower frequency.*

15.3 The student's problem representation during the interview

15.3.1 The student's problem representation with regard to Question (a): Show diagrams to describe the above stated problem

86. S15: *Now we are supposed to find the speed of car B and we also have to show diagrams to describe the*

problem. We take this one as car A and that one as car B. we take the direction to be positive and the positive direction is from the listener to the source…this is because…pause…we always take the positive direction to be from the listener to the source even if the source is moving away from the listener

87. R *How would you represent the fact that car B hears a higher frequency. In you diagram you have arrows pointing in different directions to indicate that the cars travel in opposite directions. In order to represent the idea of car A emitting a frequency that is heard by b, how would you go about doing that?*

88. S15: *On the diagram, I'll just draw…there is this thing about wavelengths…like if car…if this is the listener and this one is the source... I don't know if now confusing these things, but it goes like this if the source is stationary the wavelength will be smaller or something…pause…I'm not sure whether the wavelengths becomes smaller or what when the source is stationary…I didn't understand this well…there is thing that the wavelength is smaller on one side compared to the other side, but I'm not sure at all…if I understood that diagram showing the wavelengths being smaller on the one side and greater on the other, I 'd have been able to answer your question about why the frequency that car b hears increases as he approaches car A. The lecturer did explain it to us in class but I'm not sure whether it is smaller on this side or the other side…*

15.3.2 The student's problem representation with regard to Questions (b) and (c): Use the diagram in (a) to obtain the expression for the speed at which car B is traveling (no calculations); Calculate the speed at which car B is traveling

89. S15: *It says here use the diagram in (i) to obtain the expression for the speed at which car B is travelling. So, I have to show the expression and there is this formula which states;* $\frac{f_l}{c+v_l} = \frac{f_s}{c+v_s}$

90. R: *What formula is this and why should you use it?*

91. S15: *It is the formula for Doppler effect…it is about the listener and the source travelling…even if the are travelling toward each other or away from each other…so as we said the speed of car A is negative and that of car B is positive…we took the positive direction to be from the listener to the source, the speed of car A is* v_s *because car A is the source and the speed of car B is* v_l *the observer or listener. We have to make substitutions to find* v_l. *We make* v_l *the subject of the formula…pause…In number (iii) we have to calculate the speed at which car B is travelling we use the expression above and substitute* $c = 345 m/s$*…*$f_l = 560$ *Hz,* $f_s = 500$*Hz and then you work out* v_l. *I know that* v_l *is supposed to be positive if it comes out negative I'll know that I did something wrong somewhere…*

15.3.3 The student's problem representation during the interview with regard to Question (d): Calculate the wavelength of the sound waves observed by the driver of car B

Re-interpretation of question (d)

92. S15: *With number (iv) I have to calculate the wavelength of the sound waves as observed by the driver of car B (work quietly on the question)…there is a formula that says:* $c = wavelength \times frequency$ *. If you want to make wavelength the subject of the formula, you get:* $\lambda = {}^{c}\!/\!_{f}$ *so here they want the wavelength for car B…I have to use the velocity of car B as well as the frequency heard by car B so I used the formula:* $\lambda = \frac{c+v_l}{f_l}$ *. They want to find out the wavelength of the sound waves as observed by car B as he approaches car A. So, they ask the wavelength*

in front of car A. I didn't consider this during the test. I was supposed to have made the velocity of the listener negative and not positive as I had done in the test, it should have been: $\lambda = \frac{c-v_l}{f_l}$

93. R: *You said earlier if car B approaches car A then* v_l *becomes positive, why would* v_l *have to be negative in this case? What is it that you considering now...why are you changing you idea now. Let us look at your diagram again...you have those concentric circles around B...remember I asked you the same question earlier...where will the heard frequency be coming from, is it from car A or from car B?*

94. S15: *I think it would that of car A and not car B...*

95. R: *Why do you then use* f_l *and* v_l*...is that what you did in the test?*

96. S15: *Yes, I think I did that...(checking on her script)...ya this one...it should have been* f_s *and* v_s *because they are asking the wavelength of car A...*

97. R: *So, in the test how did you interpret it?*

98. S15: *I thought they were asking the wavelength of car B*

99. R: *Why would you calculate the wavelength of car B because car B does not sound any horn, it is car A that sounds the horn..*

100. S15: *(laughs)...*

101. R: *This discussion is really helping me a lot because when one looks at the script one doesn't know the reasons behind certain ways of doing things...now that you are reconsidering the answer, how would you go about it?*

102. S15: *The velocity will be negative. As I said in front of the source the wavelength is:* $\lambda = \frac{c-v_s}{f_s}$ *and behind the source the velocity will be positive:* $\lambda = \frac{c+v_s}{f_s}$.

15.3.4 The student's problem representation during the interview with regard to Question (e): Calculate the frequency that will be heard by the driver of car B after he has passed car A at the speed calculated in (c)

103. S15: *Here they want the frequency that will be hea rd when car B passes car A and we use the same speed as calculated in (iii). I'll use the same formula as I used in number (i)...they want the frequency of the listener so I make frequency of the listener the subject of the formula:* $\frac{f_l}{c+v_l} = \frac{f_s}{c+v_s}$ *and I'll use the speed as calculated it number (iii)=19m/s;vs = 20m/s;* f_s *= 500Hz and c = 345m/s....*

104. R: *This time around you are not considering the signs...?*

105. S15: *As I said +ve direction from the listener to source... car A will still have a –ve direction it will have to be 345-20...*

106. R: *What will your predictions be: is* f_l *smaller or greater than 560 Hz?*

107. S15: *It will have to be less than 560 Hz because car A is moving away from car B. If I got a value that was bigger than 560 Hz I would have gone back to check where I went wrong. If time ran out I would have written that the frequency calculated was supposed to be less than 560 Hz...that is what The lecturer told us...if you get an answer that you didn't expect you should state that it wasn't an answer you expected and he'd give you a mark for that.*

Stage 3

15.4 End of interview reflection in relation to the whole problem

108. R: *How did you feel about the problem as you were solving it...in the test?*

109. S15: *I did enjoy doing it, but now I know that I made a mistake in answering number (iv) and I wasn't supposed to make that mistake.*

110. R: *When you were solving the problem did you apply any of the stuff you learnt in the tutorials, like thinking about the principles that need to be applied and so forth...?*

111. S15: *Yes, I was thinking about the principle of Doppler effect to solve numbers 3- 5...*

112. R: *When you draw a diagram does it help you understand the problem and how...like what does the drawing of the diagram do for you?*

113. S15: *Okay…if you draw a diagram before the problem you look at the diagram and you see…like if I didn't draw the diagram I wouldn't have considered that car B's velocity is –ve instead of it being +ve…as you solve the problem you are forever looking at your diagram. It also helps you in understanding…*

114. R: *The diagram you drew at the beginning of the problem do you use it for the first part of the problem or do you use it continuously?*

115. S15: *I use it throughout the problem…but I didn't know that we were not supposed to draw those waves on car B that were supposed to draw them only on car…I think that is why I made that mistake in number (iii) …I used* v_l *and* f_l *instead of* v_s *and* f_s*. If I knew this beforehand I would have gotten full marks for number (iii)*

116. R: *This is the first time interviewing you, how did you cope with the first, second and third terms. Do you think that your problem solving skills have improved or what?*

117. S15: *Yes... I did…in the first term I didn't use the diagrams. I only wrote down the formulas and made substitutions, that was my problem…I think if I did pay attention to drawing the diagrams I would have done better in my tests.*

118. R: *What changed?*

119. S15: *The lecturer told us about the importance of drawing the diagram, but I didn't do it…I believed that I could solve the problems without them…but now with The lecturer he always writes down that marks will be allocated for the drawing of diagrams so I thought maybe I should try it . And sometimes you find that you make a mistake in your calculations but if your diagram is correct you do get some mark for the diagram.*

120. R: *How do you find the idea of having to solve problems in physics…?*

121. S15: *I think solving problem is the way of doing physics…but also one has to consider the theory and. in the first term I just did the end of the chapter questions and I didn't study the theory. It is important to understand the theory as well. I also found that the problems we get given in class seem easier than the ones we are given in the test. Even if you try to visualize what the problem is all about, you find that you can't it is difficult. And we told The lecturer about this and I think he did change things a bit.*

122. R: *One last question, you mentioned the word visualization, how did you visualize this problem during the test?*

123. S15: *I was expecting the problem to come up in the test. I understood this section better that the other sections we did this term. I was very happy when I saw it in the test.*

124. R: *How did you prepare yourself for the test?*

125. S15: *Most of the time I try to study the theory, understand it, and then move on to the problems. I mainly use the tutorial manual for questions because they normally have questions that are not in our textbook, problems that are a bit difficult. They show you the calculations and explain carefully what you need to consider in working out the problems, so when it comes to the theoretical part you can relate it to what you saw in the tut manual. I find these two books very useful, I use it more than I use the textbook. The textbook's problem is that they do not provide answers to the most difficult problems. The study guide has the even numbered problems and it has the step- by-step problem solutions to these difficult problems. It is not nice to work on your own on these problems and not know what the solution is. I stay in Stellenbosch and I don't have time to consult with the lecturers or the tutors.*

126. R: *The strategy that you applied in solving the problem where did you get it from?*

127. S15: *I got the theory from the textbook and I worked through a similar problem from the study guide and this helped a lot.*