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**A STUDY OF CONCEPTUALISED LINKS IN THE
UNDERSTANDING OF INTRODUCTORY NEWTONIAN DYNAMICS**

by

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ABSTRACT

Research into student understanding of university level physics has been extremely extensive over the past decade with many international studies affirming the inherent complexity and difficulty that undergraduate students typically experience in learning physics. An important and informative element of this research has focused attention on describing the variation in ways which students make sense of concepts which they experienced as being fundamentally counter-intuitive. One of the areas of most prolific research has been Newtonian dynamics. However, one important aspect from the teaching perspective which has not been examined at all is the variety of the ways in which multi-conceptual links are understood. This study has begun the examination of this aspect of Newtonian physics understanding using a group of first-year physics students enrolled at a typically good South African university.

Since the study was primarily aimed at characterising the variance in understanding of conceptual links in Newtonian dynamics the fundamental theoretical framework chosen for the study was drawn from phenomenography. The data consisted of a set of concept maps created by the students involved in the study and in-depth interviews with these students about the understanding they were attempting to represent on a multi-conceptual level on these maps.

Since an integral part of the study included exploring the role of counter-intuitiveness, the method involved creating ideal data-generating contexts for thematising drawn from an everyday problem with varying degrees of abstraction. In brief, these thematised scenarios incorporated the following: a familiar everyday experience with normal friction conditions; a familiar everyday experience with reduced friction conditions; and, an unfamiliar everyday experience with greatly reduced friction conditions.

The set of interviews formed what is known as a 'pool of meaning' in phenomenography for its associated analytic process.

The analysis had two components. The first component involved analysing the interview data across individuals to develop what is known phenomenographically as 'categories of description' to characterise the nature of the understanding in terms of conceptualisation or experience. The second component focused on learning as a function of the students' everyday and educational experiences. Here critical educational aspects emerged and their variance was identified. For example, intuition and context emerged as deeply influential factors in the ways Newtonian links are understood. Following contemporary thrusts in phenomenography this component of the analysis also looked at intra-contextual and inter-contextual shifts.

The analysis produced four distinct qualitative ways of understanding or conceptualising Newtonian links and showed the critical influence of intuition and context in the development of understanding of Newtonian dynamics at the introductory level. The analysis also contributed to phenomenographic theoretical concerns about a way of experiencing or understanding a phenomenon and the evolvment of such understanding. Collectively, these results are used to suggest important pedagogical implications for informing the improvement of physics teaching at this level.

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Glossary

Every discipline develops a set of technical terms. This glossary is intended to familiarise the reader with such technical terms as are used in this thesis. Some of the words are common in the discipline but less familiar outside of it and some are words that I have employed in a special sense.

Categories of description	characterisation of ways of understanding or experiencing a phenomenon
Concept	idea or abstract principle which relates to a particular object or event
Conception	refers to a way of experiencing something – an internal relationship between some phenomenon and the person -- meaning the discernment of something from its context, relating it to some context, discerning its parts and relating them to each other and to the whole (Svensson, 1984)
Conceptual change	relate new knowledge to relevant concepts, experiences, and propositions already known
Concept maps	in its simplest form would be just two concepts connected by a linking word to form a proposition (Gowin and Novak, 1984)

Development programme	in most South African universities is used for bridging the academic gap between schools and universities.
Discoveries	refer to the finding of a set of categories of description after going through a painstaking iterative process
Domains of applicability	refer to specific contexts
Effective teaching	allows students to appreciate their experiences and intuition in a particular context and to appreciate domain of applicability of ideas
External horizon	describe how each category of description is delimited from another
Internal horizon	describe the internal relationships that occur within each category of description
Learning	viewed as being a change in the way of experiencing the world -- a qualitative change in a person's conception of a certain phenomenon or of a certain aspect of reality – meaning to become “capable of discerning certain entities or aspects and of being capable of being simultaneously aware (focally) of these certain entities or aspects” (Marton, 1996:179).

Links	relationships made between concepts
Meaningful learning	change in the right direction in the way of experiencing the world -- relate new knowledge to relevant concepts, experiences, and propositions already known (see learning)
Outcome space	a set of categories of description together with their logical relationships
Phenomenography	the basic unit of phenomenography is “experiential, non-dualistic, an internal person-world relationship, a stripped depiction of capability and constraint, non-psychological, collective but individually and culturally distributed, a reflection of the collective anatomy of awareness, inherent in a particular perspective” (Marton 1996:172)
Pool of meaning	all the material that have been collected by the researcher (in this study all the interview transcripts)
Propositions	two or more concept labels linked by words in a semantic unit (Gowin and Novak, 1984)
Propositional knowledge	relationships formed between concepts
Referential aspect (of experience)	analytically <i>a way of experiencing</i> is divided into two components: the meaning (referential aspect)

and the structural aspect (see Structural aspect)

Relevance structure

“the person’s experience of what the situation call for, what it demands” (Marton and Booth 1997:143)

Structural aspect
(of experience)

“discernment of the whole from the context; and discernment of the parts and their relationships within the whole” (Marton and Booth, 1997:87) – See Referential aspect.

Theme (of awareness)

constitued of items of focus, i.e. discerned -- those aspects that are brought into the focal awareness (Marton and Booth, 1997)

Thematic field

consists of items relevant to the theme, i.e. tacit, taken-for-granted, has already been discerned -- those aspects that recede to the background (Marton and Booth, 1997).

Tutorial group

a small group of students meeting regularly (once a week in this case) to discuss problems given to them (in this case physics problems) at the end of each topic or subtopic

Understanding

a characterisation of *a way of experiencing* some phenomenon – also a synonym for conceptualising, seeing, perceiving, making sense of, etc (see Conception).

CHAPTER 1

INTRODUCTION

1.1 Introduction to the Problem

Physics is not an easy subject to study at university and one of the areas shown in an extensive range of studies to be particularly problematic conceptually at the introductory level is Newtonian physics. One particular area, kinematics, has a conceptual hurdle that is built upon our Aristotelian experiential world.

Introductory physics has a large number of concepts that students struggle to make sense of *in the way physics educators would like them to*. This is particularly true for concepts which appear to be counter-intuitive. Wolpert (1993) has argued that the physics of motion provides one of the clearest examples of the counter-intuitive and unexpected nature of science. He mentions that one surprising feature of motion is that, the most natural state for an object is movement at constant speed – not, as most of us think, being stationary. Another example has been well illustrated by, amongst others, Viennot's (1979) who showed how there is a tendency amongst many students to identify force with velocity instead of identifying force with acceleration – very much like DiSessa's (1982) 'Aristotelian expectation' that things go in the direction they are pushed in.

This commonsense understanding turns out to be extremely hard to successfully challenge when teaching introductory Newtonian dynamics and there are many studies that describe these difficulties in great detail.

All these studies describe understandings, variation in understanding or difficulties in understanding specific concepts. Yet gaining an appropriate appreciation of how things work in physics – what Richard Feynman calls *physics understanding* in his exemplary Lectures on Physics series written with Leighton and Sands in 1963 – must also include how a person attempting to learn physics sees the various concepts fitting together. Thus I argue that if university lecturers who teach introductory physics could also add such insight to their ‘content-specific pedagogical knowledge’ (Shulman, 1986) it could potentially open up a whole new dimension in the teaching of Newtonian dynamics. Hence this thesis reports on a study into the variation in the kinds of links or relationships that students make between basic Newtonian dynamics concepts. The links or relationships highlight how scientific concepts are interpreted and used by students. The central interest in my doing this study is thus to understand better the underlying thought processes and forms of knowledge used by students to interpret and apply scientific concepts. That is, – to identify educationally critical aspects for understanding of conceptual links in Newtonian dynamics - and use guidelines or strategies for teaching and learning scientific concepts more effectively.

1.2 Background to the Problem

During my four years of tutoring in first year Applied Mathematics (AMA103W) for engineering students at the University of Cape Town I have observed that students have tremendous conceptual problems with Newtonian dynamics. And these hurdles caused problems for them in future courses. I undertook a study for my Masters thesis to identify some of the problems the students experience in the first year course.

The literature on students’ difficulties in Newtonian dynamics I reviewed was enlightening but did not have concrete guidelines to teaching

Newtonian dynamics successfully. The literature addressed the causal factors of poor performance in isolation from educational backgrounds and students' involvement. In my Masters thesis I investigated the association between the educational background, student involvement and poor performance. Some association was found between the type of matriculation¹ examination a student wrote and the student performance in AMA103W. The investigation showed that the problems encountered were due to language, culture and mediated learning experience resulting from a poor educational background. These are fundamental gaps in the background of students which may seriously impede their grasp of the concepts that educators seek to cultivate from the beginning of an introductory physics course.

Indeed numerous investigations have revealed that many students, despite seemingly good performance in their prior science courses, often exhibit pre-scientific conceptions even when dealing with quite elementary situations (Clement 1982; McDermott 1984; Trowbridge and McDermott 1980; Viennot 1979). There is an enormous literature on students' understanding of Newtonian dynamics. On the one hand, it may seem strange to embark on a study in an already extremely well researched area. On the other hand, the extensiveness of the research is a good indication of both the scale and *extreme complexity* of an essentially unresolved ongoing problem. This study is, however, different from other studies undertaken in that it does not look at individual Newtonian dynamics concepts but rather looks at how students relate the concepts and make sense of them in a bigger picture, in what I will call *a specific domain of applicability* in this thesis. The study makes use of concept maps as a means of helping students gain insights into their own learning – becoming metacognitive – and as a means of getting the students to explain their understandings. To do this I draw on the students'

¹ South Africa's highest school leaving certificate

propositional knowledge for the nature of the relationships they understand occurring between a set of concepts in Newtonian dynamics in a specific domain of applicability.

It is against this background that I formulated the research questions as detailed in Section 1.4.

1.3 The focus of the study

The aim of the study is to look at two aspects of the ways students understand conceptual relationships. Firstly, the main part of the study is about the variation in the ways in which students conceptualise links between basic Newtonian dynamics concepts and this is done across individuals. Secondly, the study is extended to the individual level as a small case study to explore how particular individuals understand the relationships between the concepts vis-à-vis different contexts of applicability.

In other terms the study attempts to describe how students understand specific problems and phenomena from their own perspectives, as opposed to trying to describe how the students' understanding in general appears to us. Borrowing from Marton's (1981) words, I would say I am not trying to look into the student's mind, but I am trying to see what the student sees; I am not describing minds, but perceptions; I am not describing the student, but the student's perceptual world. This approach is known as phenomenography, which is detailed in Chapter 3. Following this phenomenographic perspective, the terms *conceptualise*, *make sense of*, and *understand*, are all used as synonyms for a *way of experiencing*, and I have used them interchangeably in the thesis choosing the most appropriate form for a given description.

The study focuses on the ways, and the extent to which, learning takes place in different given contexts. The idea is to get students to describe their understanding of conceptual links, drawn by them to represent the way they make sense of a given everyday theme with three different thematised scenarios (contexts) with varying degrees of abstraction (represented in this study as changes in theme content made up of everyday experience and everyday intuitional content). These different domains of application thus can be said to have thematised the given scenario as follows (in increasing abstraction):

- a. a normal sunny day (Implicit implication: a familiar everyday situation where normal frictional conditions exist);
- b. a rainy day (Implicit implication: a less familiar situation where reduced frictional conditions exist); and,
- c. a snowy day with roads covered with ice and snow (Implicit implication: an unfamiliar situation where negligible frictional conditions exist).

In this phenomenographic analysis I look at *what* is focused on, and *how* explanation is given. The aim is to generate *categories of description* which represent ways of understanding (here, the 'correctness' of a way of understanding is not an issue) which will be useful for physics lecturers teaching undergraduate physics. It would be extremely useful for Newtonian dynamics educators trying to foster 'sense making' in a counter-intuitive environment to have insights into how students make sense of *qualitative propositional conceptual links*. These insights may be used to improve outcomes of Newtonian dynamics teaching. This area of understanding has not been well researched, and I think would add to a repertoire of important Newtonian dynamics learning insights which an

introductory physics lecturer could possibly use to enhance student learning, especially when dealing with strong counter-intuitive concepts.

Yet another aim is to study in what way and to what extent learning² is taking place as a function of the students' educational experiences. The idea is to compare the students' conceptions of the same physical phenomena in different contexts, that is, in different domains of applicability. Variations in conceptions between different domains of applicability would represent cases of learning. The idea is to assist students to appreciate domain of applicability of ideas based on concept maps used in specific contexts. An attempt to understand how students conceptualise links between basic Newtonian dynamics concepts led to central questions described in Section 1.4 below.

1.4 Research Questions

1.4.1 Problem Statement

- How do students conceptualise links between basic Newtonian dynamics concepts?

The research questions drew upon explanations for a 'taxi-pushing scenario' thematised into the study-provided contexts as described in Section 1.3 above.

1.4.1.1 Empirical questions

- a) What are the qualitatively different ways which first-year university physics students conceptualise, or experience, conceptual links

² Learning here is viewed as being a change in the way of experiencing the world

- between basic Newtonian dynamics concepts as represented by their own concept maps?
- b) What kind of logical relationships emerge between the categories of description?
 - c) How do the categories relate to the contexts provided for the study?

The above empirical questions are addressed in Chapter 5. The first two questions form part of the phenomenographic investigation. The last question was addressed using statistical methods which formed part of a case study to address my theoretical questions.

1.4.1.2 Theoretical questions (based upon case study analysis)

The theoretical development of newly emerging questions in phenomenography (Marton and Pang, 1999), give consideration to questions such as:

- a) What is a way of experiencing a phenomenon?
- b) How do different ways of experiencing something evolve?

The kinds of theoretical concerns which I want to address here are those which are related to context. The theoretical concerns outlined above are addressed by considering the following questions:

- c) To what extent do conceptual shifts across contexts of differing familiarity characterise instances of learning? In other words, when all the students' descriptions are categorised in terms of the conceptions, or ways of experiencing, obtained for Empirical Research Question a), do any patterns of intra-contextual and inter-contextual shifting emerge for the individual students?

- d) To what extent is appropriate physics analysis affected by familiarity of contexts? In other words, if intra-contextual and inter-contextual shifting patterns emerge, can any patterns of contextual influence be discerned?

And lastly,

- e) What are the implications of the nature of consistency described for Theoretical Question c), for the teaching of Newtonian dynamics?

The theoretical questions c) and d) are addressed in Chapter 6 and question e) is addressed in the last part of Chapter 6 and is also discussed in Chapter 7.

1.5 Source of Data for the study

The primary sources of data for my study were concept maps, and in-depth interviews about these concept maps.

I have decided to use concept maps as characterised by Gowin and Novak, (1984), because their characterisation offers me the opportunity to get students to visually describe the structure of their thinking across the different thematised scenarios. In particular the concept maps provided a rich forum to explore students' sense making and its relationship to everyday experience and intuition across different thematised scenarios. Thus I fruitfully used these visual representations to explore student understanding of concept links in an in-depth interview situation. The descriptions obtained then formed the data pool for the phenomenographic aspect of my study as well as the case study aspect of my study.

1.6 Design and Method

I became involved with tutoring first-year physics students at the University of the Witwatersrand. Once I knew all the students well, I introduced them to concept maps and taught them how to construct them. Once I was satisfied that the students were well acquainted with constructing concept maps to represent their understanding I invented the following scenario:

A minibus is being pushed by 4 men. When it starts moving they let go and it accidentally collides with a stationary 10-seater taxi. The minibus drags the taxi with it and they both stop a few metres away.

This scenario was then set in three qualitatively different contexts. The different domains of applicability can be said to have been thematised as described earlier in Section 1.3. The aim was to generate different amounts of *contextual abstraction* in terms of everyday experience and associated intuitive thinking.

The students were asked to draw concept maps for each of these situations. Then these concept maps were used to generate a semi-structured interview protocol which formed the basis of subsequent interviews with the students where they were asked to explain the meaning of the links they had drawn between concepts on their concept maps.

The analysis had two components: one, an empirical component which was informed by taking a phenomenographic perspective to obtain categories of description, drawn from across students, as characterisations of conceptualisation, and two, a theoretical component which was proposed as part of a small case study. A second empirical component

came from the generation of a case study which, *inter alia*, mapped the students' descriptions across the three thematised scenarios described earlier.

1.7 Importance of study

The present study belongs to a relatively new area of research into aspects of student conceptualisation of Newtonian dynamics conceptual links. It also belongs to a body of studies into learning which have used and developed phenomenographic research approaches. It belongs also to the body of studies, which have taken phenomenography further to look at theoretical concerns.

The study was undertaken primarily to improve the teaching, and students' learning, of Newtonian dynamics. The underlying reason for the study is the possibility of improving teaching through students' experiences of their own learning. The present study seeks to reveal variation in the way students conceptualise Newtonian dynamics conceptual links. The study will make a contribution to the teaching of Newtonian dynamics by revealing categories of conceptualisations about links made by students between basic Newtonian dynamics concepts in a particular domain of applicability. The study also contributes to the body of knowledge on theoretical concerns by identifying educationally critical aspects of understanding from both the empirical and theoretical (case) studies.

The study is concerned with basic Newtonian dynamics concepts, which I would argue are part of the fundamental building blocks of understanding science which new undergraduate students first experience at university and there is research (for example, Linder and Marshall, 1997) which links improved physics learning to developing conceptions of science.

1.8 Limitations and scope of the study

The students in the study were first year physics students at the University of the Witwatersrand. The students were in my tutorial group and it was easy for me to use them for my study. I believed that for this study to be successful I really needed students who were willing to participate, hence I only worked with those students who volunteered to participate in the study. Thus there were five students who participated from beginning to end of the study and a larger study may have uncovered greater variation than that discovered by myself. On the other hand the analysis was extremely time consuming and complex and a larger group of students may have led to important variation differences being overlooked. And although the case studies are also small, I believe the theoretical insights revealed will contribute to theoretical developments in phenomenography. A final limitation is that the study focused only on Newtonian dynamics concepts.

1.9 An outline of the thesis

This chapter has introduced the reader to the study and has given the background against which it is undertaken. The significance of the study has been highlighted. Most importantly, the research questions have been stated. The limitations and scope of study have been discussed. The general layout of the thesis is given below.

The figure below gives a concept map of the thesis outline. The circles give the chapters and the rectangles the relationship between chapters.

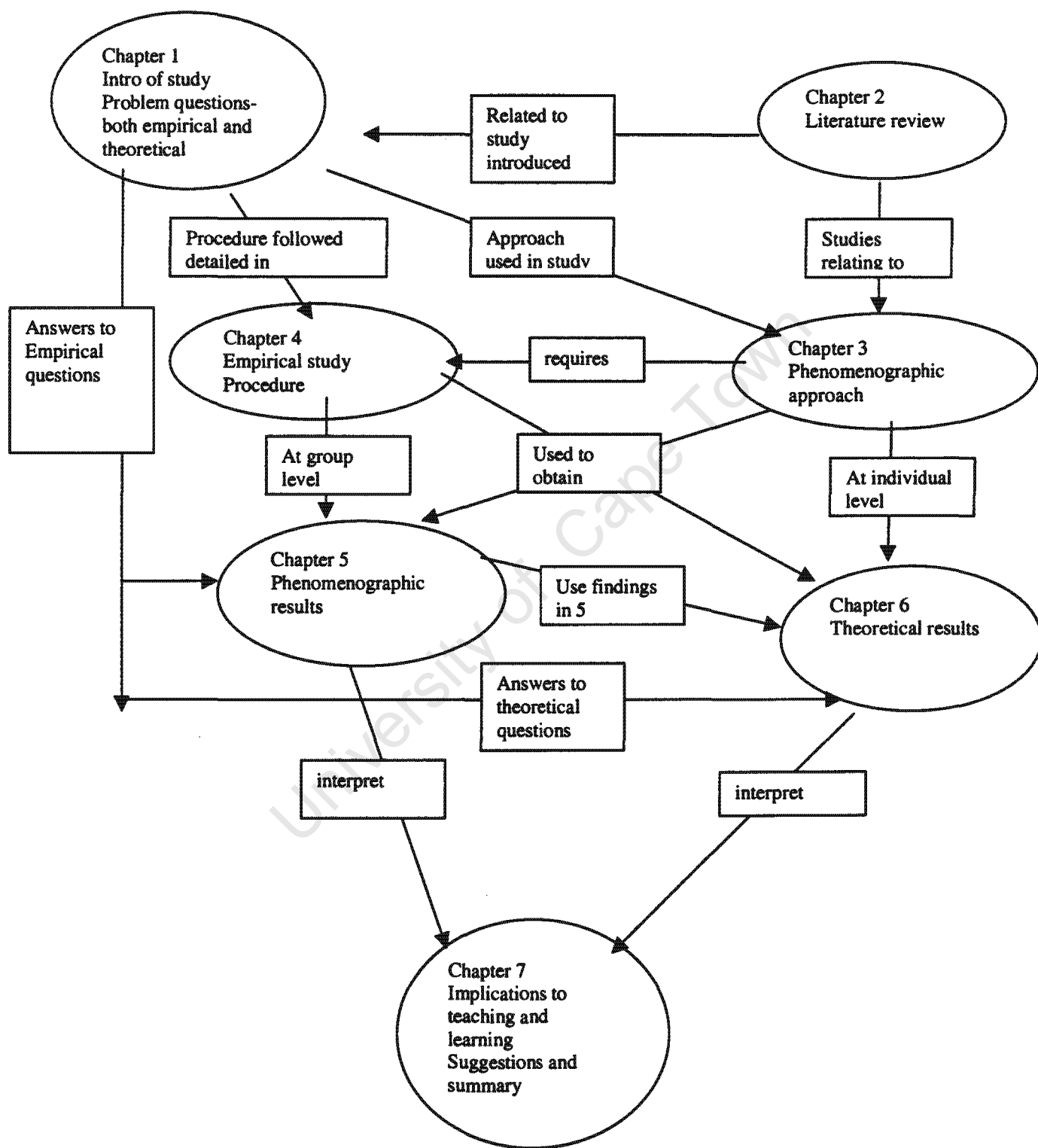


Figure 1.1 *Concept Map for thesis outline*

Chapter 2 provides a review of literature that guided the study. The key elements of the framework for the study are understanding, conceptualisation, and experiences. The background is essentially phenomenographic perspective on learning. Everyday and scientific knowledge is discussed. Concept mapping is also discussed as it is used in data gathering. Research on alternative frameworks is also discussed as it shows the vast amount of work and interest researchers have in science learning at undergraduate level. Phenomenographic studies are also discussed.

Chapter 3 gives a description of a phenomenographic approach. It introduces the reader to the notion of phenomenography as a research perspective. It describes the implications for collecting data in a phenomenographic perspective. It also looks at the analysis and results obtained by phenomenographic means. It discusses issues of reliability and validity in a phenomenographic approach.

Chapter 4 describes the empirical study. It gives a detailed account of the procedures followed in data collection, analysis and how both phenomenographic and theoretical results are obtained.

Chapter 5 publishes phenomenographic results at a collective level and discusses them. In the last part of this Chapter a statistical method is used, the results of which lead to a case study in Chapter 6.

Chapter 6 provides the theoretical results at individual level (a case study). Differences are identified from the categories of description and from the study-provided contexts and the implications of the differences to teaching are discussed.

Chapter 7 summarises the study and discusses implications for teaching and learning. It also suggests topics for further study.

The appendices contain the following supporting information:

Appendix A: Concept map problems given to the students to draw their maps from

Appendix B: Concept maps drawn by students

Appendix C: Interview transcripts on links drawn in concept maps

Appendix D: Chi-square calculations done to find if there is any correlation between categories of description and study-provided contexts

Appendix E: Detailed mappings of the distribution of categories of description for each student in different contexts.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The broad aim of the present study is to investigate students' experience of Newtonian dynamics conceptual links. In this Chapter I look at the literature that is related to and that helped in shaping my study. I first look at possible links between science and everyday knowledge. I also look at how everyday concepts shape the way students construct scientific knowledge. There is also a need to survey literature on understanding, since the main focus of this thesis is to study how students conceptualise or understand or experience links between basic Newtonian dynamics concepts. This construct, understanding, is used by many of us, and we often mean different things in different contexts.

The other important survey is on students' alternative frameworks about Newtonian dynamics concepts. This is an important section of the study since it gives us a review of other similar studies that have been carried out. However, in these studies, researchers were looking at students' conceptualisation of Newtonian concepts as alternative frameworks or preconceptions, and not seeing the world through the students' eyes. It is also important to look at studies that used the 'phenomenographic' perspective, as this approach is adopted in this study. I also find it necessary to look at concept mapping literature, as concept maps were used in gathering of data for the study. Finally, I find it necessary to look at the implications of all these to teaching, since the findings of this study will be of great importance to teachers as they will give guidance to some

possible conceptualisations or understanding students hold about basic Newtonian dynamics conceptual links. I believe all of these areas are worth reviewing as they are collateral to my own area of study.

In the next section I look at how possible links between everyday knowledge and scientific knowledge relate to the way students construct knowledge today.

2.2 Everyday knowledge and scientific knowledge

Scientific knowledge is generally against everyday knowledge. Wolpert (1993) in his book, "The unnatural nature of science" argues that generally science is counter-intuitive and against common sense – by which he says he means that scientific ideas cannot be acquired by simple inspection of phenomena and that they are very often outside everyday experience. He says science does not fit with our natural expectations. He states that "science always relates to the outside world, and its success depends on how well its theories correspond with reality" (p.2). He says that persistence of thinking in terms of impetus over the three hundred years since Newton, shows how difficult it is to assimilate a counter-intuitive scientific idea. He continues to say that there are rare exceptions to the rule that scientific ideas are contrary to common sense. Generally, the way in which nature has been put together and the laws that govern its behaviour bear no apparent relation to everyday life. Wolpert (1993:6) contends that "the laws of nature just cannot be inferred from normal day-to-day experience". He adds that understanding science is a hierarchical process: it is extremely difficult to understand the more advanced concepts until the basic concepts have been mastered. Hence the focus of this study is on basic Newtonian dynamics concepts as the author sees these as building blocks of science.

Scientific concepts are, in many respects, similar to the 'lay concepts' used in everyday life. Reif (undated) states that scientific and mathematical concepts are significantly different from everyday concepts and are notoriously difficult to learn. He further argues that the thought processes required to interpret scientific concepts are significantly different from those needed to deal with everyday concepts. He continues to say that there are numerous special concepts such as 'acceleration', 'force', 'derivative', etc. which are introduced in science or mathematics as building blocks of conceptual structures designed to explain or predict a wide range of phenomena. He says the ability to interpret and use such concepts is an essential prerequisite for solving problems in scientific fields.

The study is however, not focusing on problem solving but is attempting to foster appreciation of concept interpretation in different domains of applicability. Reif (1985) states that in quantitative sciences, such as physics, special concepts and associated principles are logically the basic blocks of the knowledge used to deduce important consequences, make predictions, and solve problems.

The emphasis in this thesis is not only on what conceptions are exhibited by students, but also on how they think and use their knowledge to arrive at their interpretations. Reif (undated) says that the effective interpretation of a scientific concept depends ultimately on the larger scientific knowledge structure within which the concept is embedded. He says a new scientific concept is formally defined in terms of other previously defined concepts and/or in terms of certain primitives. He however, states that the initial introduction of the concept is motivated by particular characteristics of a larger scientific knowledge structure. He further mentions that the validity and utility of a scientific concept are ultimately determined by the extent to which the concept contributes to an

overarching knowledge structure which is internally consistent – and capable of parsimonious and correct inferences about all the phenomena which it is intended to describe. He further states that a concept is usually related to kinds of other knowledge in a larger structure such as:

- “Primary concepts in terms of which the concept is formally defined e.g. acceleration, the primary concepts include velocity and time.
- Implications of the concept’s definition for special cases and for the properties of the concept e.g. Cases of motion along straight line and along a curved path.
- Implications and principles which relate the concept to other concepts e.g. Newton’s 2nd law” (Reif, undated).

Reif (1985) argues that “fragmentary knowledge constitutes ‘intuitive scientific knowledge’ which facilitates concept interpretation by recognition or analogical processes which are quick and effortless (although lacking the precision and coherence of more explicit interpretations)”. He however, contends that the utility of this knowledge depends crucially on the extent to which it is consistent with formal scientific concept specifications and is adequately discriminated from other intuitive knowledge (e.g. everyday knowledge) which may be inconsistent with it.

Students’ personal experiences influence their belief systems and intuitions. This has been confirmed by many studies such as, Halloun *et al*’s (1985) study, “The initial knowledge state of college physics students”. They argue that each student entering a first course in physics possesses a system of beliefs and intuitions about physical phenomena derived from extensive personal experience. They go further to state that the “system functions as a *common sense theory* (authors’ emphasis) of the physical world which the student uses to interpret his experience,

including what he uses and hears in the physics course” (p.1043). The students’ initial knowledge of Newtonian dynamics is most critical to his course performance, since the first course in physics is concerned mainly with Newtonian dynamics. I restrict attention in this study to that domain of physics. Halloun *et al* (1985) state that it is the discrepancy between common-sense concepts and the Newtonian concepts which best describes what the student needs to learn. They continue to say that the physicist’s intuitions about motion have mathematical counterparts, but the same cannot be said about the common sense intuitions of students. They mention that in everyday life the term ‘force’ is used in a chaotic variety of contexts – police force, economic force, etc. – often with vague and ambiguous associations. Thus, it is to be expected that novice Newtonian dynamics students are prone to use the term ‘force’ loosely for a variety of different concepts, some of which are not even dynamical. This study attempts to encourage students to realise and appreciate the different meanings of concepts in different contexts. I will now look at knowledge and its evolution.

2.3 Knowledge and its evolution

A constructivist view of learning is that knowledge is constructed and not discovered. Gowin and Novak (1984) argue that learning about the nature and structure of knowledge helps students to understand how they learn, and knowledge about learning helps to show them how humans construct new knowledge. They continue to state that construction of new knowledge allows us to enhance or alter the meanings of those concepts and principles, and to see new relationships between them. Incidentally, White (1988) states that August Comte’s (1855) opinion was that “A science cannot be completely understood without a knowledge of how it arose” (p.52).

Gowin and Novak (1984) argue further that construction of new knowledge begins with our observations of events or objects through the concepts we already possess. They contend that concepts, events or objects and records of events (all called facts) – come together and are intimately intertwined as we try to make new knowledge. They go on to argue that concepts and propositions composed of concepts are central elements in the structure of knowledge and the construction of meaning.

They believe that culture is the vehicle through which children acquire concepts that have been constructed over centuries; schools are relatively recent inventions for (we hope) accelerating this process (Gowin and Novak, 1984). This idea is supported by Moetsana's (1993) findings that language, culture and reduced mediated learning experience contribute toward the cognitive deficiencies students have in learning. These studies did not however, explore the students' experiential reality.

In the evolution of science Kuhn (1970) argues that new knowledge would replace ignorance rather than replace knowledge of another and incompatible sort. He states that scientists, by discarding some previously standard beliefs or procedures and simultaneously, by replacing those components of the previous paradigm with others, are able to account for a wider range of natural phenomena. Marton (1988) states that a standard scientific approach demands you to try to explain what is visible in terms of what is not. He continues to say that the different ways in which we understand the world around us are – as a rule – invisible.

2.4 Understanding, conceptualisation or experience

This study concerns itself with the understanding or conceptualisation or experience of links made between basic Newtonian dynamics concepts. Understanding is a complex term which can not be easily defined. For the

purpose of this study the terms understanding, conceptualisation and experience are taken to mean the same thing. In this context, I will take understanding to be a characterisation of a way of experiencing something. With this definition in mind let us now look at how other people define or take understanding to mean.

White (1988) argues that understanding is so valued, but the term is not well-defined. He further states that understanding can be defined as the ability to use knowledge, to cope with situations. He defines understanding in terms of elements of memory and their pattern of association. He says that part of the difficulty in defining understanding is that it takes on different meaning depending on the scale and nature of what is to be understood. He argues that part of the difficulty of defining understanding is that the word is also used to refer to a state of mind, a feeling of mastery, and to a process, the act of comprehending.

White and Gunstone (1992) contend that the person's understanding develops as new elements are acquired and linked with the existing pattern of associations between elements of knowledge. They argue further that understanding of the concept is a function of the set of knowledge. They mention that broadly, understanding improves as the amount of knowledge increases and as the various elements in it become more intensively linked with each other. They say the quality of understanding will depend on the proportions of the different types of knowledge. They think that a number of facets of knowledge are involved in understanding. The more the person knows about a concept, the better the understanding. They argue that integration is a key quality of understanding. They say the more extensive the interlinking of various statements, the better the understanding.

'Understanding' is referred to by Marton (1988) as the way in which the phenomena are discerned and apprehended. This definition is adopted in the study. He states that students in schools and universities today may very well state the correct relationship between velocity and force in response to a question in which those aspects are indicated, whereas in their everyday lives they would not be likely to focus on those aspects at all. He continues to say that this is exactly what is meant by the claim that while students learn to make Newtonian statements and to apply Newtonian procedures in school they may still retain an Aristotelian way of understanding the world around them. Marton (1988) states that both the skills and the knowledge related to a phenomenon rest on – or, rather, should rest on – a particular way of understanding that phenomenon. He says it is in this sense that he wants to argue that there is a competency, simply labelled 'understanding', which is different from and more fundamental than the two other kinds of competencies, commonly referred to as skills and knowledge.

Marton (1988) continues to say that we must instead speak of understanding in a dispositional sense: when encountering (or thinking about) a phenomenon the individual has the capability of understanding it in a certain way (or rather: in some certain ways). In accordance with this, he argues that we should speak about someone being capable of carrying out mental acts, rather than about someone having mental models.

White (1988) put forward the view that there is no central core of knowledge, which is essential to the understanding of a discipline or even of a concept. He states that understanding of a concept or of a discipline is a continuous function of the person's knowledge, is not a dichotomy and is not linear in extent. He goes on to argue that to say whether someone understands is a subjective judgement which varies with the judge and with the status of the person who is being judged. He argues further that

that is not to say that all knowledge is of equal value or relevance in understanding; the judgement of that relevance must, however, be subjective. He says that just as it was not possible to specify the essential elements for understanding of a concept or a discipline, it is not possible to say which elements must be part of the constituent concepts in a proposition for it to be understood.

White (1988) argues that it is not just the amount of knowledge that matters, the nature of the knowledge and the patterns of association between elements are important too. He argues further that naturally greater knowledge tends to engender greater understanding. He goes on to mention that the relative proportions of strings, propositions, skills, images and episodes affect the quality of understanding.

White (1988) contends that if we know what we mean by understanding, we have some chance of teaching for it effectively. He goes on to mention that there is also some value in thinking about the overt consequences of understanding, because they will suggest how we can test whether students have good patterns of knowledge or have comprehended what we tell them.

Trowbridge and McDermott (1980) in their study on "The investigation of student understanding of the concept of velocity in one dimension" suggest that an important distinction must be made between the understanding of a concept by a member of the physics community and the understanding which is characteristic of individual students. The authors consider as an indicator of degree of understanding the extent to which a student's understanding corresponds to that of an expert, i.e. the extent to which the student can define a particular concept in an acceptable operational manner, distinguish it from related but different concepts, and apply it successfully.

The present study makes use of concept maps as a way of eliciting conceptual links. From the concept maps categories of description are formed, which give possible ways of understanding these links. Concept maps are described in the next section. The 'phenomenographic' perspective is adopted to be able to arrive at these categories of description. Phenomenographic perspective is described briefly in Section 2.6 below.

2.5 Concept maps

In this study students were asked to draw concept maps in order to elicit links between concepts. Students were interviewed about the links they made in order to have a clear understanding of their conceptualisation of the links. The purpose of the use of concept maps in this study is to explore understanding of limited concepts in Newtonian dynamics. The theme of the concept map or sometimes the choice of the concepts to be mapped directs the focus of the probe.

White and Gunstone (1992:15) argue that a concept map aims to show how someone sees the relations between things, ideas, or people. I have decided to use this technique because it will elicit how students link basic Newtonian concepts and how students see the structure of a large topic. White and Gunstone (1992) argue that students may know individual facts but not know how they fit together. They emphasise that the concept maps focus more specifically on the structure and linking that the student perceives. Hence the mapping is a means of eliciting the relations each student perceives between concepts.

White (1988:66) refers to the concept maps technique as a measure of understanding of, if not a whole discipline, at least a large topic within

one. Gowin and Novak (1984) claim that concept mapping is a technique for externalising concepts and propositions. They state further that we may develop new relationships between concepts in the process of drawing concept maps. Thus, they conclude that concept mapping can be creative and may help to foster creativity. Gowin and Novak (1984) found it helpful to think about concept maps as tools for negotiating meanings.

Because concept maps represent specific propositional links between concepts, Gowin and Novak (1984) state that they are relatively precise indicators of the extent to which a person's concepts have been differentiated. They believe that concept maps are a simple tool for assessing where the students are. White and Gunstone (1992) state that this procedure tells much about the quality of the students' learning. They go further to say that it also reveals the understanding present amongst the students and hence tell much about the effectiveness of the teaching.

White and Gunstone (1992) also argue that concept maps appear best suited to probing understanding of a whole discipline, or at least a substantial chunk of one. They state that since the maps elicit the relations students see between concepts that make up a topic, naturally they reveal something of the understanding that the students have of the individual concepts as well as of the whole topic. They conclude that concept mapping will reveal whether the patterns of relationships and actions are understood.

The concept maps are used in the present study as a basis for in-depth interviews needed for the phenomenographic approach. In the next section I discuss phenomenography and phenomenographic studies.

2.6 Phenomenography and phenomenographic studies

A large number of studies following a phenomenographic approach have been conducted. Some of these studies have dealt with the content of learning and studied people's conceptions in various content domains. For example, Theman's (1983) study on conceptions of political power; Neuman's (1987) study on young children's conceptions of number; Booth's (1992) study on learning to program; Pong's (2000) study of economics students' understanding of the concept of price in economics; Linder's (1989) study of tertiary physics students' conceptualisation of sound; Cope's (2000) study on educationally critical aspects of the experience of learning about the concept of an information system; and many other studies. In all of these studies the researchers found that there is a finite number of ways of experiencing a phenomenon.

The study conducted by Dahlgren (1978) with university economics students revealed that students' conception of each principle, before as well as after their studies in economics, could be described in terms of a limited number of categories, denoting qualitatively different ways of comprehending the particular principle or concept. This difference can thus be regarded as a measure of the effects of education in this respect. Bowden *et al* (1998) explored student understanding of fundamental concepts in kinematics using the phenomenographic research method. They have found from their study that it is possible to describe a number of different ways in which senior high school and junior university students understand particular physics phenomena.

In his study on comprehending text Säljö (1982:195) concluded that "learning difficulties can be conceived of as resulting from and reflecting the mode of organising knowledge that is used in the particular cultural environment in which the learning takes place". Säljö (1982) also

concluded that just as the kind of text used in his study “is the product of a certain scientific community’s ideas and assumptions about what characterises knowledge, we are inclined to conceive of the difficulties in understanding which some participants show not as indicative of a lack in their intellectual capacities, but rather as revealing an inadequate familiarity with the premisses according to which this community organises knowledge”(p.195-196).

Phenomenographic studies have also investigated learning approaches in many different situations. Marton and Säljö, (1976); Svensson, (1977) have looked at students’ approaches to learning when reading a text; Hodgson (1984) investigated students’ learning approaches in lectures. In these studies two approaches to learning were found, surface approach and deep approach. Bowden and Marton (1998) have argued that an approach to learning is a relation between a student and the phenomenon being learned in a particular learning context. Ramsden (1984) adds that in different learning contexts the same student has been found to take different approaches to learning about the same phenomenon. In this study the different approaches of understanding are also discussed (see Section 7.3.1).

Recent studies have extended phenomenography to theoretical concerns. These studies are looking at how a way of understanding or experiencing evolve, for example, Pong’s (1999) study on “The dynamics of awareness”; Pong and Marton’s (2001, in press) study on “Conceptions as ways of being aware of something”. In these studies there was evidence of inter and intra-contextual shifts. And in most cases a shift in focus was followed by a shift in meaning. The present study also looks at these kinds of shifts. Other studies have looked at the influence of context in the way phenomena are experienced (for example, Adawi, *et al*, 2001, in press, Linder and Marshall, 2001, in press). Context plays a major role in

the present study, and its influence in ways of experiencing phenomena is discussed in detail in Chapters 6 and 7.

Phenomenography is a perspective that reveals educationally critical differences in our understanding of the world around us. In this study I have adopted the phenomenographic approach to be able to form categories of description about students' understanding of links between basic Newtonian dynamics concepts. The categories of description will give a qualitatively different ways of understanding or experiencing a phenomenon. Phenomenography as Marton (1981), the father of phenomenography, defines it, aims at description, analysis and understanding of experiences. Phenomenography is described in detail in Chapter 3.

In the following section I discuss literature on conceptions and conceptual change. Since in the present study I look at students' descriptions categorised in terms of conceptions, or ways of experiencing, and also look at patterns of shifts that emerge for the individual students, I find it necessary to discuss conceptions and conceptual change.

2.7 Conceptions and conceptual change

The view that learning happens when conceptual change occurs – i.e. models which include as a goal, having students give up one conception and adopting an alternative - has been challenged by Linder (1993). Many other researchers have supported Linder's view that students are capable of constituting multiple conceptions (for example, Svensson, 1989; Linder, 1989; Pong, 1999; and Linder and Marshall, 2001, in press).

Mortimer (1995) took the challenge on conceptual change further by drawing an overview of a model to analyse conceptual evolution in the classroom, based on the notion of a conceptual profile. This model differs from conceptual change models in suggesting that it is possible to use different ways of thinking in different domains. His model differs from some of the constructivist models of learning by showing that the process of construction of meaning does not always happen through an accommodation of previous conceptual frameworks, in the face of new events or objects, but may sometimes happen independently of previous conceptions.

The present study looks at students' different ways of understanding conceptual links in different domains of applicability. The ultimate goal is for students to appreciate the different domains of applicability.

In the next section I will discuss studies on students' alternative frameworks.

2.8 Research on students' alternative frameworks or preconceptions about Newtonian dynamics

Since this study is also concerned about basic Newtonian concepts, I find it worthwhile to look at studies made on students' alternative frameworks in Newtonian dynamics. The conceptual categories arrived at in this study will shed some light on how these alternative frameworks relate to the way students see the world around us.

There is an enormous body of literature that concerns itself with the difficulties encountered in learning specific science concepts. More evidence for the existence of alternative frameworks concerning the basic

notions of Newtonian dynamics at all levels of schooling is found in many studies.

In the research conducted by Zhaoyao (1993), students' responses showed that experience had not only resulted in pre-instruction views but has also brought about modes of thinking. These experiences play an important part in students' learning of Newtonian dynamics. Zhaoyao (1993) believes that this may be why it is more difficult to change students' beliefs in Newtonian dynamics than in any other aspects of science.

McDermott (1984) reports that many able students, including future teachers and physics graduates, display alternative frameworks and misunderstanding about force. She says that difficulties with usage and meaning of the term 'force' have been documented with other populations besides college students.

A review of research work on similarities of research done by different people reveals some of the responses given by students on force and motion. Gunstone and Watts (1985) state that students' perception about forces is that forces are to do with living things. Often students believe that constant motion requires a constant force. Furthermore, Gunstone and Watts (1985) report that students believe that the amount of motion is proportional to the amount of force. They report further that students believe that if a body is not moving then there is no force action on it. Moreover, if a body is moving then there is a force acting on it in the direction of motion (see also Gamble 1989).

Clement (1982) gathered data from written tests and videotaped problem solving interviews, and these showed that many physics students have a stable, alternative view of the relationship between force and acceleration. He found that students often include a force in the direction of motion,

'motion implies a force' preconception. He reports that it is difficult for students to think about an object continuing to move in one direction with the total net force acting in a different direction. He also found that students usually show the direction of motion changing instantaneously in a noncontinuous manner, apparently to correspond to instantaneous changes in the direction of applied force. He also reports that students believe that a force 'dies out' or 'builds up' to account for changes in an object's speed (see also McDermott 1984). In most studies it was found that the relatively high percentage of college students maintain their intuitive conceptions despite instruction.

Watts (1983) in his study found that a conception common to a broad group of students is that forces are obligations to complete an action against some resistance. For example, if you hit the ball it has to go up. This is very much the everyday meaning, to force someone or something to act. Throughout the interviews that he made it was common for the pupils to treat force as a single entity, rather than an interaction between bodies. It is evident that the students understood forces in a different context from that of their interviewer.

Watts (1983) also reported that force is seen as a property of collisions – force happens when things collide. It has strong similarity with the physicist's notion of momentum in elastic and inelastic collisions. He goes further to report that the other common alternative framework formed by the students was that forces are required to cause and maintain motion. It is evident that some of the students do consider the force - causing motion to be the resultant force. Others make no distinction between a force and a resultant force. Watts (1983) reports that the other part of this framework gives the impression that motion occurs when there is an imbalance of force. The other part of the framework is that if motion is

caused by a force and that force acts along the line of motion and that when the force stops so will the motion.

Aguirre and Rankin (1989) state that the interpretations of their results were that in some cases students failed to understand the formal explanation because they appear to be counter-intuitive; in other cases students could hold both the correct or expert's conception and their own. Students use the former for schoolwork and the latter for practical out-of-school situations.

In Watts' (1983) study, forces are seen to be used up. This framework is very similar to the physicist's notion of energy. Viennot (1979) argues that although the concept of energy is sometimes used correctly, (especially in connection with potential energy) in other situations it is inextricably mixed with the concept of force in a single undifferentiated explanatory complex.

Watts (1983) argues that it also seemed difficult for students to conceive forces acting-at-a-distance and they describe forces as necessarily having a medium to act through. A force is seen as an actual event, and is presented as a physical presence, a positive, large entity. It is rather similar to a physics notion of pressure. He further states that like the word power, force has a suggestion of something overwhelming.

Brown (1989) in his study of the importance of understanding Newton's 3rd law found that students have a naive view of force as a property of objects. The data from Brown's (1989) study support the hypothesis that the persistence of alternative frameworks concerning the 3rd law may result from students' general naive view of force as a property of single objects rather than a relation between objects.

Trowbridge's (1979) study shows that many students do not really discriminate between position and velocity when confronted with actual motions. Trowbridge and McDermott (1980) report how college students in an introductory physics course were unsuccessful in using the concept of velocity in real physics situations, although they were able to give an acceptable definition of it. Another difficulty that Trowbridge (1979) found is that often students fail to discriminate qualitatively and intuitively between velocity and acceleration in simple situations. This failure partly results in the well known students' difficulty which concerns the situations at the end of the swing of a pendulum or at the top of the flight of a ball thrown vertically upward – the instantaneous velocity = 0, but the acceleration is not.

Aguirre and Rankin (1989) carried out a research to identify first year college students' perceptions regarding several vector characteristics. They found that about 50% of the students held views consistent with the physicists' approach when dealing with orthogonal components. They assumed that the problems encountered by the other half could possibly be due to the fact that the students did not really grasp the concept of independence of direction when composing simultaneous orthogonal velocities and maintained their intuitive view. McDermott (1984) found that a lack of understanding of the concept of a vector and an inability to apply the rules of vector algebra to the situation at hand were significant problems for many students.

McDermott (1984) in her research on conceptual understanding in Newtonian dynamics found that students could not distinguish clearly between the concepts of speed and position. McDermott *et al* (1980) in their study, "Helping minority students succeed in science", found that between 50% and 100 % of students initially confuse the concepts of speed and position. McDermott (1984) also reports the students' inability

to make connections between kinematical concepts and their graphical representations. She concluded that not only does a word, such as force or acceleration, have a meaning in physics different from its everyday meaning, but the same word is frequently used indiscriminately by the layman for concepts that are clearly distinct to a physicist, e.g. 'force' and 'momentum' are used interchangeably by students. McDermott *et al* (1980) also found that there is lack of connection between reality and representation among students.

Trowbridge and McDermott (1980) report that students in an introductory physics course are likely to have a wide variety of somewhat vague and undifferentiated ideas about motion based on intuition, experience, and their perception of previous instruction. They point out that a student expresses the belief that when two objects reach the same position they must have the same speed; and he/she (student) also associates being ahead with being faster. They also found that students associate the idea of being ahead with having a greater speed. They report that students have difficulty distinguishing between the ideas 'reach the same speed' and 'reach the same place'.

They further report that students also have difficulty in separating the concepts of velocity and position at a particular instant. They say that this difficulty is related to the problem students have with extending the concept of speed over a finite interval of time to the case of an infinitesimal time interval. The authors found an indiscriminate use of nondifferentiated protoconcepts (i.e. confusion between velocity and position). They point out that the principal conceptual difficulty demonstrated by students' participation in the study was an inability to discriminate between position and velocity.

White and Gunstone (1992) found that students who came to learn about Galileo's and Newton's laws of motion were found to adhere to Aristotelian views such as velocity rather than acceleration being proportional to force and hence that if something is moving there must be a force on it. McDermott (1984) found that students often hold simultaneously both Newtonian and non-Newtonian conceptions of force. She concludes that 'Aristotelian' or 'medieval' belief systems that have often been suggested as the source of student difficulties with dynamics seem inadequate to account for errors made in these more complicated situations. Thus, the present study is investigating the qualitatively different ways in which students experience or conceptualise Newtonian dynamics conceptual links; and also advocates the appreciation of the context in which the links are experienced or understood.

I will now look at the impact of all these on teaching.

2.9 Implications for Teaching

Many researchers have suggested that understanding that students bring to the learning of Newtonian dynamics is firmly held and difficult to change. Since many concepts in Newtonian dynamics are often used in everyday work and life, people often understand them according to their own experience. McDermott (1984) concluded from her research on conceptual understanding in Newtonian dynamics, that the persistence of difficulties suggests that they are not easily overcome, and need to be addressed explicitly during instruction.

Clement (1982) states that it should be remembered that historically, pre-Newtonian concepts of dynamics had a strong appeal, and scientists were at least as resistant to change as students are today. He gives an example of Galileo's explanation in his manuscripts *De Motu*, that "the impressed

motive force is greater than the resisting weight” is similar in many ways to the students’ explanations, e.g. one student said: “force of the throw ... overcoming the force of gravity”, another said, “upward original force ... is greater than the gravitation”.

Marton (1981) argues that if we think of the content of learning in terms of what is in the students’ minds rather than what is in the textbook, it clearly seems preferable that the content of learning should be described from a second-order (or experiential) perspective. This view is based on the argument that the question of content of learning does not necessarily concern the *correct* (author’s emphasis) meaning of the concepts but rather the meaning the students put into the concept. Marton (1981) also quotes Bohm (1980) who has argued against restricting attention to *correct knowledge* only. Whatever an individual feels that he knows contributes to his actions, beliefs, attitudes, modes of experiencing, etc.

Marton (1981) argues that the conceptions held by the students – as a rule – differ from those which the author of the textbook or teacher is trying to make the students acquire (construct). He says this discrepancy is certainly there during the learning process and it is not infrequently there too when the class has to proceed to the next topic. He says if we accept the thesis that it is of interest to know about the possible alternative conceptions students may have of the phenomena or the aspects present in, related to or underlying the subject matter of their study, it is these questions specifically which we must investigate. Marton (1981) states that if there is a common structure underlying the ability to handle different concepts and different contents, we should expect certain homogeneity of behaviour across tasks that have this structure in common.

Marton (1988) says if we can determine children’s ways of understanding the problem, their answers will be explained, in the sense that they will

appear comprehensible to us. He goes further to say that we have to explore and describe the children's experiential reality, we have to explore and describe a particular phenomenon as experienced or understood by them. He argues that when we aim at an experiential description we are trying to look with them (and see the world as they see it).

McDermott *et al* (1980) in their paper "Helping Minority students succeed in science", found that many of the problems exist among first, second and third year students in university indicate that the time and the university environment alone cannot be relied upon to solve them. They advise that what is needed is instruction in which concrete experience and individual attention foster the development of intellectual skills, study habits, and self-confidence along with subject matter understanding. They suggest that the approach to instruction should entail addressing concept formation and reasoning development together. They believe that concept formation and reasoning development are mutually dependent and must be addressed together. They go on to suggest that proper formation of a concept cannot be fully realised unless the associated reasoning is thoroughly stressed. Conversely, they believe that development of reasoning skills cannot be fully realised unless these skills are applied to significant subject matter which is part of a cohesive body of knowledge.

McDermott *et al*'s (1980) experience has strengthened their conviction that for students whose reasoning skills are not yet fully developed, scientific concepts should be introduced in the laboratory or tutorials. They say many students initially do not distinguish between naming and understanding a concept. Thus, the authors introduced technical terms only after the ideas behind them have been explored.

McDermott *et al*'s (1980) study showed that students have limited ability to transfer reasoning to new contexts. They argue that the difficulty with

analogies has strong implications for instruction aimed at developing reasoning skills. They say that work on reasoning must continue as new concepts are presented. They argue further that failure to provide opportunities to confuse the concepts may leave them undifferentiated in the minds of many students. The authors consider the specific choice of subject matter in the courses to be of secondary importance to the stress on reasoning and concept formation. They argue that coverage of subject matter is reduced to allow the students time to acquire a thorough understanding of basic concepts and to become engaged in the reasoning that is associated with a particular concept.

McDermott *et al* (1980) point out that among the most important are the emphasis on the laboratory or tutorials, the stress on reasoning, the role of examinations, the use of homework, and the increase in challenge as the courses progress. In their study, the curriculum designed has adopted instructional strategies to match the capabilities of the students. They argue that the ability to reason clearly, to connect representations with reality, and to draw analogies are also required in many other fields.

Arons (1981) argues that didactic explanation and a concentrated remedial exercise do not help the majority of students overcome a cognitive difficulty. Much greater success is achieved through providing students with repeated opportunity, in slightly different situations, to trace the line of reasoning and articulate it in their own words, either orally or in writing. In his experience, we need four or five repetitions, in altered context and spread over a period of weeks to engender stable control of the reasoning in a substantial majority.

Trowbridge and McDermott (1980) argue that students bring to the formal study of physics an intuitive sense of the meaning of common concepts associated with motion. They say that these protoconcepts generally lack

precise operational definitions which enable them to be distinguished unambiguously one from another and to be assigned definite numerical values. They go further to state that although inadequate for a description of motion in the physicists' sense, terms like speed and acceleration nevertheless have commonly shared meaning in everyday life.

Clement (1982) states that the quotations from Galileo's manuscript *De Motu*, in explaining the motion of an object thrown upwards, indicate that real conceptual change in kinematics is an extremely difficult task that should not be underestimated. Clement (1982) argues that the diversity of situations in which this preconception, force 'dies out' or 'builds up', surfaces suggests that it is a major source of the difficulties encountered by students in understanding the physical principles associated with the equation $F = ma$. He goes on to say that the results of the same test that was given to freshers, somophores and senior students supported the hypothesis that for the majority of these students, the 'motion implied a force' preconception was highly resistant to change. He continues to say that this conclusion applies to the extent that the students could not solve basic problems of this kind where the direction of motion does not coincide with the direction of the net force.

Clement (1982) reports that the findings of his research suggests that it may be necessary to devote more attention to fundamental principles underlying the Newtonian view than is currently practised, and that teaching strategies limited to expository presentation may be unlikely to succeed in this area. He advises that preconceptions need not however, be viewed exclusively as obstacles to learning. He says preconceptions can be thought of as 'zeroth-order models' that the students possess; models that can be modified in order to achieve greater precision and generality.

Trowbridge and McDermott (1980) advise that the concepts of motion deserve special attention since Newtonian dynamics comprises a major part of the content of virtually every introductory physics course in both high school and college. In exploratory interviews the authors found that students with no previous study of physics, thought of the word 'speed' as a relation between the distance travelled and the elapsed time but not necessarily as a ratio. They report that the word 'accelerates' was also generally used in its primitive sense, i.e. to indicate that an object 'speeded up'.

Clement (1982) found that questions about the direction and relative magnitudes of forces, velocities, and accelerations at different points of the motion are quite challenging to introductory students. He states that in the absence of formulas to 'plug into', such questions are an effective way of getting students to think about their own preconceptions. He suggests that many of the concepts presented in this area of force and motion must displace or be remoulded from stable intuitive concepts that the student has constructed over a number of years.

Trowbridge and McDermott (1980) interpreted the students' belief that when one object has 'caught up' to another object, they must be going at the same speed, as indicating that these students lack an adequate procedure for deciding when two objects have the same instantaneous speed. They say instead students focus attention on the perceptually obvious phenomenon of passing to make the required comparison. They argue that a successful comparison usually requires that an individual focus attention on the separation between the objects and identify an instant when this separation is neither increasing nor decreasing.

Trowbridge and McDermott's (1980) study has shown that prior to instruction the student typically has a repertoire of procedures, vocabulary,

associations, and analogies for interpreting motion in the real world. The authors say these taken together, may be considered as a set of protoconcepts which antedate understanding of the concepts of kinematics. It has been Trowbridge and McDermott's (1980) observation that for some students the acquisition of physical concepts seems to depend strongly upon the establishment of satisfactory connections between these new concepts and the protoconcepts with which the student is already familiar. They suggest that a conscious effort should be made to try to help students relate physical concepts to their experience.

It was apparent throughout Trowbridge and McDermott's (1980) investigation that the use by students of technical terms did not necessarily correspond to a physicist's understanding of how these terms differ from one another and of how they relate to physical experience. They advise that the relationship between the use of technical vocabulary and the understanding of physical concepts needs to be examined carefully. They say however, just as it would be a mistake to assume that all misuse of technical vocabulary reflects lack of understanding, it would be equally erroneous to dismiss without careful probing ambiguous use of technical vocabulary as mere carelessness. The authors have found that the inability to discriminate between related concepts often accompanies the indiscriminate use of technical vocabulary.

McDermott (1984) found that her study provided striking evidence that a student's ability to define a concept properly and to apply it in standard physics problems does not necessarily imply that the student can apply this concept correctly to an actual situation. Marton (1988) argues that students may very well express themselves as Newton did and they may carry out calculations consistent with the way Newton did, while still seeing the phenomenon they are talking about, or making calculations on, in the same way as Aristotle did, but Newton did not.

McDermott (1984) says it has become increasingly clear that many students emerge from their study of physics or physical science without a functional understanding of some elementary but fundamental concepts. Her particular concern is the apparent failure of universities to help precollege teachers develop a sound conceptual understanding of the material they are expected to teach. She concludes by saying that if the development of conceptual understanding is a primary goal, then instruction must reflect this priority.

Marton (1988) states that in order to develop teaching methods which are reasonably effective in bringing about changes in the understanding of various phenomena we have to start by revealing the nature of the actual differences in the understanding of those phenomena. He says consequently, teaching methods have to be characterised and developed in relation to each phenomenon taught about. He goes on to point out that in fact, the students' conceptions often resemble ways of thinking that were common earlier in the history of science. He concludes that educational experiences seem to bring about only very limited changes in this respect.

Marton (1986) states that if we understand the relationship that exists between an individual and what he or she is trying to learn, our pedagogical opportunities are greatly expanded. By changing that which has to be learned or understood, we change the relationship between the object of learning and the individual. He argues that what is of immediate pedagogical interest is how students' conceptions can be changed by teachers and how better understandings can be arrived at by students. He suggests that by encouraging teachers to pay attention to students' ways of thinking and to facilitate students' realisation that there are different ways of thinking may be the most important pedagogical implications of a phenomenographic view of learning.

Bowden *et al.*, (1992) in their paper "Displacement, velocity and frames of reference: Phenomenographic studies of students' understanding", contend that the task for teachers is to discover students' conceptions of the phenomenon under study and to devise ways of helping their students change their understandings. Marton (1986) believes that describing content as understood by the students is, in his opinion, the best way of describing the outcome of learning. He argues that the outcome of learning is seen as the student's way of understanding the content, learning is conceptualised as a change in how someone understands something.

White and Gunstone (1992) argue that students must take more responsibility for their learning, and become more purposeful and reflective (see also White 1988, Osborne and Freyberg 1985, Baird and Mitchell 1986, Brown 1980 and Paris, Saarnio and Cross 1986). White and Gunstone (1992) argue that richness of meaning of understanding is important in education. They argue that the meaning people give to understanding affects the way they teach things and how they learn them. They go further to suggest that an increase in methods of probing understanding will broaden teaching methods and learning styles.

White and Gunstone (1992) feel that concept maps are indeed useful in promoting understanding. They contend that the construction of concept maps by a group encourages discussion and reflection, but even individual mapping helps understanding. They say reflections on what maps reveal about teaching can cause reconsideration of teaching style. They go on to advise that we can use concept maps to help students link a new concept into their ideas. They also suggest that we can use concept maps to promote linking in new ways and to stimulate higher-order thinking. They contend that by selecting widely separated (but connected) terms, you can promote divergent thinking. They suggest a further use of concept maps

in teaching as in planning lessons. That is, to do a concept map in order to determine the sequence of presentation of ideas to identify relations that are to be emphasised.

2.10 Conclusion

The literature survey indicates that there is a need for educators and teachers to appreciate the students' view of the world and see the world through the eyes of students. There is a need to identify the various ways in which students' understand or conceptualise Newtonian dynamics phenomena. The differences in the ways of understanding will form educationally critical aspects that educators will need to focus on. The different ways in which students understand phenomena in different contexts can be used in encouraging students to appreciate domains of applicability. Identification of the ways of understanding phenomena will help educators to see where their students are, and prepare instructional material accordingly. In the next Chapter I give a detailed description of phenomenography, as this approach is adopted by the study.

Chapter 3

Phenomenography – a research perspective

3.1 Introduction

For this study the fundamental theoretical platform is drawn from the phenomenographic research perspective. I chose to use this theoretical framing because my aim in this study is to describe the variance in understanding of Newtonian links in well-defined and delimited contexts in terms of critical attributes of the structure and meaning of ways of understanding that emerge within these contexts. Within this broad aim a central focus makes the adoption of phenomenography particularly appropriate – describing the understanding of Newtonian links from the students' perspectives and not mine. The aim of this Chapter is thus to introduce phenomenography as a research perspective in terms of its origin, aims, value, and the rigour associated with the method, and how generalisability issues such as reliability and validity may be appropriately dealt with. However, since my study is essentially about understanding I will do the above by focusing on important aspects of how the phenomenographic perspective views learning, and will begin by describing some early aspects of the development of phenomenography which are pertinent to my study.

3.2 Phenomenography as a tradition in learning research

Phenomenography owes its origin to a change in research focus made by a group of researchers, led by Ference Marton, in the early 1970's in the Department of Education at the University of Göteborg in Sweden. In this

type of research they were studying the qualitative differences in the way students learn.

Phenomenography has been strongly influenced by phenomenology, but at the same time it has developed into a distinctly different research perspective from phenomenology. Phenomenography's epistemological position is built on Frantz Brentano's concept of intentionality (see Spiegelberg, 1982) which provides the basis for what is known as "a non-dualist view of human cognition that depicts experience as the internal relationship between human and the world" (Marton and Pang, 1999:1). Since phenomenography is orientated towards the way people experience a phenomenon rather than the phenomenon itself, phenomenography is said to adopt a *second-order* rather than a *first-order perspective*.

The roots of phenomenography lie in a set of empirical studies of Swedish University students' learning from reading academic texts (Marton, 1974; Dahlgren, 1975; Säljö, 1975; Svensson, 1976). The aim of these studies was to investigate the following empirical questions. a) "what does it mean, that some people are better at learning than others?" and b) "why are some people better at learning than others?" (Marton, 1992:1)

When exploring the first question, it was found that there are a limited number of distinctively different qualitative ways of understanding, or experiencing, or apprehending, or making sense of the text. These qualitatively different ways of understanding were not individual characterisations, but characterisations drawn from across individuals and were called *categories of description*. *Categories of description* and *conception* are seen in phenomenography as representing two sides of the same coin with the *category of description* side facing the *collective level*

and the *conception* side facing the *individual* level of the characterisation of a way of experiencing some phenomena¹.

Johansson *et al* (1985) argue that categories are however, not identical with the conceptions – rather, they are used to denote them. They contend that to the extent that conceptions reflect the terms in which people interpret the world around them, categories of description express our interpretations of others' interpretations. They argue that as our interpretations may be more or less correct, there is certain relativity linked with the choice of the categories of description. They mention that categories of description have a considerable degree of autonomy in relation to what they refer to (i.e. ways of understanding something). They continue to say that categories of description are invented to characterise conceptions found in concrete situations, but these categories may be lifted out of the context where they have been found or invented in order to be used as tools for understanding conceptions of similar phenomena or aspects in different situations.

Marton (1996) in his paper "Cognosco Ergo Sum" gives a clear distinction between categories of description and conceptions. Marton (1978) had earlier made the split using Lewis Carroll's metaphor "the grin of the Cheshire cat"; "if 'conception' is the cat, the 'category of description' is the grin left when the cat is separated from the grinning" (Marton, 1996:172-173). The word 'conception' has been replaced by the phrase 'a way of experiencing'. A category of description is a way of describing a way of experiencing something.

The second question was answered from the finding that there was a strong relationship between people's understanding of the text itself and

¹ This distinction is a complex one - a conception is 'a way of experiencing something' and a category of description is a characterisation of a way of experiencing something. In this thesis *understanding* is taken to be a synonym for *category of description*

their acts of text reading, which supported the principle of intentionality that plays a pivotal role in defining phenomenography (see Marton, 1981). The qualitative variations in the outcome of learning were found to be closely linked to the variation in approach to learning (which the researchers then characterised as 'deep' and 'surface' approaches to learning).

The early researchers' interest was in exploring the relationship between *what (the content)* and *how (the act)* students learn, and between the process and the outcome of learning. This interest led them to place "greater emphasis on *what* rather than *how much* the students learned, contrary to the dominant paradigm" (Dall'Alba, 1996:7) in research on students' learning. The aim was to describe learning through the eyes of the student. Learning is understood as learning *something*. The content of learning is seen in the sense of *content as understood by the student*. Hence describing content as understood by the students was seen by the early researchers as the most useful way of describing the outcome of learning when improving both teaching and learning is of central interest.

The initial purpose of establishing this approach was as explained by Sandberg (1996:129) "to obtain a better understanding of learning by studying people's ways of experiencing specific learning tasks in different subject areas". More specifically, phenomenography was detailed as an empirical qualitative method, in response to the cognitivist and psychological dualistic view of human cognition and also limitations of the then dominant quantitative methods used in educational research. Marton and Svensson (1979:472) also argued that traditional research about learning took the researcher's perspective as the point of departure.

The emergence of phenomenography as a research approach as suggested by Dall'Alba (1996) can be seen to be in line with the broader qualitative

research tradition. Denzin and Lincoln (1994:2) in the *Handbook of Qualitative Research* refer to qualitative research as “multi-method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them”. As a qualitative approach, phenomenography is the empirical study of the different ways in which people experience, perceive, apprehend, understand, conceptualise various phenomena in - and aspects of the - world around us.

Säljö (1982) was concerned that many of the assumptions guiding research in the field of learning are inappropriate in revealing the nature of the phenomenon as it is structured and experienced within and outside of educational contexts. He argued that “if research is to contribute to an understanding of how people learn it is important that its driving-force is not simply that of ‘efficiency’ i.e. a search for insights into the conditions under which people can be shown to learn effectively. We also need to develop insights into what it means to learn and be more sensitive to what counts as learning within certain cultural boundaries” (p.195). Säljö (1996:22) states in the earliest studies, the interest in qualitative differences in the outcome (and process) of learning was related to theoretical notions of the nature of knowledge and knowledge apprehension. He now argues that a weakness of phenomenography is “its lack of a theory of language and communication, and in its almost dogmatic disregard for paying attention to why people talk the way they do” (p.24). Marton (1996:168-169) strongly disagrees in general, and I do not think that this criticism is applicable to my type of study because both language couching and reasons why students describe their understandings as they do, form a central part of both my analysis and its discussion.

Psychological research, in its attempt to investigate learning processes has restricted its definition of learning (Marton, Hounsell and Entwistle, 1984). Marton, *et al* (1984:24) contend that “to learn is to strive for meaning, and to have learned something is to have grasped its meaning”. They argue that the qualitative approach to research on learning rejects the description of knowledge as discrete pieces of knowledge, passed passively from teacher to student, and tested in terms of whether or not the student can reproduce verbatim those elements. Instead of concerning itself with ‘how much is learned’, it seeks to investigate ‘what is learned’. Phenomenography emerged from research with an establishment of “‘experience’ as an internal relation between person and world (or something in the world)” (Marton, 1996:177), concerned with actual circumstances rather than general theories and with an empirical bias. Phenomenography is about the description of things as they appear to us.

Since knowledge was seen as an understanding of something in the real world, learning had to be measured in terms of the quality of that understanding and its relevance to the learning situation. The most important notions introduced in this early work, in the development of phenomenographic approach to studying learning, were those of *categories of description* of qualitatively different ways of understanding, the *outcome space* of these categories, and the *logical structure* between and within its components.

“There is a fundamental shift from a view of knowledge as being quantifiable, reproducible where learning is the acquisition, retention and recall of the knowledge, to one in which knowledge is an understanding of something in the real world, which is acquired through experience of the real world” (Marton *et al*, 1977:11-12). Booth (1992) argues that this shift represented a move towards defining ground on which phenomenography would subsequently stand.

In the early days of phenomenography, learning itself was defined as a change in conception. Marton *et al*, (1984:31) believed that when "learning has occurred, there is a shift from one conception to another which is qualitatively distinct". However, my study together with other recent studies acknowledge the lack of purpose in defining learning as conceptual change, and advocate the idea of conceptual dispersion or what is known as 'multiple conceptions' perspective (see Linder, 1993; Pong (1999 and 2000); Linder and Marshall, 2001, in press; and Pong and Marton, 2001, in press). Thus learning in this perspective is viewed as being a change in the way of experiencing the world.

The early studies helped phenomenography to evolve into a research specialisation which is aimed at describing qualitatively different ways in which people experience, understand, apprehend, conceptualise, etc, various kinds of phenomena in the world around them. Phenomenography is a research orientation, aimed at describing conceptions in different contexts like learning, studying, teaching and instruction (Svensson, 1977; Marton, 1981; Marton and Booth, 1997). The questions addressed in this kind of research are "what are the qualitatively different ways of experiencing a phenomenon? and How are these related to each other?" (Marton and Pang, 1999)

Marton (1986) states that phenomenography is more interested in the *content* (author's emphasis) of thinking than is traditional psychology. He argues that psychologists are interested in studying how people perceive and conceptualise the world. However, he states that their focus is usually on the act of perception or conceptualisation itself, and their aim is to characterise the process of perception and thought in general terms. Marton (1986) argues that within phenomenography, thinking is described in terms of what is perceived and thought about; the research is never

separated from the object of perception or the content of thought. An effort is made to uncover all the understanding people have of specific phenomena and to sort them into conceptual categories; which is why I began this Chapter by saying that phenomenography is the theoretical platform I chose for my present study.

Marton (1986) points out that phenomenographers do not make statements about the world as such, but about people's conceptions of the world. However, he also states that phenomenography is also interested in mistaken conceptions of reality. He argues that the mapping of the hidden world of human conception should be a specialisation in its own right. He contends that a careful account of the different ways people think about phenomena may help uncover conditions that facilitate the transition from one way of thinking to a qualitatively "better" perception of reality. He says the point of departure in phenomenography is always relational, that is, the relation between the individual and some specified aspect of the world. He goes on to say that he tries to describe an aspect of the world as it appears to the individual. He tries to characterise how things appear to people. He argues that human beings do not simply perceive and experience, they perceive and experience things.

Marton (1986) further explains that what people react to is not the situation in itself but the situation as perceived, and perceptions of situations, as a rule, differ. He says that we take the subjects' rather than the researcher's definition as a point of departure for our analytic descriptions. Furthermore, he argues that even if people's perceptions of the same situation may differ, there is a sufficient degree of commonality in our interpretations of the world to make reasonable predictions about how a situation will be perceived by others in similar contexts. He points out that all people usually do not perceive the same situation in the same way. So in phenomenography what is of interest is the description of

variation on the collective level, in that sense “individual voices are not heard” (Marton and Booth, 1997:114).

In phenomenographic study, Marton (1981) argues that structural properties of human cognitive functioning are determined by qualitative properties of the content of conceptions held about the world around us. And that a failure of the education system is that it introduces concepts and principles in such a way that they are not easily recognisable by the students against the background of their own experience. And that this is a serious symptom of its general lack of relevance to reality as it is experienced by the students, something which I am trying to address through this study.

The theoretical development of phenomenography is discussed in the section below.

3.3 The theoretical development of phenomenography

3.3.1 Background

From the early work in phenomenography a finite number of qualitatively different ways was found to describe the way a phenomenon was experienced. Marton and Pang (1999) argue that in order to characterise the qualitatively different ways in which people experience various phenomena, it is important to understand what it means to experience a phenomenon in a particular way. Phenomenography has thus shifted to include addressing questions such as “what is ‘a way of experiencing something’?” or “what is the actual difference between two ‘ways of experiencing the same thing’?” (Marton and Pang 1999:5)

From the work of Marton and Booth (1997) on the 'anatomy of awareness', it has been postulated that the unit of a phenomenographic research, 'a way of experiencing something', is related to how people's awareness is structured. The way of experiencing something can be described in terms of the *structural* aspect or the *referential* (or meaning) aspect or both. The structural aspect is "discernment of the whole from the context on the one hand, and discernment of the parts and their relationships within the whole on the other" (Marton and Booth, 1997:87). What the descriptions *mean* gives the referential aspect. These two aspects are only separated for analytical reasons, they do not exist as two independent entities of experience, they are dialectically intertwined.

Marton and Booth (1997:111) take the object of phenomenographic research to be 'variation in ways of experiencing a phenomenon'. Marton and Pang (1999:2) have recently argued that this variation is in two faces, the one face refers to the study of variation between different ways of experiencing the same phenomena, in which categories of description are derived, as we have done in Chapter 5. The other face is addressing the questions, "what is a way of experiencing a phenomenon?" and "how do different ways of experiencing something evolve?"

Marton and Pang (1999:16) argue further that this second face of variation is attempting to "depict a conception or a way of experiencing something in terms of critical aspects of the phenomenon in question *discerned and focused upon simultaneously*" (emphasis added) creating a shift in primary emphasis of phenomenography, from methodological, as detailed in Chapter 5, to theoretical concerns as discussed in Chapter 6.

3.3.2 Theory of awareness

The idea of structure of awareness in phenomenography has its roots in the ideas of the phenomenological philosopher Gurwitsch (1964). Booth (1994:9) states that the structure of awareness can be thought of as “a relationship between the person and the object of consciousness”. Booth (1994:9) argues further that in any situation, “there is a theme figural in awareness” – the object of thought, “and associated with the theme there are other aspects of a situation, related by some relevance to them”. The object of thought is known as a theme of awareness and all the rest form the thematic field (Marton, 1994). The theme consists of items that have been focused upon; and the thematic field consists of items relevant to the theme, that is, items that are tacit.

Booth (1994) argues that the structure of awareness is dynamic. By this she means that the object is carefully considered from different aspects which brings different thematic fields into awareness, and as this happens new themes arise from preceding thematic fields. In Marton and Booth's (1997) summary of the ‘anatomy of awareness’, the theoretical position of phenomenography in this regard is outlined as the way people's awareness is structured is related to a way of experiencing something.

Marton and Pang (1999) describe how the structural aspect of phenomenographic analysis represents the discernment of the whole from the context and the discernment of the parts and their relationships within the whole; while the referential aspect captures the meaning. In this theory, the two aspects are only separate units as analytic tools; as parts of ways of experiencing the two constructs are “dialectically intertwined and occur simultaneously when we experience something” (Marton and Booth, 1997:87).

Marton and Booth (1997:82) argue that “certain structures of awareness are implied by certain ways of understanding; that the student is simultaneously aware of certain aspects of a situation or a phenomenon; that her awareness of certain aspects logically imply a tacit awareness of other aspects; that certain aspects become figural, in focus whereas other aspects recede to ground”. Thus in the phenomenographic theory of awareness, a *situation* is always experienced with a context, a time, and a place – whereas a *phenomenon* experienced is abstracted or discerned from the context. The theory of awareness opens the possibility that people can have multitudes of conceptions, and can thus only reveal those conceptions that are at their focal awareness at any given time. Thus characterising comprehension involves identifying and categorising what is relevant, that is, in focus, and what is in background. What is unknown is deemed to be uncomprehended as it is neither in focus nor in background. The characterisation of these aspects is important to this study.

3.4 Phenomenographic perspective on learning

In the previous sections of this Chapter I described the historical development of phenomenography. In this section I will look at phenomenography as it applies to my study, in terms of its beliefs, the questions it attempts to answer, and the assumptions which underlie research.

Some researchers (for example, Linder, 1993; Pong (1999 and 2000); Linder and Marshall, 2001, in press; and Pong and Marton, 2001, in press) depict learning as involving ‘multiple conceptions’ whilst others (for example, Hewson, 1981; Nussbaum and Novick, 1982; Posner *et al*, 1982; Osborne and Wittrock, 1983; and Brown and Clement, 1987), depict learning as ‘conceptual change’. The former suggests that teaching should

not be focused on trying to get students to abandon old ideas in favour of new ones, but rather to extend their repertoire of ideas about the physical and cultural world (e.g. Gunstone, 1994). Johansson, Marton and Svensson's (1985:235) view of learning is that it is a "qualitative change in a person's conception² of certain phenomena or of a certain aspect of reality how that phenomenon is perceived, how it is understood, and what meaning it carries for the learner". Johansson *et al* (1985:235) illustrate their argument by describing how students master certain methods of calculation without having adopted the conceptualisation underlying them, and they ascribe this to the fact that students may have at least two different conceptions, one that is implied by the correct way of handling the calculation, and one that is the unchanged common-sense conception. For analytic purposes Marton and Booth (1997:85) divide learning into two components, a *how (act)* aspect and a *what (content)* aspect. In their analytic depiction *how* is directed to *what* through what is known as the indirect object of learning. This indirect object represents the intention of the learning act.

The phenomenographic theory has the relationship between the student and the world as being non-dualistic. This means that there are not two worlds – the world of our mind and the world out there – but that both together constitute our experiences. Ramsden *et al* (1993:303) describes this as follows "There is only one world to which we have access – the world-as-experienced". Earlier I explained that in phenomenography conceptualising is viewed as an internal relationship between the experiencer and the experienced, not a mental entity.

In the introduction I explained that the variation in ways people experience or conceptualise phenomena in their world is fundamental to phenomenographic studies. Marton (1981) states that we can probably

² conception in phenomenographic perspective refers to 'a way of experiencing'

always find a variation in the way students understand the concepts and principles presented by the teacher, or by the author of a textbook. He goes on to say that the concept or principle is understood by some students in a way which is similar to the teacher's or the author's conception and by other students in ways which differ from it (and from each other). He says the 'authorised' conception, can then be considered as one of several possible ways of understanding the concept or principle in question.

In his seminal paper on phenomenography, Marton (1981) argues that we only have access to the world through experience. This implies that we cannot separate that which is experienced from the experience per se. Differences in thinking reflect differences both in experiences and in realities and one cannot separate the structure and the content of experience from each other. Viewed in this way judgements concerning cross-cultural or cross-strata comparisons of levels of intellectual development are pointless. Thus taking a phenomenographic perspective implicitly carries an understanding that it would not be surprising to find variation in intellectual development described across cultures and different social strata. In this respect Marton (1996) makes a point of noting that in growing up, people learn to conceptualise their own reality. He says,

"We are born into the world and we experience it somehow from the very beginning We can explore it, we can gradually discern more and more, and relate more and more to each other. We probably learn initially to divide the world into two parts: "mother" and "not mother". At a certain point we develop the notion of human beings, then their attributes, some good, some not. Out of the good qualities people may have, we perhaps differentiate "virtuous". This we do against the background of our awareness of the world. We do not find out about an independently constituted reality, we participate in an ever ongoing constitution of the world. And it is also different from saying that we simply grow into a world already constituted."

Marton (1996:176-177)

In this Chapter I have tried to capture the essence of phenomenography in terms of two questions central to my study: "what does it take to learn?"

and “why do some people learn better than others?” In this regard Marton and Booth (1997:1) pointed out that people do things differently, “some do it better, others do it worse, rather they have learned differently – some better, some worse – to do it”. They further argue that in phenomenography there is a distinct shift of focus from measuring the quantity of stuff learned and the psychological means of achieving greater quantity more efficiently to examining the *quality* (my emphasis) of what students learned and the educational implications. The shift being away from viewing the student from the outside to one that tried to see learning from the student’s point of view.

It is for the reasons outlined in this Chapter so far that I decided that phenomenography would be an appropriate perspective to adopt for my study as it fundamentally deals with questions which look at the different ways in which people experience, interpret, understand, apprehend, perceive or conceptualise various aspects of reality. It is sufficiently interesting in itself, not least because of pedagogical potentiality and necessity of the fields of knowledge to be formed.

3.5 The implications for collecting research material

Bowden (1996:49) suggests that phenomenographic research methods of data collection and analysis can be used to study a range of issues, including approaches to learning, approaches to teaching, understanding of scientific phenomena learned in school, or understanding of general issues in society unrelated to educational systems.

The phenomenographic research approach has implications for the sort of data to be collected, and the way that data is collected in empirical investigations. The most common way of collecting data for phenomenographic research is by holding interviews with a ‘purposeful

sample' of population of interest – meaning that a choice for the sample is made in some theoretically appropriate way. Other ways of collecting data include, filming or videotaping observations for later note-taking, or with on-site note-taking, prior to analysis. In the current study, data was collected from interviews, which were formulated from the concept maps that students constructed.

For my kind of study phenomenographers prefer semi-structured interviews. The semi-structured interview gives the phenomenographer the possibility to probe the subject's understanding, of one or several phenomena, by having a small number of predetermined questions, which deliberately approach the phenomenon from a variety of directions, thus increasing the chances of a full exploration of the theme under examination. Researchers need to be highly knowledgeable about the subject matter because they are implicitly open to unexpected turns in the resulting discussion, and need to be both knowledgeable about how to use them and prepared to do so to illuminate the question further, and adapt later interviews accordingly.

From the point of view that the main aim of phenomenographic research is to identify variation it can be argued that the validity of the whole research study lies heavily in the interview context. By this I mean that the interview situation should be agreed upon by both the interviewer and the interviewee. In addition, the interview method must be sensitive to identifying shifts in focus, which might otherwise be misleading data for analysis. The interviews are recorded and transcribed verbatim, with an effort to maintain the sense of being there by adding notes on non-verbal communication.

3.6 The analysis approach used

The analysis used was typical of that used in many phenomenographic studies, however, it was not algorithmic but a hermeneutically circular procedure whereby I iteratively searched for differences and similarities in descriptions of students' ways of experiencing or conceptualising something, until equilibrium was reached, in order to generate my categories of description (the aim of the analysis being to yield descriptive categories of the qualitative variation found in the empirical data).

This type of analysis demands a multi-faceted understanding of the domain of the phenomenon of interest coupled with an open attitude towards it. It demands data which adequately covers the relation between the subjects of interest and the phenomenon which is the focus of the research. With a research approach such as mine, the transcripts are analysed across individuals while at the same time looking at individuals' descriptions for the interpretations that lead to the formation of the categories of description. The resultant categories of description represent an 'outcome space' which comprises "distinct groupings of aspects of the phenomenon and the relationships between them" (Marton and Booth, 1997:125).

In more detail the process involves looking at similarities and differences that can be found in these quotes or descriptions. From this process categories emanate, where descriptions with similar characteristics will be grouped together to form a category. The categories are not pre-determined but arrived at through a lengthy iterative procedure (see Chapter 4). This procedure uses 'parts' to evolve the 'whole' and the 'whole' to determine the 'parts'.

Johansson *et al* (1985) describe how categories of description are essentially discovered entities, and argue that consequently what phenomenography calls 'conceptions' are discovered idealised ways of thinking, and they make up the main results in my kind of investigation where the point of departure is finding out the different ways in which a certain phenomenon or certain aspect of reality are experienced, understood, and conceptualised. Johansson *et al* (1985) also argue that my kind of analytic outcomes are generalisable (see Section 3.8 below).

I would like to end of this section on the analytic approach I adopted by pointing out an important attribute of such analysis. This is, as Marton (1988) argues, that there is just one thing, the phenomenon-as-understood, and this is exactly what I describe. The point he is making is that our understanding of the world around us – the experiential sense – is fundamentally of relational character and this is what sets my kind of study apart from other cognitivist-based studies dealing with students' conceptions. Marton (1981) argues further that the descriptions arrived at from phenomenography are autonomous, i.e. not derived from what we know from the general properties of the human mind. In my study the categories I created are formed from the conceptual links the students described and not on how physicists know the links ought to be described.

3.7 The results obtained by phenomenographic means

I have described how the fundamental results of a phenomenographic research are a set (or sets) of categories of description. These descriptions are carefully worded, and are supported by appropriate quotations from, or descriptions of, the data. The results are always presented at a group level. The categories of description are not representative of individuals but of the whole group under study. However, because of the theoretical framing in terms of awareness for the analysis, the categories of description can be

extended to a larger population of interest. The categories do not form an exhaustive system but are complete in the sense that nothing in the collective experience manifested from the sample is left unspoken.

In this Chapter I have described forming categorisations of collective descriptions of understanding as one of the primary outcomes of phenomenographic research. When I was creating my categories, I was not merely sorting data; I was looking for the most distinctive characteristics that appear in those data; that is, I was looking for structurally significant differences that clarify how a group of physics students understand the conceptual links in Newtonian dynamics.

Within this framework Marton (1986) argues that we look for the most essential and distinctive structural aspects of the relation between the individual and the phenomenon. He adds that it is a goal of phenomenography to discover the structural framework within which various categories of understanding exist. Such structures should prove useful in understanding other people's understandings. He points out that the phenomenographer must discover and classify previously unspecified ways in which people think about certain aspects of reality. He states that categories and organised systems of categories are the most important component of phenomenographic research. He argues that the original finding of the categories of description is a form of discovery, and discoveries do not have to be replicable.

Marton (1981) states that the outcome of a phenomenographic research can be viewed as categories of description considered as abstract instruments to be used in the analysis of concrete cases in the future; or we can focus on the applicability of these categories in concrete cases, considering the possibility of applying the categories in order to make a statement about a historical fact such as, for instance, that individual A

exhibited conception B under circumstance C. In this study we will view the results as the outcome space that can be used in the analysis of concrete cases in the future.

Marton (1986) argues that when investigating people's understanding of various phenomena, concepts, and principles, researchers repeatedly found that each phenomenon, concept, or principle can be understood in *a limited number of qualitatively different ways* (author's emphasis). Since then this has been empirically verified many times. The reason is that while there may be an unlimited number of ways of making sense of something there is a limited number of essential characteristics which go into the formation of this unlimited array of possible thinking and phenomenographers capture those essential characteristics - i.e. a limited number of ways that key aspects are experienced. Marton (1981) argues that the forms of thought should not be considered as *categories representing individuals (although we can classify individuals in terms of them)*, but as categories for describing ways of perceiving the world around us.

The categories of description are discerned from the interviews in terms of their meaning (referential aspect) and structure. The background to descriptions is known as the *external horizon* in phenomenographic language. The internal relationships between the parts that occur within each category are known as the *internal horizons* in phenomenographic language. These external and internal horizons form the basis for discernment of one category from another.

Marton (1981) states that when forming categories of description, then, researchers need to 'bracket' the dynamic-activity perspective and one can thus consider the categories almost as if they were 'frozen' forms of thought. He argues that these categories of description, denoting forms of

thought are arrived at by separating forms of thought both from the thinking and from the thinker.

All categories found together with their logical relationships form what is known as an *outcome space* of qualitatively different ways of experiencing.

3.8 The issues of validity and reliability

The question of validity is interwoven with every aspect of phenomenographic study, from the design of the study to the presentation of results and conclusions. Phenomenographers like any other researchers need to be clear about the purpose of their studies and the strategies by which they will achieve the outcomes. The study has to be grounded on a sound understanding of the subject content. The procedures followed - from data collection to analysis - should be conducted on phenomenographic principles. The choice of the study sample should be done appropriately in the context of what needs to be achieved. When collecting data through interviews, interviews should be conducted in an appropriate context. Bowden (1996:58) emphasises the importance of the appropriateness of the interviewees from whom the data are collected, in the context of the purpose for which the outcomes of the research will be put.

Altheide and Johnson (1994:488) are of the view that all knowledge and claims to knowledge are “reflexive of the process, assumptions, location, history, and context of knowing and the knower”. From this point of view, they claim that validity depends on the ‘interpretive communities’, or the audiences – who may be other than researchers and academics – and the goals of the research. They argue that validity will be quite different for different audiences.

The reliability of phenomenographic results is sometimes questioned by non-phenomenographers. A question frequently asked by people not adequately familiar with the theoretical framing of phenomenography is: would another researcher working independently find the same categories and conceptions found by the original researcher? Sandberg (1996:130) argues that in mainstream social science, the most common criterion for measuring the extent to which research results are reliable is replicability. If one other independent researcher achieves results similar to the original researcher when studying the same data the original researcher's results with the same theoretical framing are deemed to be reliable. According to Marton (1996:169), "no reliability measures can ever be other than necessary, but not sufficient, conditions for accepting the results". Marton (1986) argues that there are two issues concerning replicability in phenomenography. The first issue concerns the researcher's discovery of the different conceptions among a group of individuals. The question is, would other researchers reach the same categories of description as the original researcher? The second issue concerns whether other researchers could recognise the conceptions identified by the original researcher, through the latter's categories of description. Marton (1986:35) argues that it is reasonable to require replicability for phenomenographic results in the second but not in the first case. In the first case we are dealing with discoveries³ and discoveries cannot be expected to be replicable.

In this regard Johansson *et al* (1985) have argued that once the categories of description are made explicit, other researchers should be able to identify them when they are applicable in varying contexts. They mention that in accordance with this, indicators of reliability should not concern the extent to which categories are discovered independently, but the extent to

³ discoveries in this study refer to the finding of a set of categories of description after going through a painstaking iterative process (as described in Chapter 4)

which they are identified once they have been specified. They argue that another implication of the view that categories of description are discovered is that we cannot specify methods that would ensure certain predetermined outcome.

Marton (1981) contends that since the same categories of description appear in different situations, the set of categories may be considered to be stable and generalisable between the situations even if individuals move from one category to another on different occasions. Marton (1988) argues that the variation in understanding can be generalised even if the individual's understanding may not be so (the same child may often show different understandings of numbers when dealing with different problems).

In phenomenographic studies we do not sample people but variations in ways of experiencing or understanding something. In such studies we can not claim generalisability in a traditional statistical way, but can make 'naturalistic generalisations'. Stake (1978, 1995:85) describes 'naturalistic generalisations' as "conclusions arrived at through personal engagement in life's affairs or by vicarious experience so well constructed that the person feels as if it happened to themselves". In phenomenographic studies we provide opportunity for vicarious experience through descriptions, and these allow readers or other researchers to form 'naturalistic generalisations'. From vicarious experience it is possible for other researchers to find the kind of variations in ways of experiencing something that has been found by another researcher. Everyday in our lives we experience 'naturalistic generalisations'. These generalisations are interpretations based largely on experience. For example, lawyers often refer to and draw from past cases when presenting new cases; medical doctors refer to similar past cases when confronted with new cases when diagnosing; teachers also use

past experience when planning their lessons or dealing with students with learning difficulties in a classroom.

Sandberg (1996) discusses different reliability measures and suggests researcher's interpretative awareness as a possible criterion in phenomenographic research. He argues that reliability as interpretative awareness takes into account the researcher's procedures in the research process and accords with the epistemology of intentionality underlying the phenomenographic approach.

To address all the issues just described for my study involves pointing out the nature of my discoveries as contributions to the body of knowledge in terms of providing sufficient detail of the study and my analysis -- sufficient for any reader to appropriately appreciate how I did the study and exactly how the analytic outcomes were arrived at. Any replicability concerns form the basis of future associated studies with different student groups by other researchers. The usefulness of the understandings described will form part of naturalistic generalisation and the results of informed teaching-practice changes.

3.9 A study of conceptualising Newtonian links from a phenomenographic perspective

The phenomenographic perspective has been chosen for the reasons outlined in this Chapter. The central question in this thesis is, how do students conceptualise conceptual links they make between basic Newtonian dynamics concepts? In other words, students' understanding of links they make between basic Newtonian dynamics concepts is the central research interest. The population of interest consists of university students on a physics introductory course.

Hence my study is fundamentally exploratory. Gathering data for this phenomenographic study meant ensuring that I could get as close as possible to both the intended investigation and to the subjects of the study. Concept maps in predefined contexts were used to get students to construct the links. Students were interviewed about the links they made, and transcripts of these interviews were subsequently made. The outcome of understanding the links was presented in the form of categories of description. Qualitatively different ways of understanding the links were thus characterised. The study goes further in an attempt to make a contribution towards the theoretical development of newly emerging questions in phenomenography, “*what is a way of experiencing a phenomenon and, how do different ways of understanding something evolve*” (Marton and Pang, 1999:2), in order to address the theoretical concerns as outlined in Chapter 1.

The procedure for the empirical study is detailed in Chapter 4.

Chapter 4

The Empirical Study

4.1 Introduction

In the previous Chapter I introduced the theoretical platform which I based my thesis study on. Part of that Chapter dealt with issues related to the concepts of reliability, validity and generalisability. I concluded this discussion by saying that in a study such as this one needed to provide sufficient detail to enable a reader to understand and appreciate all aspects of the study.

According to Prosser (1994) there is no prescriptive method for phenomenographic studies, however, there are differences in procedures across the studies depending on their particular circumstances. Since my study is fundamentally in phenomenography, some aspects of it -- when I look at the individual level -- extend beyond phenomenography. These aspects I have characterised as case studies and thus what I want to do in this Chapter is to discuss qualitative aspects in general as these stretch across phenomenography and my case study, and then introduce case studies in the context of a study such as mine. Finally I will describe the actual analytic method of both the phenomenography section (Empirical Research Questions a) and b)); and the case study section (Theoretical Research Questions c) and d)).

Given that my aim was to understand how students think about Newtonian dynamics conceptual links, I had to choose an appropriate method and related theoretical perspective aimed at generating understanding. Both phenomenography and my case study have an associated qualitative method (although I also attempt a statistical interpretation for a small part

of my case study – reasons for this are discussed in Chapter 5). And in broad terms the purpose of this Chapter is to provide justification for the choice of the methods adopted for the study.

The theory of phenomenography called an ‘anatomy of awareness’ forms the fundamental framework for my study which is why I devoted the previous Chapter to its exploration. In this Chapter I will detail how my research focus developed through a pilot study and why part of my study extended beyond phenomenography.

The following were the preliminary research questions which I had in mind as I started my study.

4.1.1 Initial Research Questions

I began my study by posing a wide range of questions for a pilot study which I hoped would facilitate the emergence of research questions critical to the teaching of undergraduate Newtonian dynamics which had not been previously addressed.

The questions I created for my pilot study were created after extensive reading of the literature relating to learning and teaching problems in introductory undergraduate physics. This literature review revealed that whilst an enormous amount of research had been done into student understanding of Newtonian physics, the ways students thought about physics conceptual links had essentially not been investigated at all. So I created the following exploratory questions for my pilot study:

- Given a context or an instance in Newtonian motion, how do students conceptualise it?
- What concepts do they think about in the context of motion?
- How do they link these concepts? (i.e. how do they conceptualise these links?)

- How does their propositional knowledge compare with experiential knowledge?
- Having categorised these conceptualisations into those that are intuitive and counter-intuitive, how do the intuitive conceptualisations compare with Newtonian concepts?
- Given these comparisons which will best describe what needs to be learned, what learning and teaching strategies or guidelines can be used for learning Newtonian concepts using the right context i.e. Newtonian domain vs. own intuition.
- Of what assistance has the use of concept maps been to their learning?

The students I used for the pilot study were computer science students who had either physics or applied mathematics as their second major and were in the second year of a three-year Bachelor degree programme. All the students who agreed to participate in my pilot study had come from *educationally deprived* schools. However, having successfully participated in a special bridging programme at the university to address this deprivation, at the time of the study the participants could be considered fairly typical of successful 2nd year science students.

I began by teaching the pilot study participants how to draw 'concept maps' (Gowin and Novak, 1984). In brief this was done by creating one simple map together in class. The students were then asked to draw simple maps using computer science concepts and were asked to think about all possible links and to write down the nature of each link. We then moved to drawing maps in Newtonian dynamics. This exercise took about six weeks before the students could produce their own maps without help.

The students were then given twelve concepts -- motion, force, velocity, acceleration, speed, displacement, weight, work, energy, mass, impulse and momentum -- to explore on their concept maps. The students were told that they could add more concepts if this would bring more meaning

to their maps. They were also allowed to leave out links where they thought there were no relationships at all. I strongly emphasised that I did not want them to use equations or formulae in their descriptions of links, my aim being to encourage the students to give as simply and as naturally as possible their own understanding of the links they had made. They were also made aware of the fact that they could have more than one link between concepts.

The students appeared to enjoy drawing their concept maps because this activity was open and not focused on drawing a correct map. Then it also seemed that having their computer science lecturer engage them in this way made the physics exploration a less threatening exercise – one that was enriching through this new facilitation of free discussion of some of the problems they encountered in physics or applied mathematics. The maps used in the pilot study were all drawn in class.

This pilot study revealed the need to probe students further by interviewing them about the links they made in their concept maps, in order to get clarity on their propositional knowledge. My attempts to analyse the concept maps constructed in the pilot study also suggested the need to have the students construct concept maps in a given context, what I have called *specific domains of applicability* in this thesis. As the study evolved the preliminary research questions underwent a process of subtle refinement. My understanding of the theoretical constructs deepened as I started applying these constructs to the emerging data. Thus, the above research questions evolved into the research questions detailed in Chapter 1.

Let us look at the methodology used in my study.

4.2 Methodology

4.2.1 Research Method - Qualitative

In Chapter 3 I described how the nature of phenomenographic studies is qualitative, describing variation in ways of experiencing aspects of the world. "The unit of phenomenographic research is a way of experiencing something ... and the object of the research is variation in ways of experiencing something" (Marton and Booth, 1997:111). The main aim in my type of study is not to measure certain qualities of individuals but to reveal as yet unknown qualities of their relations to the world. However, I wished to use my phenomenographic results to enter the world of the individual and so I also designed an accompanying case study. This should not distract from the discussion which follows since both the phenomenography and qualitative case study analysis share the same kind of theoretical concerns. I will now discuss these as they apply to my study.

In my research design I have made use of concept maps and interviews as described earlier. What is fundamental in this kind of research is that the procedure used should be sufficiently open to allow the subjects to express their own ways of structuring the aspects of reality that they are relating to, and to give them the opportunity to choose the terms in which they interpret the situation they are facing. For example, students decided themselves on the concepts to use when drawing their maps. For the interviews it was made clear to the students that my interest was in *what* they understood and *how* they understood, rather than in their producing right answers.

The central research thrust for this study falls under the qualitative research method umbrella (see data collection in Section 4.5 below). Denzin and Lincoln (1994) argue that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret phenomena in terms of the meanings people bring to them. Denzin and

Lincoln (1994:2) argue further that “qualitative research involves the studied use and collection of a variety of empirical materials – case study, personal experience, introspective, life story, interview, observational, historical, interactional, and visual texts – that describe routine and problematic moments and meanings in individuals’ lives”. Leedy (1993), one of the qualitative research advocates, points out that the task of a qualitative researcher is one of analysis and synthesis. Huberman and Miles (1994) argue that qualitative studies ultimately aim to describe (at some level) a pattern of relationships, which can be done only with a set of conceptually specified analytic categories.

Another qualitative research advocate, Allan (1991:178) argues that qualitative methods represent “inquiry from the inside” with researchers seeking more flexible involvement with their respondents. Denzin and Lincoln (1994) point out that an appropriate way to get closer to the ‘actor’s’ perspective is through detailed interviewing and observation. In my study in-depth interviewing is used to probe for further understanding.

Stake (1995) argues that qualitative researchers have pressed for understanding the complex interrelationships among all that exists. He says there is a vital distinction between that inquiry for making explanations versus that inquiry for promoting understanding. He further states that in addition to its orientation away from cause and effect explanation and toward personal interpretation, qualitative inquiry is distinguished by its emphasis on holistic treatment of phenomena (p.43).

4.2.2 Case Study for the individual-level analysis of this study

In this study I have used a mix of elements drawn from various perspectives, chosen and combined for the particular purposes of addressing my research questions. Part of my research study may be regarded as phenomenographic (across individuals) and part as forming a case study (at the individual level). The following research questions fall under the case study approach,

- When all the students' descriptions are categorised in terms of the conceptions, or ways of experiencing, obtained for Empirical Research Question a), do any patterns of intra-contextual and inter-contextual shifting emerge for the individual students?
- If intra-contextual and inter-contextual shifting patterns emerge, can any patterns of contextual influence be discerned?

Phenomenography is discussed in detail in Chapter 3 and in this Section of this Chapter I will restrict my discussion to case studies as I used the concept.

A case as defined by Stake (1995:133) is “a special something to be studied, a student, a classroom, a committee, a program, perhaps, but not a problem, a relationship, or a theme”. He mentions that a case consists of a careful focus on something that is not sufficiently well understood. Part of what I am trying to do in this study is to understand the individual nature of conceptualisation of Newtonian dynamics connections across contexts.

Rose (1991) mentions that in a case study we concede a ‘snapshot’ picture. Yin (1989:23; 1994:13) defines a case study as, “an empirical enquiry that: investigates a contemporary phenomenon within its real-life context, especially when – the boundaries between phenomenon and context are not clearly evident; and in which – multiple sources of evidence are used”.

Mitchell (1983:192) characterises the case-study approach in terms of “detailed examination of an event (or series of related events) which the analyst believes exhibits (or exhibit) the operation of some identified theoretical principle”. He states that the case-study approach depends on the ‘cogency of the theoretical reasoning’ for the validity of any logical inferences from a case or cases. A similar argument is made by Yin (1994), who likens the case study in this respect to the experiment, since it does not represent a statistical sample and the goal of the investigator is to ‘expand and generalise theories (analytical generalisation) and not to enumerate frequencies (statistical generalisation)’. Mitchell (1983) argues

that the practical consequence for extrapolation from case studies is that generalisation depends upon the adequacy of the underlying theory and related knowledge, and must be qualified by the relevant contextual conditions.

Rose (1991) argues that the methods used in case study research may be either qualitative or quantitative, or a combination of them¹. He states further that the two aspects of case study approach are representativeness and generalisability. The other aspect of this matter of representativeness is that the findings from a study such as this are clearly not intended to be generalised in a statistical sense to a defined population of students. Rose (1991) mentions that these aspects of the case study approach – representativeness and generalisability – are often viewed by its detractors as major weaknesses. However, he also states that to advocates of the approach these methodological points can be answered and, moreover, turned into a virtue. In this study both qualitative and, to a certain extent, quantitative methods were used. This study is not for generalisability in the statistical sense – it is more of a case study with the discovery of categories of descriptions from the data. Rose (1991) cautions that the emphasis is on investigating contemporary phenomena in the subjects' real-life context.

It has been pointed out by Rose (1991) that under the influence of quantitative method, representativeness has come to mean typicality in the sense of a statistically reliable random sample from a population. He continues to say that similarly, generalisability has come to mean the ability to extrapolate with statistical confidence from that sample to the population from which it was drawn. He states that in case-study research, by contrast, it is considered more appropriate to treat representativeness in terms of a qualitative logic for the selection of cases for study, rather than a quantitative logic of sampling from a population.

¹ I tried using a statistical analysis to supplement my qualitative analysis – see Chapter 5, Section 5.4.1.2

4.3 The course selected for the study

The course selected for the post-pilot study is first year university mechanics course offered in both first year physics and applied mathematics at the College of Science at the University of Witwatersrand, which is a development programme². The course was chosen because on the one hand it was directed towards a group of university students who want to follow a career in physics but whose school backgrounds are judged to be insufficient to enter directly into the conventional programme. In this respect the course can be considered as being part of a school-university bridging programme. In effect the traditional first year course is split into two years to allow for bridging the gap between students' physics knowledge level and the desired university entry level.

4.4 The students selected for the study

The students used in the study were physics students attending the course described above at the University of Witwatersrand (Wits) College of Science. These students were in the second year of the two year split already described. All of these students volunteered to participate in the study. There were five students in all. These students were part of my physics tutorial group³.

4.5 Data collection

4.5.1 Concept maps

In this study concept maps were the basis for the design of my phenomenographic study in order to take into account the links the students had made. The students were shown how to draw concept maps

² A development programme in most South African universities is used for bridging the academic gap between schools and universities.

³ Tutorial group – a small group of students meeting regularly (once a week in this case) to discuss problems given to them (in this case physics problems) at the end of each topic or subtopic

for eight weeks. Two of these five students had already spent a year using concept maps in their studies. The phenomenographic part of the research was however, not on the students *per se*, but on the identification of ways of experiencing Newtonian dynamics conceptual links. Hence the phenomenographic analysis of the students' concept maps was not on the individual maps but across all the maps. Marton and Booth (1997:136) argue that "whether or not a certain person is really capable of experiencing the phenomenon in question in this particular way, or under what conditions she is capable of doing so, is a question that falls outside phenomenography". My study extended beyond phenomenography by looking at the empirical question c) how do the categories relate to the contexts provided for the study? The procedure that is followed when addressing the above question is detailed in Section 4.7.2 below.

Students were introduced to concept maps according to Gowin and Novak's (1984) definition of concept mapping, by doing one simple map together during a physics tutorial. Gowin and Novak (1984) claim that concept mapping is a technique for externalising concepts and propositions. They state that we may develop new relationships between concepts in the process of drawing concept maps. Thus, they concluded that concept mapping can be creative and may help to foster creativity. Gowin and Novak (1984) found it helpful to think about concept maps as tools for negotiating meanings.

Because concept maps represent specific propositional links between concepts, Gowin and Novak (1984) state that they are relatively precise indicators of the extent to which a person's concepts have been differentiated. They believe that concept maps are a simple tool for assessing where the students are. White and Gunstone (1992) state that concept mapping tells much about the quality of the students' learning. They go further to say that it also reveals the understanding present amongst the students and hence tells much about the effectiveness of the teaching.

White and Gunstone (1992) also argue that concept maps appear best suited probing understanding of a whole discipline, or at least a substantial chunk of one. They state that since the maps elicit the relations students see between concepts that make up a topic, naturally they reveal something of the understanding that the students have of the individual concepts as well as of the whole topic. They conclude that concept mapping will reveal whether the patterns of relationships and actions are understood.

White and Gunstone (1992) contend that a concept map aims to show how someone sees the relations between things, ideas, or people. In this study the concept maps were used to reveal the variance in the links the students made between Newtonian dynamics concepts. In addition White and Gunstone (1992) argue that concept maps focus more specifically on the structure and linking that student perceives. The mapping is a means of eliciting the relationship each student perceives between Newtonian concepts.

White and Gunstone (1992:36) have argued that the concept maps “are a means of seeing the shape of the wood, not the state of individual trees”, and that concept maps naturally reveal something of the understanding that students have of the individual concepts as well as the whole topic. They do not believe however that concept mapping is an efficient method for probing understanding of a single concept, since it does not reveal enough detail. Hence the use of other techniques like interviews in this study to probe further the revelations of the concept maps.

It is important to point out that in this study, the maps are used to generate discussion through a semi-structured interview protocol. This discussion aims at collecting descriptions to investigate the variance in ways of thinking about conceptual links, and not to investigate individual understanding in the ways described by White and Gunstone (1992).

Students were given themes or instances from introductory physics when drawing concept maps to see what concepts they think about given a particular theme or instance; and how they understood what they thought of these links. The students had learned Newtonian dynamics concepts from university introductory physics and also from school physics. The experimental maps were checked every week after the physics tutorial for refinements. The students were told that there could be more than one link, and that they should exhaust all the links. It was made clear to the students at the beginning of the exercise that the concept maps had nothing to do with correct answers, but the exercise was there to assist them in monitoring how they had understood the concepts, and also to assist me in getting to know the nature of the propositional knowledge they had about Newtonian conceptual links in dynamics.

The students were given the following instance so as to create a 'theme' for their concept maps, and this was set in three different contexts or scenarios as detailed in Chapter 1. The problem was as follows:

A minibus is being pushed by 4 men. When it starts moving they let go and it accidentally collides with a stationary 10-seater taxi. The minibus drags the taxi with it and they both stop a few metres away. Given this scenario what concepts and/or principles do you think about? Draw a concept map about these concepts and link them together, clearly stating the nature of the relationship. Please do not put down the equations or translations of equations.

This exercise will help you and me to see how you understand the whole scenario, and how you understand the links you make between the concepts. That is, this will give me the propositional knowledge that you have about the whole scenario and the Newtonian dynamics concepts involved in this case. Please take this exercise as an educational one as it will indicate to you how you have experienced and learned these concepts.

NB: remember you can have more than one link between concepts.

The students were given this problem four days before they could draw the maps, to give them time to read through and understand the problem; to allow them to think of all concepts that are involved in the problem together with the relationship these concepts have. The students all drew

the maps in one room on a Saturday morning. The maps for the different contexts were drawn on different Saturdays.

The concept map exercise was repeated for each given context so that students could appreciate the domain of applicability. The three different contexts provided were meant to assist students appreciate the domain of applicability⁴ of ideas based on concept maps used in a specific context.

While drawing the maps the students started asking themselves questions and trying to relate these concepts to their everyday life experiences. The links from the concept maps formed the basis for the interviews.

4.5.2 Interviews about Newtonian dynamics links

Students were then interviewed about the links they made on their concept maps to probe the ways they experienced the conceptual links. I studied the concept maps to design a semi-structured interview protocol and used this protocol for the interview. Each interview took on average, 50 minutes and the interviews were conducted after the construction of each map.

The study made use of qualitative interviews, which Jones (1991) argues are distinguished from survey interviews in being less structured in their approach and in allowing individuals to expand on their responses to questions. She says in conducting interviews it is obviously necessary to retain a critical awareness of what is being said and to be ready to explore some issues in greater depth – what Measor (1985) calls ‘listening beyond’. She advises that in putting together an interview schedule it is wise to leave sensitive or more complex issues until rapport and trust has been established, perhaps for later interviews if more than one is to be conducted with each individual. She points out that the interview setting also needs to be taken into account. In our study the students decided on

⁴ Domains of applicability refer to specific contexts in this study.

the time and location for the interviews. Rose (1991) suggests that we need to 'understand beyond', to be aware of how the social and cultural factors which both the interviewer and the interviewee bring to the encounter affect what happens thereafter.

Fontana and Frey (1994:367) argue that because the goal of unstructured interviewing is *understanding* (their emphasis), "it becomes paramount for the researcher to establish rapport". They state that the interviewer must be able to put him/herself in the role of the respondents and attempt to see the situation from their perspective, rather than impose the world of academia and preconceptions upon them. In my case, I had a very good rapport with these students from my tutorial group. Fontana and Frey (1994:367) state that "close rapport with respondents opens doors to more informed research, but it may also create problems, as the researcher may become a spokesperson for the group studied, losing his or her distance and objectivity, or may 'go native' and become a member of the group and forgo the academic role". This is a limitation of this method.

4.6 Transcribing of interviews

Interviews were subsequently transcribed verbatim. Students were given the transcripts for verification and acceptance. The transcripts were then analysed (see detailed analysis in the next section). The interviews were transcribed per context and all the transcribed descriptions were put into a single 'pool of meaning'⁵.

From the interviews I focused on picking the descriptions that were relevant in relation to the Empirical Research Question a) what are the qualitatively different ways in which first-year university physics students conceptualise, or experience, conceptual links between basic Newtonian dynamics concepts as represented by their own concept maps? The interpretation of each statement has to be made in relation to its context in

⁵ Pool of meaning – all the material that have been collected by the researcher (in this case all the interview transcripts)

the protocol where it appears. The statements gain their significance through comparisons with other statements in the same protocol and in others that are found to be relevant. As a result of such comparisons made on the basis of the interpretative work, a pattern of similarities and differences emerge.

4.7 Analysis of data

4.7.1 Analysis of phenomenographic data

One way of looking at my research is an attempt to describe the variance in the experienced reality in learning Newtonian dynamics. Leedy (1993) however argues that we have only descriptions of our perceptions not perceptions of the students. I agree with him to a certain extent, however, the phenomenographic analysis adopted in this study allows researchers to describe variation in students' perceptions as idealised ways of thinking lifted out of their context.

In this study the propositional knowledge from concept maps and interviews are grouped with a focus shift to the relations between the groups of description. The groups are made by using *what* is focused on, and *how* the explanation is given. A set of categories of description in terms of which we can characterise the variation in how a certain phenomenon is experienced, conceptualised, understood is developed by establishing the critical attributes of each group, and what the distinguishing features are between the groups.

For the phenomenographic research question (Empirical Questions a) and b), see Chapter 1) I transcribed all the interviews verbatim and then read and re-read them several times while listening to the audio tapes to make sure I appreciated the voice-inflection nuances embedded in the descriptions and at the same time began to gain an appreciation of the core elements of the descriptions. From this 'pool of meaning' obtained from the transcribed interviews, I started sorting them to generate categories

using the referential and structural phenomenographic constructs to *hermeneutically* generate the categories (an iterative process of generating, and delimiting new, emerging categories).

I then started cutting up these descriptions and colour-coding them so that I could look for differences and similarities amongst the extracts and formulate categories keeping in mind that the categories should emerge from the data and should not be pre-defined in any way. Then my procedure followed a *hermeneutic* iterative format: that is, a cycle of cutting, colour-coding for the sorting of descriptions into piles, followed by splitting and merging of piles, re-sorting, re-splitting and re-merging of piles -- on and on until equilibrium occurred and the categories of descriptions had emerged. In other words, until no further sorting could take place. The cut descriptions were put in different labelled envelopes for each category. It must be noted that in order to get to the final set of categories of description I had lifted the students' descriptions out of their contexts. Finally the following steps took place *for each* of the thematised scenarios:

- Once the categories had reached equilibrium, I had to qualitatively describe the understandings which the categories of description characterise.
- Then I had to qualitatively describe how each category was delimited from another in terms of the phenomenographic notion of *external horizon*.
- Then I had to qualitatively describe the internal relationships that occur within each category – the *internal horizon*.
- To complete the descriptions of the categories of description I then needed to give the referential aspects of each category (the meaning aspect of the understanding).
- I then drew up a summary table for each of the thematised scenarios (answering empirical question a)) and then lifted the commonalities

out of these contexts to get a list of qualitatively different understandings.

- Lastly, I ranked the categories of description in the summary table according to their logical relationships to form an *outcome space*.

4.7.2 Analysis of non-phenomenographic data

Once the categories of description were found, I looked at the logical relationships that emerge between the categories of description. I mapped categories of description with the study-provided contexts to look for evidence of trends. I noted the observed frequency of the categories of description in each context. I then used Chi-square statistic to test association between categories of description and the contexts (see results in Appendix D). The results showed statistically significant evidence that there is some association between categories of description and contexts even though it is not very strong. This result then prompted me to further look at this relationship at an individual level, hence the case study.

The case study then penetrated deeper the association between the categories of description and the contexts at student level. My approach was to look at the students' descriptions given within and across study-provided contexts. I used the categories of description obtained in Chapter 5 to sort the students as individuals, and then used the phenomenographic framework 'anatomy of awareness' to search for critical aspects discerned and focused upon by the students in and across the study-provided contexts.

I mapped each student with categories of description in different contexts, within and across contexts. I also looked at observed frequency of categories of descriptions in each context for each student. Again I was looking for evidence of trends. Patterns of shifts emerged between and within contexts. These patterns emerging from the mappings, together with examples of students' descriptions are discussed in detail in Chapter

6, Section 6.3. From this discussion variation in ways of experiencing context emerged as a critical aspect in ways of experiencing Newtonian dynamics conceptual links (see full discussion in Chapters 6 and 7, Sections 6.3.1.3 and 7.2.4 respectively).

4.8 The results to be presented

4.8.1 Phenomenographic results to be presented

A limited number of distinct qualitatively different ways of conceptualising Newtonian links were found and are presented in Chapter 5. The procedure to get to the categories was a lengthy and painstaking iteration with continual modifications until equilibrium had been reached. The qualitatively different ways were presented as categories of description. These categories of description were discerned from the interviews in terms of their meaning (referential aspect) and structure in terms of background to descriptions; what descriptions drew on; and nature of discourse. The structural aspect was concerned about how the link was conceptualised, and the referential aspect was concerned about the meaning given to the link.

Constructing categories of description may be depicted as a kind of iterative *hermeneutic circle* procedure which uses the 'parts' to evolve the 'whole' which in turn delimits the contributing 'parts'. Once a category of description was constructed, a way of experiencing was generated by framing the category of description as a characterisation of a way of experiencing something.

A logical relationship existed between the different categories. This was a hierarchical structure based on logical complexity and specificity. The categories of description together with their logical relationships formed the outcome space. The categories of description represented the results for the phenomenographic investigations.

The categories of description are not analogous to the concept maps (Gowin and Novak, 1984) which are representative of individual patterns of reasoning. Categories of description are rather a kind of collective identification of important explanatory attributes. Categories of description, as the collective outcomes of research into students' experiences – characterised in my study as *sense making* – in a specific area, represent “an abstract system of description, a gigantic space of categories, in which individuals move – more or less freely – back and forth” (Marton, 1984:62). However, this does not preclude an individual from having such an internal representation, there are simply no claims made in this regard. Nor does it preclude individuals being mapped onto a category of description as is done in the analysis for the last empirical research question.

The general validity and reliability of phenomenographic studies is sometimes a thorny issue amongst non-phenomenographers. Validity and reliability in phenomenographic studies has been discussed in detail in the previous Chapter, see Section 3.8. In the next Chapter we discuss the categories of description found in exploring the qualitatively different ways in which students conceptualise Newtonian dynamics links.

4.8.2 Non-phenomenographic results to be presented

The study was carried beyond phenomenography to look at theoretical research questions and the full theoretical results are presented in detail in Chapter 6. The theoretical results contribute to addressing the following questions,

1. What is a way of experiencing a phenomenon? and,
2. How do different ways of experiencing something evolve?

The mappings of individuals with the categories of descriptions found were made to establish the existence of any correlation across and within contexts. There was evidence of patterns of shifts between and within

contexts. Each shift was supported by examples from students' interviews. The variation in ways of experiencing context was also evident. The discussions of the theoretical findings can be found in Chapter 6.

The educationally critical aspects from both phenomenographic and theoretical results are discussed in detail in Chapter 7 together with the implications to teaching.

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Chapter 5

Students' conceptualisations of links between basic Newtonian Dynamics concepts – Results at a collective level

5.1 Introduction

The aim of this analysis chapter is to yield *descriptive categories* of the qualitative variation found in the empirical data. That is, the categories will provide a kind of analytical map of variations of ways in which conceptual links are conceptualised or experienced. These categories resulted from an intensive examination of the data as outlined in Chapter 4. The empirical study as detailed in Chapter 4, was designed to investigate the research questions,

1. What are the qualitatively different ways in which first-year university physics students conceptualise, or experience, conceptual links between basic Newtonian concepts as represented by their own concept maps?
2. What kind of logical relationships emerge between the categories of description?
3. How do the categories of description relate to the contexts provided for the study?

In this Chapter, I present my analysis for research question 1 in section 5.2, research question 2 in section 5.3, and research question 3 in section 5.4. Before I begin with the details of my analysis I think it would be useful to give a brief overview of phenomenography and my associated analytical method (for the full account see Chapters 3 and 4).

5.1.1 Brief Overview of phenomenographic analysis

As an introduction to the analysis provided in this Chapter, a brief summary of the analytical details is given. In a study such as this, ways of experiencing mean ways of seeing, understanding, conceptualising or

making sense of, in terms of how parts of a phenomenon are discerned from the context, how parts relate to other parts, and how these are related to the whole - as characterised by Svensson (1984a), in my case, how links are discerned from a given context, how they are related to other links, and how they are related to a context. In this study I am thus using ways of experiencing, understanding, making sense of, and conceptualising interchangeably from time to time. However, in this Chapter, I will predominantly be using the term conceptualisation to mean way of experiencing. The term context in this study refers to the provided context, or domain of applicability.

Phenomenography is a non-dualistic perspective which means that any analysis done with phenomenographic framing is neither looking at mental structures nor environmental factors which may influence the workings of such mental structures. The variation in ways in which people experience or conceptualise phenomena in their world is fundamental to phenomenographic studies. In my case, I am describing the variation in the ways in which students conceptualise the conceptual links based on their own concept maps of basic Newtonian dynamics concepts.

The objective of this analysis is to reveal the variation captured in qualitatively distinct categories of ways of experiencing the phenomenon in question, regardless of whether the differences are differences between individuals or within individuals; “a description of a way of experiencing might apply in some sense across a group, or, there again, might apply to some aspect of an individual” Marton and Booth (1997:124). A brief overview of categories of description is given in the next section (for details see Chapter 3).

5.1.2 Brief overview of categories of description

In Chapter 4, I discussed how my analysis followed a *hermeneutic circle* procedure to iteratively search for differences and similarities in descriptions students made about the conceptual links, until equilibrium was reached, in order to generate categories of description. I have used these categories of description to represent characterisations of category of description, or ways of experiencing. The categories characterise or rather denote the category of description discovered. Johansson, *et al* (1985:249) state that category of description reflects the terms in which people interpret the world around them, categories of description express our interpretations of others' interpretations.

Marton and Booth (1997:127) define categories of description as, "the way in which ways of experiencing are described". In a study such as this, one shifts attention from individual interview to the 'pool of meaning' consisting of relevant quotes selected. The process involves looking at similarities and differences that can be found in these quotes or descriptions. From this process categories emanate, where descriptions with similar characteristics will be grouped together to form a category. The categories are not pre-determined but arrived at through a lengthy iterative procedure (see Chapter 4). This procedure uses 'parts' to evolve the 'whole'. The categories presented in the study do not form an exhaustive system, but are complete in the sense that nothing in the collective experience manifested from the sample is left unspoken.

All categories found together with their logical relationships form what is known as an *outcome space* of qualitatively different ways of experiencing or conceptualising the links between basic Newtonian dynamics concepts. The outcome space of variation in ways of experiencing the links is summarised in the next section, and the categories are then described.

5.2 Phenomenographic results

5.2.1 Background

Using the phenomenographic analytic approach, my way of capturing the variation in the essence of what was being thought involved the use of a structural aspect consisting of the background to the descriptions, what the descriptions drew on, how the descriptions were drawn on (nature of discourse), and the meaning of the links (the referential aspect). To do this, the students involved in my study were interviewed so that I could use their descriptions to analytically capture the essence of what was being thought about. During the interviews I used pre-defined conceptual contexts, which I created for their concept maps, to explore how the students conceptualised the links which they had made. However, as described in Chapter 4, once I had identified categories of description within these conceptual contexts, I then decontextualised them by identifying and describing critical aspects of the categories of description in terms of their structural and referential identities (see earlier discussion of these terms in Chapter 3, Section 3.7).

5.2.2 Summary of the results for research question 1

The phenomena, which from the outset are central to this study, are the links students make between basic Newtonian dynamics concepts. The variation found in the ways of conceptualising or understanding the links between basic Newtonian dynamics concepts is summarised in Table 5.1, in terms of a four-tiered outcome space of ways in which students conceptualise links between basic Newtonian dynamics concepts. The outcome space of these four qualitatively different ways of conceptualising links discovered from the study, are ordered in terms of the logical relationships discussed in research question 2 (see Section 5.3). These categories of description were discerned from the interviews in terms of their meaning (referential aspect) and structure in terms of

- a) background to descriptions;
- b) what descriptions drew on; and
- c) nature of discourse.

a) Background to descriptions

The background to descriptions is discernment from the context. The background shows how each category is delimited from another. It is the delineation between categories. It shows what students are focusing on. This is known as the *external horizon* in phenomenographic language.

b) What descriptions drew on

This is discernment of parts and their relationships within the whole. It shows internal relationships that occur within each category. It shows how students focus on something. This is known as the *internal horizon* in phenomenographic language.

c) Nature of discourse

The nature of discourse is used in this study to mean the nature of the language used to describe a conceptual link (in other words, the couching of the descriptions). In each of the illustrations of the categories below, examples of discourse are given. The nature of discourse illuminates the delimitation between the categories found in terms of the couching used.

5.2.2.1 The structure of the conceptualisations of the students in the study

The results of research question 1 are presented in three stages, a summary of the results is given, followed by illustrations from the data, followed in turn by a discussion of results. I need to point out that none of the

illustrations can capture all aspects of any category of description; they only serve to show how the essential attributes and delimitations present themselves.

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Table 5.1 *Analysis of variance in descriptions of meanings of conceptual links in conceptual maps of basic Newtonian dynamics concepts*

<i>Structural Aspect</i> <i>“How do they conceptualise links?”</i>				<i>Referential Aspect</i> <i>“What is the meaning of the link?”</i>
Category of description as a characterisation of a way of conceptualising conceptual links	Background to description	What descriptions drew on	Nature of discourse (couching of description)	What the link is seen as
A. Links are Cause and Effect relationships based upon intuitive deductions	the everyday world in generalised form rather than in any specific form.	intuition and common sense	vague and in everyday language	an intuitive connection describing cause and effect
B. Links are Cause and Effect relationships based upon textbook definitions, formulae and laws	classroom physics as viewed through vague recollections of physics concepts	a mixture of common sense and of recalling textbook definitions, formulae and laws	vague and tendency to move towards textbook language, but strong in terms of academic discourse – that is trying to pick up on potential definitions	a connection representing definitions and symbolic representation (physics formulae) in describing cause and effect
C. Links are Cause and Effect relationships based upon application of laws and formulae	classroom physics as viewed through recollection and application of definitions and formulae	formulae, definitions, laws, and dependencies in relationships or formulae	abstract with an introduction to using formulae; takes on an interpretative value	a connection representing application of laws and formulae in describing cause and effect
D. Links are Cause and Effect relationships based upon integrated physics explanations (beginning of formal and systematic thinking)	the world is beginning to move from classroom physics into the world of physics, and experience is about this physics which is everywhere	establishing a conceptual framework within which to consider a situation; carefully selecting concepts, definitions, laws, and formulae and using them to give a conceptual meaning to a situation.	is about this physics which is everywhere	a connection representing conceptual meaning in relation to context in describing cause and effect

I will now discuss each of these categories together with illustrative excerpts from the interviews which formed part of the associated category of description. I must mention here that in all the categories the links were seen as some form of cause and effect. Cause and effect is the qualitative description of how each category is delimited from one another, that is, the discernment from the context.

5.2.3 Examples and discussion of categories of description discovered

Examples are given below to illustrate these categories of description. Each example presents what is focused on, with examples of discourse used to give an explanation.

5.2.3.1 Category A: Links are cause and effect based upon intuitive deductions

In this category we find intuition manifesting itself in two themes:

- a) **links based on own experiences (everyday and school); and**
- b) **links based on everyday meaning of words.**

These two themes are discussed below.

5.2.3.1.1 Links based on own experiences

Here a link is an immediate impression, a visualised event or experience based on acquired beliefs, where these beliefs seemingly could come from everyday experiences or are based on isolated fragments of knowledge from classroom physics. The links seem to be imagined explanations extrapolated from everyday experiences. This is illustrated below.

Student S1 was comparing the first scenario where the road was dry with the second scenario where the road was wet.

Link(s): "force of friction reduced by road wetness"

I: ... you talk about force of friction reduced by road wetness. What do you mean by that?

S1₂¹: ... since it was wet it means there was lesser friction, that's what I mean. There was lesser friction compared to that (referring to first scenario) ... - *there was less grip for the men to try and overcome* the – I think if you had to compare the two scenarios, the men would be able to push a car easier in a drier place than in this wet road. That's what I mean.

He later said,

S1₂: ... when the road is dry I think it will be easier to push anything, okay, provided it was - I assume that you are wearing a proper gear, not something that is slippery, okay?

I: Now, about friction, is it going to be less or ...

S1₂: Yah, the friction is going to be higher on a dry ground which will help you push the thing easier, because friction is what we use to walk, is what we use to overcome a lot of things, so if it's wet there's very less friction which means *there's greater resistance or greater problem that you're faced with.*

I: ...you say it's a force of friction reduced by road wetness, that is creating problems for the four men. Can you elaborate more about that?

S1₂: ... so if it's wet, the friction is reduced, hence *the grip is reduced and then you'll have greater problems.*

The focus is on friction on the feet of the men pushing the minibus. We can see that from the student's experience when the road surface is wet the men will slip easily and hence the men will have difficulty pushing the minibus, and this slipperiness is attributed to the fact that friction is reduced since the road surface is wet.

Here the surface is of importance, it is the ease or difficulty with which the men will be pushing that will determine the magnitude of friction. From

the example above, less friction implies greater resistance or difficulty in pushing the car, while more friction enables men to walk and to push the car. This is summarised below as what has been focused on and couched.

FOCUS:	friction (e.g. friction on men's feet)
DISCOURSE:	intuition and common sense (e.g. "less grip for the men to try and overcome", "wearing a proper gear", "less friction means greater problem that you are faced with")

Here is a similar example from student S4's interview.

Link(s): "taxi slips on the wet ground"

- I: Um, what prevents the wheels from rolling? That's my question?
- S4₂: Yah, I say the road is wet and it is muddy, *then the force on the ground won't be enough to grip those wheels to be able to roll, hence they will have to slip.*
- I: Okay. Which force are you talking about?
- S4₂: The ground force actually, ... like I've mentioned, there is a relationship that I've shown between the ground and the force, the retarding force. ... the ground exerts the force, that force. You see, the one won't be enough to allow or to make the wheels to roll.

Again frictional force is not enough and this means there is an inability for wheels to roll. Here retarding force sounds like it is force of friction. It could possibly come from the fact that friction in most school textbooks is defined as a force that opposes or retards motion, hence retarding force.

FOCUS:	retarding force (friction) on the ground
DISCOURSE:	intuition and common sense (e.g. "not enough to grip those wheels to be able to roll")

When asked about the impact of the differences between the wet road and the snowy road on his concept maps, S4 replied,

¹ The subscript 1 denotes interview 1 and subscript 2 denotes interview 2

Link(s): "men slip on the snowy ground"

- S4₂: Yes, there are differences. Well, the snowy road it should be - should be having *more of the grasp than the wet road* if we want something to move from one point to another [indistinct].
- I: What obstacles are you talking about?
- S4₂: In this case, the major obstacle which, to me, should be the retarding force that is exerted by the ground. The different surfaces do by - I mean the forces do -- they both differ by different surfaces which will basically not be the same.
- I: Okay, now, comparing the three maps, can you tell me, this retarding force, where is it greater?
- S4₂: Er, I think it should be greater in the snowy one, because knowing, or considering how snow should be, and I expect this to be because usually, you know, snow is something above the ground and you find that *usually it's not easy to move on the snowy road than to move on the dry road*, hence [indistinct].
- I: Okay. Can you compare the wet road and the earlier map. The retarding force, which one will be greater?
- S4₂: It should be greater in the other one, the first one, not the wet one, water should have a lower force, retarding force.
- I: Okay. So you are saying with a snowy road we will have the greatest retarding force, followed by the earlier map (i.e. dry road), and then lastly the wet road?
- S4₂: Yes, I agree.

Here the focus is on the retarding force that is caused by the surface of the road and motion. Once again the ease or difficulty one has in moving on a surface is associated with retarding force (friction). The difficulty implies high friction.

FOCUS: retarding force (friction) on surface

DISCOURSE: intuition and common sense (e.g. "snowy road should be having more of the grasp than the wet road")

The level of intuition used here could be attributed to the fact that the student has not experienced snow before. This was also explicit in another interview with another student S1.

S1₂: ... if you want something to move faster, that is why you find that, *I think I've seen it on TV, people in Europe playing with those things called like sledges, moving on the snow.*

5.2.3.1.2 Links based on everyday meaning of words

Here everyday use of words is juxtaposed with terms used in physics. Most students have difficulty understanding concepts like velocity, acceleration, force, mass and power, as they have already made sense of these concepts in everyday world (see Viennot, 1979, Trowbridge and McDermott, 1980). This is illustrated below.

Here force, power and strength are synonymous.

S4 indicates such a way of experiencing the links. Here, for example, relating power and men; and, power and acceleration

Link(s): "men produce power" and "minibus produces power"

I: How do the men produce power?

S4₁: The fact that they have exerted a force on minibus and minibus is moving implies that, may be we should cancel this link, (silence), because it implies that power is involved because (silence) I can't remember the definition of power (silence).

I: Should we cancel the link?

S4₁: No, wait a minute (silence) in this link I thought of *literally exerting power*, what came into my mind was imagining those men struggling to get the minibus to move and ultimately getting it to move *they must have applied more power on it to get it moving.*

I: How does the power move the minibus?

S4₁: I think basically when explaining that they produce power, *it is power in the form of men*, I'm referring to the power produced by these men, I'm referring to men because *this power is in the form of men since they produce it.*

Later on when asked what he meant by "power accelerates taxi", he responded,

Link(s): "Power accelerates taxi"

I: What do you mean by power accelerates taxi?

S4₁: In this case regard of the power produced by minibus since after collision both cars are stuck together which means *power produced by minibus caused movement of taxi*.

We can see from the above example that student S4 interprets force as 'power' and also as 'strength'. This explanation could possibly come from the fact that in everyday use of language, force is associated with power, for example, police force.

FOCUS: power

DISCOURSE: intuition and common sense (e.g. "men struggling to get the minibus to move", "they must have applied more power on it to get it moving")

Discussion

The two themes described above, form sub-categories of description for cause and effect relationships based upon intuitive deductions. Here the links seem to be imagined explanations extrapolated from everyday experiences, and/or from fragmented knowledge from classroom physics. Statements seem to be made without understandable and integrated explanations. This could indicate that the statements are used without any underlying understanding (i.e. without fully understanding in depth).

Again we do not get an appropriate scientific explanation of cause and effect, but it seems to be first impression made on the phenomenon based on prior knowledge. Where attempts are made to give a scientific explanation 'half-truths' or superficial explanations (i.e. explanations involving only the most obvious aspects of a phenomenon, and not those aspects that require more effort to understand) from classroom physics experience are used. In other instances where there is no experience at all e.g. snowy condition, an imaginary explanation is given based upon

intuition of how they think the situation should be. Students are purely drawing from intuition and using common sense to give an explanation of a phenomenon. The language used is from the everyday world as opposed to Newtonian dynamics language (see examples of discourse).

The focus in most cases is on the surface of the road which is determining the ease or difficulty with which the men walk or push the car. On a wet road it is difficult to walk (the grip is reduced) or push the car hence there is less friction, contrary to what was said initially, that on a snowy surface, it is difficult to walk hence there is more friction. On a dry surface it is easy to walk or push a car, and friction is more but less than in snowy conditions. Another argument that was raised by student S5 is that there would be more friction on a wet surface than a dry surface, and the least friction on a snowy surface.

In another instance in an interview with student S4, velocity was seen as *how fast an object goes*, and the same could probably be said about acceleration (see Appendix C). Velocity is related to mass the way physicists relate acceleration with mass, i.e. mass is inversely proportional to acceleration. It is clear from this that the student does not understand fully the distinction between velocity and acceleration. This is not surprising as many students in introductory physics have difficulty with these two concepts. Physical concepts like velocity, acceleration, force, mass and power are metaphors drawn from everyday speech, to which physicists give profoundly altered scientific meaning, only vaguely connected to the meaning in everyday speech. Hence, the difficulty in distinguishing between everyday concepts and physical concepts. When these concepts are taught in introductory physics, students have to discard that prior knowledge, which forms their central concepts, and accommodate new meanings of concepts.

Structural Aspect

The internal horizon of this category of description, that is, those aspects of links between basic Newtonian dynamics concepts simultaneously focal in awareness, consists of intuition and common sense. The everyday world in a generalised form and everyday language are part of the external horizon. The external horizon delimits a link to a simple common sense or everyday relationship between concepts.

Summary of category A

In summary, this category of description consists of immediate representations or impressions, visualised and imagined events, informed guesses and experiences based on acquired beliefs. Discourse is vague and in everyday language. The links are cause and effect related to intuitive deductions.

5.2.3.2 Category B: Links are Cause and Effect based upon textbooks definitions, formulae and laws

Links are seen here as textbook definitions, laws and formulae. Students recall and state textbook definitions, formulae and laws to explain the links. They either state a formula as in textbooks or they give a translation of formula in words. This is illustrated below by the following examples:

Here students are stating definitions.

Student S5 states the definition of friction.

Link(s): "friction opposes motion"

I: What do you mean by friction opposes motion?

S5: Since these men are applying a force in whatever direction then there is obviously a force in the opposite direction which is friction, opposing motion

even when they have stopped applying force, that is, after releasing, the two cars will move for some time and stop. It is friction which is causing them to stop because the surface is not smooth and also wind resisting the motion.

I: Is wind resistance friction?

S5₁: You may say so because it is force acting on opposite direction.

I: Is every force that is acting in opposite direction friction?

S5₁: Not every force but *every force that opposes applied force is friction*.

Here the definition of friction is given as a force that opposes applied force.

FOCUS:	friction
DISCOURSE:	classroom physics definitions (e.g. "every force that opposes applied force is friction")

In another interview student S1 gives a definition of friction.

Link(s): "friction caused them to stop" and "force on minibus and taxi caused them to accelerate with opposite direction to their motion"

I: How did friction cause them to stop?

S1₁: *Friction always opposes motion*, right, so in this case the two cars accelerated in the opposite direction to their motion.

I: What do you mean opposite direction, to what?

S1₁: Remember when these guys were pushing they let it go and the minibus collided with the taxi pushing it forward and remember there is no external force at the moment they start moving but there was external force at the moment the bus hit the taxi. Friction was the only force acting on them and *it always opposes motion*, then it causes the two cars to stop at some instance.

FOCUS:	friction
DISCOURSE:	classroom textbooks definitions (e.g. "friction always opposes motion")

Somewhere in the interview student S1 said friction enables us to walk (see category A above).

Here student S2 gives a definition of force as is taught in schools.

Link(s): "four men exert force on stationary minibus" and "applied force exerted by an external environmental factor (four men)"

I: How do the four men exert force on stationary bus?

S2₁: *The force is the regular push or pull*, in this case it's a push, the simplest explanation of a force is a push or pull.

I: Is friction a push or pull?

S2₁: It's a simplistic or very elementary description of a force which I came across at school, I can't describe friction as a push or pull.

He gives here an elementary definition of a force as it is taught in schools.

FOCUS: force

DISCOURSE: classroom textbook definitions (e.g. "force is the regular push or pull", "elementary description of a force which I came across at school")

Here students are stating laws.

Here student S1 recalls laws and use them to explain the links.

Link(s): "momentum was conserved" and "in inelastic only momentum was conserved"

I: What do you mean by momentum was conserved?

S1₁: It means the momentum that the two cars had before is equal to momentum after in magnitude.

I: What makes them to be equal?

S1₁: That's the principle of Linear conservation of momentum that we were taught.

I: Do you believe in this principle? Do you think this is true in everyday life?

S1₁: I don't think I've really seen it work, ...mmmm ... Okay, I remember I did a Lab practical on linear airtrack, which can be applied to real life situation.

The laws are stated without really believing in them as illustrated above.

FOCUS: Linear conservation of momentum

DISCOURSE: classroom textbook (e.g. "That's the principle of Linear conservation of momentum that we were taught")

Here students are stating formulae in words.

Here student S2 is stating definition of momentum by formula.

Link(s): "linear momentum is conserved before and after collision"

I: What do you mean by linear momentum is conserved in the collision?

S2₁: *The definition of momentum is mass times velocity of the object concerned, when we say Linear momentum is conserved in this particular example, objects collide, they have initial velocity before collision, and final velocity after collision which may or may not change, so the product mv before is equal to mv after regardless of whether it is elastic or inelastic collision.*

FOCUS: conservation of momentum

DISCOURSE: classroom textbook (e.g. "the definition of momentum is mass times velocity")

In another interview student S5 gives the definition of work as follows,

Link(s): "four men do work" and "force is applied over a certain time"

I: What do you mean by four men do work?

S5₁: Because they are applying force over a certain time.

FOCUS: work

DISCOURSE: vague recollection of classroom textbook formula (e.g. "applying force over a certain time")

Here student S5 incorrectly recalls the textbook definition or formula for work, he uses time instead of distance.

Discussion

It can be seen that in all cases students are recalling and stating, either correctly or incorrectly, definitions of concepts, laws and formulae as stated in most textbooks. This is evident where the focus is on frictional force, as most school textbooks define this force as a force that opposes motion. Students do not necessarily understand or even believe some of the definitions, as has been seen with student S1 when stating the Linear Conservation of Momentum.

From a physics perspective, friction is a passive force. This type of force is defined as a force that adjusts itself in response to active ones, hence, it seems to be a difficult concept to understand. Students focus on frictional force only as a force that opposes motion of an object, and do not look at situations where friction can act in the same direction as the velocity of an object. The view that friction always opposes motion, ignores the fact that in order to get something moving, e.g. pushing a car, friction can be thought of as aiding the getting of the car into motion. This view is restricted in its application as it does not cover all aspects of friction, however, it is true as far as it goes.

If we look at the increase (or adjustment) of a passive force like friction, it cannot take place indefinitely; it continues only to the point at which it *breaks* something or gives way, as in sliding friction. Friction builds up from zero to a maximum value. A situation where friction builds up from zero to its maximum value happens when friction acts to accelerate a body, as in the case of a block on an accelerating cart. The frictional force exerted on the block by the floor of the cart increases as the acceleration of the cart increases, since there are no other horizontal forces acting on the block, this situation is fundamentally very different from the one in which a block is acted on by an external horizontal force while resting on a stationary platform (Arons, 1990).

In the previous category, students said that friction enabled them to walk, but in this category this was not the case, as they state that friction always opposes motion. Most students fail to accept that friction can accelerate an object, they only see friction as a force that opposes or retards motion.

Structural Aspect

The internal horizon of this category of description, that is those aspects of links between basic Newtonian dynamics concepts simultaneously focal in awareness, consists of textbook definitions, formulae and laws. The school physics or introductory year at university as it is packaged in courses is part of the external horizon. The external horizon delimits a link to textbook definitions, and translation of laws and formulae into words.

How is this category related to the previous one?

In this category discourse is still vague and in textbook language as in the previous one, however, now it is more strongly in terms of academic discourse, that is trying to pick up on potential definitions. This category differs from category A in that here the focus is on what has been learned and taught in class, it is not on the everyday world in the generalised form as is the case in category A. The way of conceptualising in the second category of description is in a specific form in that the world is the world of introductory physics courses, i.e. a school setting, while in the previous one the world is in a generalised form. There is a tension between the two: one can suggest that the student 'really believes' the first (intuitive) description, even though it is incoherent or even contradictory, but learns and reproduces the second (more formal) one because that is what is expected of her/him in the class situation.

Summary of category B

In summary, this category of description consists of textbook definitions, formulae and laws as they are arranged in classroom physics. The discourse is still vague and in textbook language, but it is in terms of academic discourse that is trying to pick up on potential definitions. The links are cause and effect related to textbook definitions, formulae and laws.

5.2.3.3 Category C: Links are Cause and Effect based upon application of formulae and laws

The application of formulae and laws has manifested itself in two themes:

- a) **Links as recollection and application of formulae and laws** (in which formulae and laws are recalled and used to explain the link); and
- b) **Links as dependencies in relationships** (in which, if two or more concepts are dependent on the same primary concept, a change in one affects a change in another).

The above themes are explained below and examples are used for illustration.

5.2.3.3.1 Recollection and application of formulae and laws

Here we see students recalling formulae and laws, and then using them to illustrate a link. Sometimes this is illustrated by substituting numbers into a formula or a law and not necessarily taking into account considerations that have to be made in a specific situation, such as, looking at applied force when applying Newton's second law instead of looking at resultant force. See examples below.

S4 gives an application of Newton's second law of motion.

Link(s): "force gives rise to acceleration"

I: What do you mean by force gives rise to acceleration? How does it give rise to acceleration?

S3₁: In this case, force is applied on minibus as it is applied on, the minibus moves and it accelerates as it moves.

FOCUS: force and acceleration

DISCOURSE: (e.g. "force is applied as it is applied on, the minibus moves and it accelerates as it moves")

Here it is applied force that gives rise to acceleration not resultant force.

In another interview with student S1 illustrates conservation of both momentum and kinetic energy in an elastic collision.

Link(s): "in elastic collision both momentum and kinetic energy will be conserved"

I: Okay. You also mention that in elastic collision, both momentum and kinetic energy will be conserved. What do you mean by this?

S1₂: ... if you had to calculate the kinetic energy for the bodies before they collided and the kinetic energy afterwards, it should be the same, hence that's what I mean by, er, conserved. because there's no energy lost and there's no momentum lost.

FOCUS: principles of conservation of momentum and conservation of energy

DISCOURSE: (e.g. "if you had to calculate the kinetic energy for the bodies before they collided and the kinetic energy afterwards it should be the same")

5.2.3.3.2 Application of formulae and laws based on dependencies

Here, if two or more concepts are dependent on the same primary concept, a change in one concept will affect the other. In other cases, one concept causes another. This is illustrated by the examples given below.

In this interview student S3 shows that work is dependent on force.

Link(s): "work is caused by force"

I: ... you say work is caused by force, what do you mean by that?

S3₂: For work to happen, there must be force involved. Um, okay. I guess that the men are pushing on the minibus, the men are using force and as a result they are applying force to push the minibus and they are doing – they are doing work on the minibus as they're pushing.

FOCUS: work and force

DISCOURSE: (e.g. "for work to happen, there must be force involved")

In another interview, student S4 shows that if two concepts are dependent on one primary concept, then a change in one will affect a change in another.

Link(s): momentum causes energy (kinetic)"

I: What do you mean by momentum causes kinetic energy?

S4₁: Again the fact that the minibus is moving and momentum is changing that will affect kinetic energy or change in kinetic energy.

I: How will it affect kinetic energy?

S4₁: If momentum reduces, *kinetic energy will also reduce because they both depend directly on speed.*

FOCUS: momentum and kinetic energy

DISCOURSE: (e.g. "if momentum reduces, kinetic energy will also reduce because they both depend directly on speed")

Discussion

Students recall formulae and laws and use them to explain their understanding of the links. They do not necessarily seem to select formulae or laws relevant to a specific situation. Students are dealing with momentum and energy concepts. They are dealing with principles of conservation of momentum and energy. They are vaguely applying the principles without necessarily defining the *system* that will be under consideration.

In some cases figures are substituted into a formula to illustrate a link. In other cases, when two or more concepts are dependent on a primary concept, a change in one will cause a change in another. The links are seen as an explanation of relationships between concepts, and such explanations use dependencies, substitution of numbers into formula to illustrate the relationship.

Structural Aspect

The internal horizon of this category of description, that is those aspects of links between basic Newtonian dynamics concepts simultaneously focal in awareness, consists of application of definitions, formulae and laws, or application of dependencies in relationships or formulae. Here there is a process of abstraction (relating specific instances to general principles), with an introduction of symbolic description – using formulae is part of the external horizon. Thus, the discourse becomes abstract with an introduction of the symbolic description – using formulae to express cause and effect relations. The external horizon delimits a link to application of formulae or application of dependencies in relationships.

How is this category related to the previous ones?

In this category, unlike the previous ones, discourse becomes abstract with an introduction of the symbolic description – using formulae. Discourse now takes on an interpretative value. This category of description is inclusive of the previous one B in that it recalls definitions, laws and formulae and uses them, while in B definitions, laws and formulae are only stated. Category C is more complex than the previous ones, since abstraction takes place, which was not the case in the previous ones.

Summary of category C

In summary, this category of description consists of application of formulae, laws and definitions. The discourse is abstract with an introduction of the symbolic description – using formulae which relate general situations to specific cases. Discourse now takes on an interpretative value. The links are cause and effect related to application of laws and formulae.

5.2.3.4 Category D: Links are Cause and Effect based upon integrated physics explanations

Here students begin to show a physicist's way of conceptualising the conceptual links they have made in their own concept maps. The examples below illustrate this.

In an interview with student S5, he explains velocity in different instances in the problem.

Link(s): "change in velocity is acceleration"

I: What do you mean by change in velocity is acceleration?

S5₁: That is, it is not moving at constant velocity because it is stationary first then it moves until it collides, and moves and stops, obviously the velocities are different in those stages.

FOCUS:	acceleration
DISCOURSE:	(e.g. "velocities are different in those stages")

Here change in velocity is given explicitly in terms of change in magnitude, however, change in direction could also be implied during collision.

Later in the same interview S5 uses Newton's first law to explain a phenomenon.

Link(s): "four men apply force on mass of the minibus" and "force is applied to mass of the minibus"

I: What do you mean by force is applied to mass of the minibus? Similarly, what do you mean by four men apply force on mass of the minibus?

S5₁: I would say they are applying force, since the minibus is stationary obviously there are forces acting on it which are balanced, the men would apply another force which will request the minibus to move, that is, adding another force that will cause motion, which is unbalanced, that is, at rest implies balanced forces and from rest to motion implies unbalanced forces.

FOCUS:	force and motion (at rest to motion)
DISCOURSE:	(e.g. "rest implies balanced forces, from rest to motion implies unbalanced forces")

In another interview with student S2, he describes Newton's second law.

Link(s): "Newton's 2nd law relating acceleration of an object with resultant force applied to object and with mass of object"

I: How does Newton's second law relate acceleration and force?

S2₁: That is, if you apply a force you will get acceleration, those two are proportional, you gonna get acceleration if there is a resultant force, but if it is only applied it

does not necessarily mean you get acceleration, e.g. when pushing a wall and wall does not move.

I: Is Newton's second law applied here as well?

S2₁: Definitely.

FOCUS: resultant force

DISCOURSE: (e.g. "if it is only applied it does not necessarily mean you get acceleration e.g. when pushing a wall and wall does not move")

I would like to mention here, that a counter example, that the student has given here, of "pushing a wall and wall does not move", is still a cause and effect relationship. The effect here is that the wall does not move. Here the reaction force (from the wall) adjusts itself to counter the applied force, hence the resultant force is zero. If the effect were to be "the wall moves" then the applied force would be greater than the wall's breaking strain, and we would see the wall falling over.

In another interview student S2 explained transfer of energy from system into environment as follows. Here the student focuses on the system not on objects individually.

Link(s): "energy transfer from system into environment"

S2₂: ... the system has – has – has, um, lost energy in – the form of the energy has been changed and, um, the environment has – has gained a certain amount of energy from the – from the collision in the form of perhaps light, um, you might have a few sparks or whatever coming off, and – and in heat. Heat will be also another form of energy which will be released into the – to the sort of external agent or environment.

FOCUS: system

DISCOURSE: (e.g. "the system has lost energy")

Discussion

The links depict a Newtonian way of thinking. This is the beginning of a systematic way of thinking which we did not see in earlier categories. Here there is a means of establishing a conceptual framework within which to consider a situation. Concepts, definitions, laws, and formulae seem to be carefully selected, taking context into account, since considerations for a situation are taken care of, and used to give a *conceptual meaning* to a situation. The links show understanding, seeking meaning, unlike in the first three categories where the links were primarily just reproducing to some extent, what has been taught, and also showing superficial understanding.

We see a student describing acceleration in terms of change in velocity. He is looking at velocity change in terms of magnitude and direction, although not explicitly stated. In this respect the student has given change in velocity a conceptual meaning. We also see student S2 in another interview using counter examples to explain how Newton's second law relates acceleration and force. He gives an example of pushing a wall and the wall does not move, to illustrate that Newton's second law is applied in such a case as well.

Earlier in the interview S5 explained the motion of minibus in terms of forces acting on it. He described the motion in terms of Newton's first law of motion. Although the description does not make mention of constant velocity, it could possibly have been omitted since it is not relevant to the current situation, he only talks about at rest with balanced forces.

Structural Aspect

The internal horizon of this category of description, that is those aspects of links between basic Newtonian dynamics concepts simultaneously focal in awareness, consists of establishing a conceptual framework within which

to consider a situation before selecting and applying formulae and laws. The world of physics is part of the external horizon. Here the discourse and experience is about physics. The external horizon delimits a link to physics relationship between concepts, whereby a conceptual framework within which to consider a situation is established before selecting and applying formulae and laws.

How is this category related to the previous ones?

In this category, unlike the previous ones, discourse and experience is about physics, an abstract scheme of general understanding that can be applied to understanding and determining outcomes in specific contexts. Here a conceptual framework is established within which to consider a situation - taking context into account - before selecting and applying formulae. This category of description is inclusive of previous categories in that one has to recall definitions, formulae and laws, and then select relevant ones for the situation in question, and then apply them. It also differs from the others in terms of specificity, in that the world is the world of physics where a specific situation with specific laws, application of laws, deductions, specific quantities and physical inferences is considered.

This category differs from the previous one, C, in that formulae and laws relevant to a situation are selected and used, unlike in C where formulae and laws are selected where they are not necessarily relevant to the situation, and numbers are substituted to illustrate a link. This last category is more complex than the previous ones in that careful analysis of a situation has to be established first, and formulae and laws relevant to the situation are carefully selected and used.

Summary of category D

In summary, this category of description consists of establishing a conceptual framework within which to consider a situation before selection and application of formulae, laws and definitions. The discourse and experience is about this physics which is everywhere. The links are cause and effect related to conceptual meaning in relation to context.

From Table 5.1, in category A, students simply use common sense and intuition. In category B they are just stating and recalling definitions and formulae and not implementing them. Here, they are trying to formalise it in a form of symbolic representation but not carrying it through by implementing. While in category C, they use definitions, laws and formulae to analyse and deduce but might not necessarily select the relevant laws and formulae for the situation. Here we see abstraction beginning to take place. In category D, the meta-level or meta-understanding comes into play, they know which law or formula to apply and how to apply it. Here they correctly select the concepts, definitions, laws and formulae that are relevant to the situation at hand, and they apply them in an integrated way, i.e. they know which one and in what order to apply them, for a particular situation.

The variation between the different ways of seeing the problem can thus be understood as a variation in the extent to which the various aspects of a full understanding of the problem are discerned and are simultaneously present in the students' focal awareness. Marton and Booth (1997) suggest two constituting aspects of awareness - as - the delimitation of a theme from the context; and the discernment of the parts that contribute to the theme. They argue that certain structures of awareness are implied by certain ways of understanding, that the student is simultaneously aware of certain aspects of a phenomenon. The delimitation of a theme further suggests that certain aspects become figural, in focus, whereas other aspects recede to ground. In experiencing a phenomenon there are always

certain aspects of the phenomenon at the time given to us simultaneously in our focal awareness (Marton and Booth, 1997).

5.3 Logical relationships emerging between categories

There are relationships that can be seen between the categories. In this section we look at what type of relationships are present between the categories found. The question we are addressing here is,

“What kind of logical relationships emerge between the categories of description?”

5.3.1 Relationships based on complexity

From Table 5.1, we see a hierarchical structure based on logical complexity and specificness (to be discussed later). The responses are increasingly better in quality in terms of complexity or depth at which they give their answers. B is more complex than A in the sense that the world is not a generalised world but narrowed down to the world of classroom physics as experienced by students. C is more complex than B and A in the sense that abstraction takes place here and focus is on formula and its application. D is more complex than the first three in the sense that now the world has become a specific world, a world of physics, where context is understood and taken into account.

In each of the four categories, cause and effect is used differently. The four different ways of conceptualising the links are ordered in a hierarchy in terms of complexity and specificness, see Figure 5.1 below. The four ways of conceptualising links between basic Newtonian dynamics concepts represent different degrees of partial understanding of the whole.

The hierarchy moves from preconceived or alternative physics in A, to relying exclusively in textbooks and lecture notes in B, i.e. memorising

textbooks definitions, and in C, recalling formulae and laws and superficially using them to explain phenomena, to improved understanding of physics in D. In D, Newtonian description, the problem is seen within a scientific world, a world in which certain abstractions have to be considered and used in an appropriate way. The Newtonian experience, in contrast to intuitive understanding, relates the concepts in such a way that rest and uniform motion are associated with equilibrium, and the presence of force is associated with change of uniform motion (acceleration or deceleration). It introduces momentum and energy concepts, the necessity of defining the system and distinguishing clearly between open and closed systems is required.

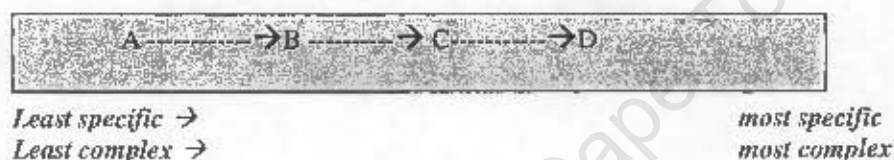


Figure 5.1: *The hierarchy of increasing complexity and specificity of ways of experiencing the links between basic Newtonian dynamics concepts*

Figure 5.1 represents a hierarchy of increasing complexity and specificity of ways of experiencing links between basic Newtonian dynamics. The increasing complexity is based on the move from a generalised world with intuitive deductions to a world in a specific form with conceptual meaning.

5.3.2 A general view of logical relationships between categories

Figure 5.2 below gives a summary of the categories of description with their sub-categories.

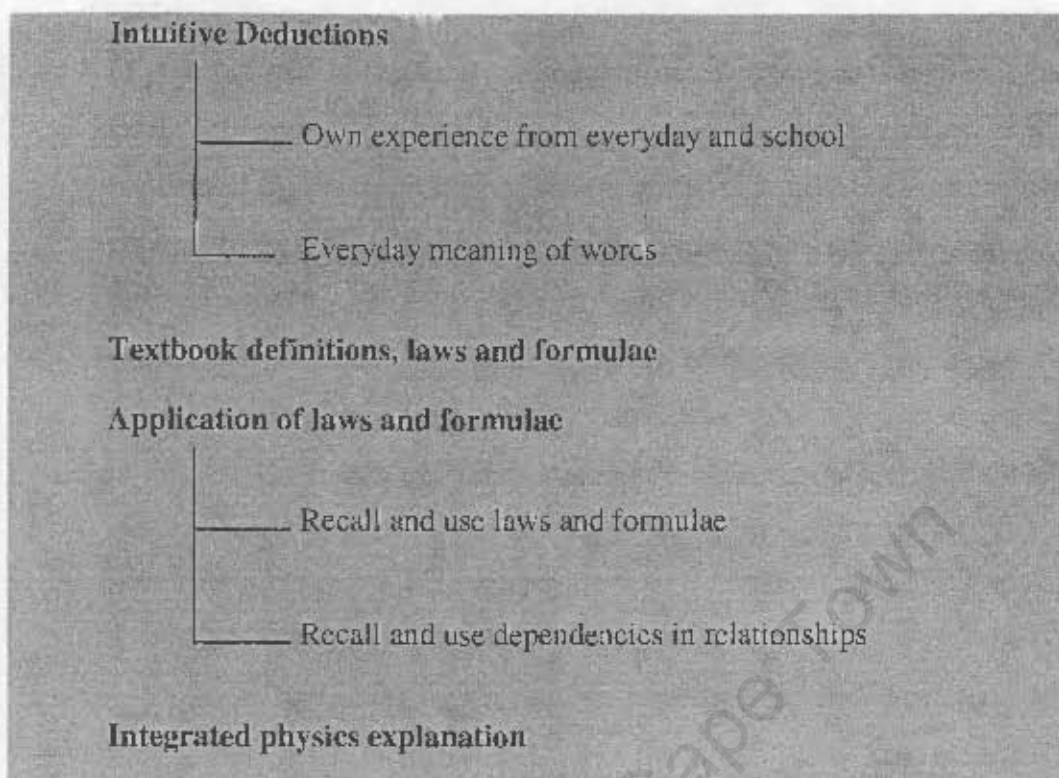


Figure 5.2: *Summary of categories of description with their sub-categories*

Here we attempt to show the logical relationships between these categories of description. Figure 5.3 below illustrates the relationships between these categories of description, using a schematic framework.

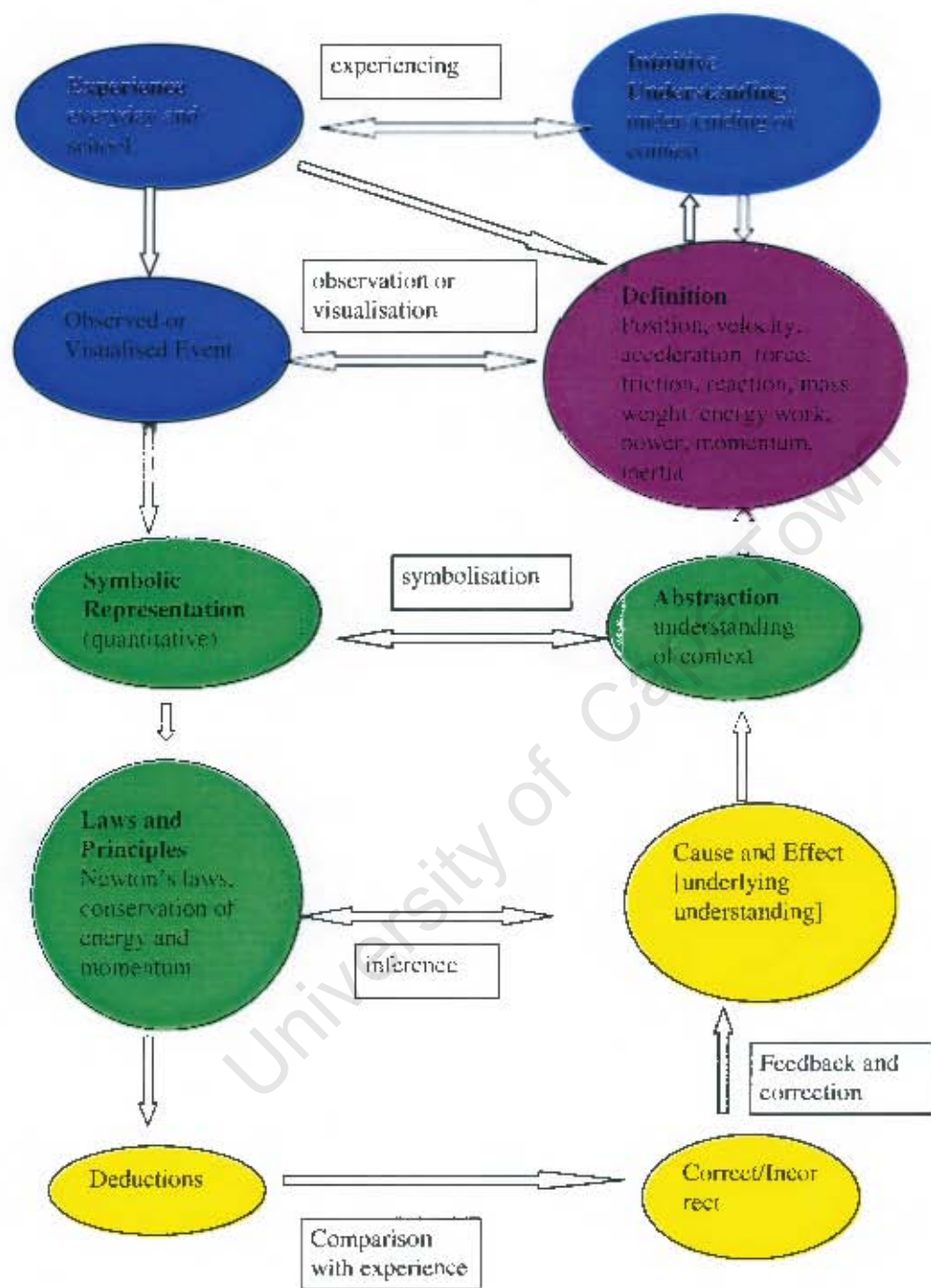


Figure 5.3: Schematic diagram of categories

In Figure 5.3 above the categories in the schema are depicted by different colours. The blue colour depicts the everyday world, the violet colour depicts school physics, and the green colour depicts application of laws. All the colours depict the world of physics.

From the schematic diagram, we can see that the understanding of the context is crucial. The context is very important – it introduces a meta-level which makes one decide which frame of thinking one should be using, e.g. formal, intuitive, etc. The way the students understand the study-provided contexts is different from the way physicists do. This is very clear from their responses in the interviews, and from the categories of description discovered. The understanding of contexts determines the nature of abstractions that one makes.

If we look at the schema, abstraction changes understanding by introducing definition and symbolic representation, which in turn will change the way laws are interpreted and used. The schema also illustrates that the different everyday experiences will lead to different intuitive understandings, i.e. the understanding of context, and this will lead to different definitions, etc. Anything can go wrong at any stage in the cycle, and one needs to establish where this happens. From the responses we can see that certain stages of the cycle were used, not the whole cycle. This is not covered in the current study, but could be followed up in future studies.

5.3.3 Relationships between categories based on specificity

From Table 5.1, we see a hierarchical structure based also on logical specificity. The next diagram, Figure 5.4, gives an illustration of specificity in categories of description.

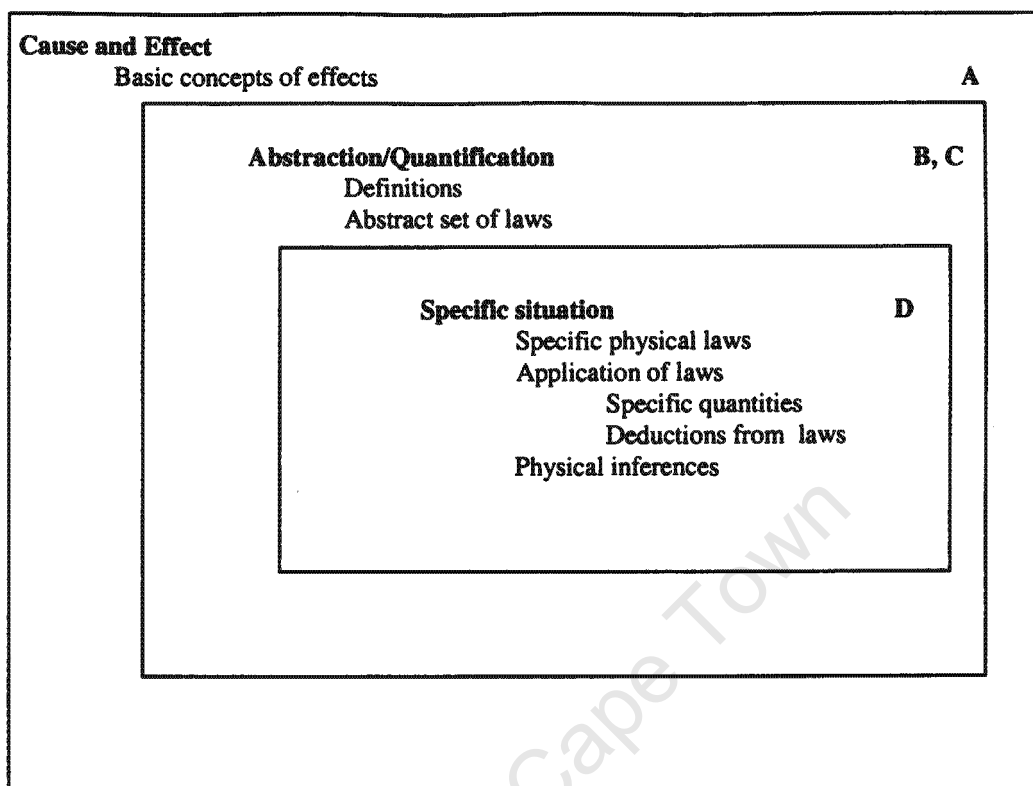


Figure 5.4: *Specificness of categories of description*

Figure 5.4 above shows the different worlds as discerned from the context. It indicates that category A is in a more generalised world than other categories. Categories B and C are a little bit more specific in that the world is narrowed down to the world of introductory physics with definitions and set of laws. Category D is a more specific world in that it looks at a specific situation with specific physical laws, application of laws and physical inferences.

In the next section we will look at the different mappings between categories of description and study-provided contexts, to determine the relationship between categories and the given contexts.

5.4 Mappings between categories of description and study-provided contexts

In this section we seek to address the question,

“How do the categories of description relate to the contexts provided for the study?”

The question is addressed by working within the difficulty of trying to map all segments of the students' descriptions into the categories. As these mappings are done a general set of trends emerge. Let us now look at the mappings.

5.4.1 Mappings of different ways of conceptualising per context at a collective level

Table 5.2 below gives a visual picture of the mappings of different ways of conceptualising links per context.

Table 5.2: *Mappings of categories of description and study-provided contexts*

Context	Categories of description: Links are Cause and effect relationship based upon ...			
	A:intuitive deductions	B:textbook definition, formulae and laws	C:application of laws and formulae	D:integrated physics explanations (beginning of formal and systematic thinking
1.A familiar situation where friction is moderate (dry surface)	x	x	x	x
2.A less familiar situation where friction is less (wet surface)	x	x	x	x
3.An unfamiliar situation where friction is negligibly small (snowy surface)	x	x	x	x

It is clear from Table 5.2 that it is very difficult to see if context and categories are related. However, I will look at the frequencies of

utterances found for each category within a context to look for trends that could emerge from the data. Table 5.3 gives such frequencies.

Table 5.3: *Observed frequencies for each category within a context*

	A	B	C	D
Context 1	27/86 (31.4%)	35/86 (40.7%)	20/86 (23.3%)	4/86 (4.6%)
Context 2	29/61 (47.5%)	19/61 (31.2%)	12/61 (19.7%)	1/61 (1.6%)
Context 3	23/38 (60.6%)	7/38 (18.4%)	7/38 (18.4%)	1/38 (2.6%)

The frequencies give the number of times a description belonging to a certain category appeared in a given context. We are looking for evidence of trends rather than trying to quantify in any absolute way.

5.4.1.1 Discussion and Significance

From the raw data it can be seen that with category D there are fewer responses in all the contexts. Since the students are in their introductory year, it is not surprising that they do not yet see the world of physics as physicists do.

In context 1, which is a more familiar context to the students, most responses are in category B. This makes sense as these students are in their introductory year and see the world as the world of introductory physics courses. In contexts 2 and 3 which are less familiar, most of the responses are intuitive, i.e. in category A.

In context 3, which is an unfamiliar situation and which students have not experienced, but can only imagine, there are significantly fewer responses in other categories than in category A, the intuitive one. One can therefore conclude that in an unfamiliar context, like in 2 and 3, when friction is

less, links are conceptualised as cause and effect related to intuition. This is very significant in context 3 where friction is negligibly less.

Another argument could possibly come from the fact that interviews for context 1 were done on a different day from interviews for contexts 2 and 3 which were on the same day. This could be seen as a possible influence to the way students responded to the interviews. As a researcher, my observation was that the concept maps for the first context were carefully drawn, whereas the other two maps were not as complete, students felt some parts of the maps could be taken from the first one. However, in this case students had made it clear in their responses that they had not experienced the third context given to them, hence they used imagination and knowledge derived from movies and television to make sense of it.

Category A increases significantly as we move from context 1 to context 3. This could be attributed to the fact that we move from a familiar context, to a less familiar, to an unfamiliar context. All other categories are significantly reducing as we move from context 1 to context 3, except for category D where there is a slight increase from context 2 to context 3. Again there is a significant decrease in all contexts as we move from category A to category D except in context 1 where there is a slight increase from category A to category B. There is a significant drop in responses in category D. This indicates that most students are still thinking intuitively and in classroom Newtonian dynamics, and they haven't moved beyond these points. This has strong implications for Newtonian dynamics teaching. More work still needs to be done to get the students to begin to see the world as physicists do. Newtonian dynamics in general, is counter-intuitive, it is against common-sense knowledge and outside everyday experience, however, it is easy to use common sense when confronted with such problems, hence it is not surprising that there are significantly more responses, in all contexts for category A, which is based upon intuition and common sense.

The shifts from one category to another across the contexts suggest that we cannot pin down a student to a category, as each student describes each link with the help of whatever concepts and principles are within his/her focal awareness at the time. This will be discussed further in the next Chapter when we look at the individual level.

5.4.1.2 Statistical analysis

The statistical analysis was used to provide another way of looking for context dependency. The analysis used non-parametric tests since no assumptions were made about the distribution of the population. The Chi-square statistic was used to test association between the categories of description and the contexts and the results are given in Appendix D. Overall, they showed a statistically significant result that there is some association between categories and contexts even though it is not very strong.

5.5 Summary

The main question addressed here is how students conceptualise links between basic Newtonian dynamics concepts. The main goal was to get the categories of description. Once the categories had been identified, I looked at how these categories could be made real, and lastly I looked at how these categories could be related to the provided contexts. Four qualitatively different ways in which students conceptualise links between basic Newtonian dynamics concepts were identified and the variation analysed in terms of the structure of experience. The different categories of description represent a hierarchy or increasing complexity and specificity of ways of experiencing links between basic Newtonian dynamics concepts. The increasing complexity is based on logical specificity in that the world of physics was discerned and the conceptual links were recognised in a specific form.

The least complex ways of experiencing the conceptual links represent cause and effect in a generalised world with basic concepts of effects. The more complex ways of experiencing the conceptual links represent cause and effect in terms of abstraction and quantification with an abstract set of laws and definitions. The most complex ways of experiencing the conceptual links represent cause and effect in a specific situation with specific physical laws, application of laws, specific quantities, and deduction from laws and physical inferences, see Figure 5.4 above.

Two of these ways of experiencing are considered as primarily reproducing what has been taught and are unproductive in terms of making sense of physics, the next category shows a combination of memorisation and abstraction, which depicts superficial learning, while the last category is essentially seeking conceptual meaning or understanding. Whilst not a totally unexpected result in the light of the findings of other studies, the existence of variation in the way conceptual links in basic Newtonian dynamics were experienced is a useful formal way of characterising the different approaches and levels of understanding. As a personal teaching experience, it was an enlightenment. The implications of these findings will be discussed in detail in Chapter 7. In the next Chapter I will seek to answer the theoretical question, “how do different ways of experiencing something evolve?”

Chapter 6

How do different ways of conceptualising links between basic Newtonian Dynamics concepts evolve? – Results at an individual level

6.1 Introduction

In phenomenography, research focuses on variation in experiencing a phenomenon, or set of phenomena. Chapter 5 consists of analysis of the variation between different ways of experiencing the same phenomenon. In this Chapter an attempt is made to contribute towards the theoretical development of newly emerging questions in phenomenography (see, for example, Marton and Pang, 1999), which give consideration to questions such as:

1. What is a way of experiencing a phenomenon? and,
2. How do different ways of experiencing something evolve?

Instead of as in Chapter 5 examining variation as sensed by the '*researcher*', in this Chapter variation experienced by the '*experiencer*' is scrutinised "within the framework of the anatomy of awareness" (Marton and Pang, 1999:2). The analysis of the kinds of questions outlined above represents a shift towards theoretical concerns. The kinds of theoretical concerns which I want to address here are those which are related to context (see for instance, Adawi, Berglund, Ingerman and Booth, EARLI, 2001, in press) by considering the following questions:

- When all the students' descriptions are categorised in terms of the conceptions, or ways of experiencing, obtained for Empirical Research Question a) (see Chapter 1, Section 1.4), do any patterns of intra-contextual and inter-contextual shifting emerge for the individual students?
- If intra-contextual and inter-contextual shifting patterns emerge, can any patterns of contextual influence be discerned?

My approach for the analysis will be to look at the students' descriptions given within and across study-provided contexts. I will use the categories obtained in Chapter 5 to sort the students as individuals, and then use the phenomenographic framework of 'anatomy of awareness' to search for critical aspects discerned and focused upon by the students in and across the study-provided contexts.

Before presenting the analysis a brief recount of the idea of 'anatomy of awareness' will be given (a fuller account is provided in Chapter 3, which deals with the theoretical framework and method).

6.2 Summary of phenomenographic 'anatomy of awareness'

In Chapter 3 phenomenography was introduced as a theoretical perspective which had two orientations. The first and most established orientation is the study of variation in ways of experiencing; the second is developing discipline-based concepts for studies of this kind. The results of such studies have yielded categories of description similar to those derived in Chapter 5, which form an outcome space of how people conceptualise such features. Such studies are not studies of individuals but are taken across individuals to study ways of understanding and to capture the

essence of the variation between different ways of understanding the same concept, or set of concepts (for example, Marton, 1974; Dahlgren, 1975; Säljö, 1975; Svensson, 1976; Booth, 1992).

The categories of description in Chapter 5 have been categorised in terms of structural and referential aspects. In the 'anatomy of awareness', the structural part of conceptualisation denotes the relationship between different aspects of the phenomenon that are taken to constitute its meaning. So some aspects come to the fore – they are thematised from the thematic field of taken-for-granted or tacitness. To understand some aspect of physics in a particular way in a given context requires a certain kind of discernment from the context. The parts which make up this discernment interplay with each other to give meaning. But at the same time in order to discern something from a context, it needs to be given meaning – to be seen as something specific. Thus the structure and meaning are dialectically related to each other and as such provide a theoretical way to understand a way of conceptualising a phenomenon.

6.3 Inter and Intra-contextual shifts

In order to understand the ways of experiencing a particular phenomenon, Marton and Pang (1999:6) contend, "discernment, variation, contemporaneousness and simultaneity are conceived to be fundamental". They continue to say:

"Discernment assumes experienced variation. When certain aspects of phenomenon vary while other aspects remain invariant, then those varying aspect will be discerned. Something that we focus upon implies that it is being discerned, those taken for granted represent that which has already been discerned and those absent are that which has not been discerned".

(Marton and Pang, 1999:7)

In the previous Chapter I was addressing the question, how do the categories of description relate to the contexts provided for the study when looked at across individuals? I found that it was difficult to map the categories to the study-provided contexts. The statistical analysis showed that there was evidence that some relationship existed between the categories and the contexts, but it was barely significant. In what follows is an analysis of this relationship at an *individual level*.

Table 6.1 below gives a summary of the distribution of categories of description for each student in different contexts (see Appendix E for detailed mappings). In this section I intend to look at and discuss patterns that might emerge from these mappings.

Table 6.1 *Summary of the distribution of categories of description for each student in different contexts*

Student	Context 1: A familiar situation where friction is moderate (dry surface)	Context 2: A less familiar situation where friction is less (wet surface)	Context 3: An unfamiliar situation where friction is negligible (snowy surface)
S1	ABC	ABC	ABC
S2	ABCD	ABCD	ABCD
S3	ABC	ABC	ABC
S4	ABC	AC	A
S5	ABCD	AB	A

Table 6.1 above shows that in most cases students manifested more than one conception of a phenomenon in a particular context. It is therefore almost impossible to ascribe a certain conception to a particular individual.

In some cases, as one move from one context to another there is an inclination towards certain conceptions. Some of these shifts were triggered by the interviewer's follow-up questions, many others occurred spontaneously as the interview developed. The shifts within and between contexts are discussed in more detail below, together with examples of these shifts in Sections 6.3.2 and 6.3.3. These shifts are an indication that what students are focusing on at a particular time determines that which is discerned.

I had brought in an explicit variation in the form of study-provided contexts and this variation determined that which needed to be focused upon. The different conceptions shown by the students could be attributable to the different contexts created and/or provided. The different contexts created in some cases by students and/or provided determine which aspects of a phenomenon are brought into focal awareness, and which remain in the *thematic field*. Those aspects that are brought into the focal awareness are known as the *theme*, and those aspects that recede to the background the *thematic field* (Marton and Booth, 1997). According to Marton and Booth's (1997) 'structure of awareness' conceptions are comprised of dialectically intertwined referential and structural aspects, that is, the interplay between what is focused on and the meaning. The figure below illustrates the relationship between the theme and the thematic field.

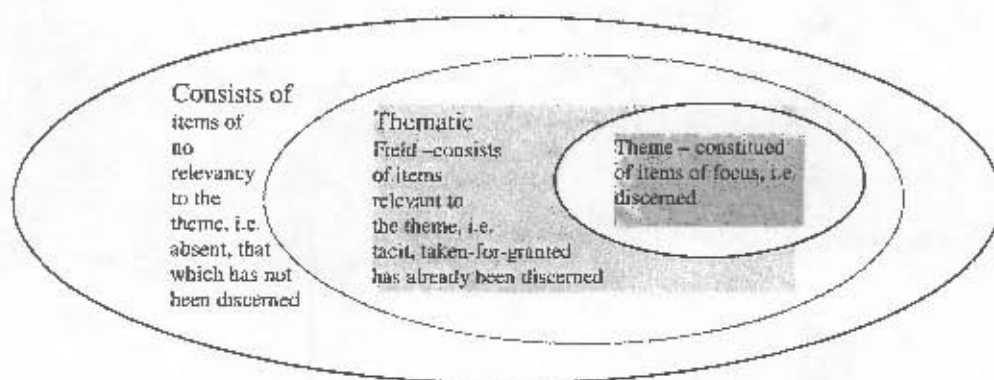


Figure 6.1 *Relationship between theme and thematic field (from Marton 1994:266-267)*

The theme can change causing the thematic field also to change in composition. As the old theme changes the new theme emerges from the thematic field which consists of items relevant to the old theme. The theme can loosely be seen as the primary focus and the thematic field as the secondary focus.

This analysis led me to look closely at the mappings of the students with these categories of description in each study-provided context and across these contexts to see how these patterns are formed and to suggest what they may imply in educational terms.

6.3.1 Mappings of students with categories of description within and across study-provided contexts

6.3.1.1 Mappings across the study-provided contexts

Here the aim is to look at the frequencies of the descriptions observed for each student across all contexts. The frequencies give the number of times

a description belonging to a certain category appeared in a given context. The descriptions were cut out from a printed text of the interviews and put in different labelled envelopes for each category, and a count was taken to determine the frequency of each category. I am looking for evidence of trends rather than trying to quantify in any absolute way.

Table 6.2 *Observed frequencies across study-provided contexts*

Student	A	B	C	D
S1	20	22	7	0
S2	7	9	9	3
S3	25	19	16	0
S4	16	1	11	0
S5	11	10	0	2
Total	79	61	43	5

The mappings across study-provided contexts for all students show that categories A and B are the most frequent. This means that across the study-provided contexts there is high inclination towards intuition and classroom definitions and formulas. However, looking at each individual, they all have their own inclinations. This led me to look further at each student in relation to context, hence the mappings for each study-provided context.

6.3.1.2 Mappings for each study-provided contexts

At a collective level a reasonably significant correlation between categories and context did not emerge. As part of trying to contribute to the theoretical issues discussed earlier in this Chapter I now look at

the data at an individual level. I will observe the frequencies of the descriptions for each student in a given context.

- a) **Study-provided context 1: a familiar everyday context where an easily recognisable frictional force could be expected**

Table 6.3 *Observed frequencies in context 1*

Student	A	B	C	D
S1	2	15	1	0
S2	1	3	7	2
S3	11	7	4	0
S4	11	1	8	0
S5	2	9	0	2

Students S1 and S5 show a strong inclination to what may be characterised as classroom Newtonian dynamics since most of their descriptions in this context are based on textbook definitions, laws and formulae. For example, S1 in the first interview said, “... *since we know that momentum is the product of mass and velocity, ...*”. S5 in his interview when asked how collision involved momentum, replied, “... *a moving mass that has velocity has momentum by definition*”.

From observed frequencies students S3 and S4 show a strong inclination to intuitive deductions. For example, S4 in his interview when asked what he meant by “power accelerates taxi”, he replied, “...*power produced by minibus caused movement of taxi*”.

Student S2 is more inclined to application of laws and formulae. For

example, S2 said, “*acceleration is proportional to the resultant force applied to the object and inversely proportional to the mass of the object, that is, if there is more mass acceleration will be less*”.

Students S5 and S2 are the only students who have descriptions in category D. For example, S2 when asked how Newton's second law relates acceleration and force, replied, “... *if you apply a force you will get acceleration, ...you gonna get acceleration if there is a resultant force, but if it is only applied it does not necessarily mean you get acceleration, e.g. when pushing a wall and wall does not move*”.

In study-provided context 1, students have shown different conceptions of the phenomena with strong inclinations towards certain ones. This difference in conceptions could imply that the context was thematised differently by different students.

b) Study-provided context 2: a familiar everyday context where a reduced frictional force could be expected

Table 6.4 *Observed frequencies in context 2*

Student	A	B	C	D
S1	11	6	4	0
S2	4	3	1	1
S3	8	9	4	0
S4	2	0	3	0
S5	4	1	0	0

In context 2, students S1 and S5 show a strong inclination to intuitive

deductions in relation to other categories. For example, S1 said, *"if you are pushing something in a dry ...it's going to be easier, provided you're wearing a proper gear to push ..."*.

Students S2 and S3 show a combination of intuitive deductions and textbook definitions, laws and formulae. For example, S3 said, *"if the number of men were ...to be doubled, ...there will be ...greater force and ...as a result accelerate faster than when it was only four men ..."*. Student S3 elsewhere in the interview states a definition of kinetic energy and said, *"...is the energy of a moving object"*.

Student S4 shows a combination of intuitive deductions and application of laws and formulae. For example, S4 said, *"...basically I don't expect the wheels of the taxi to sort of roll, show movement, so I expect since it was stationary then it will just move without the wheels being rolling"*. He later said, *"during collision there is ... transfer of energy between the two objects ..."*. Here he uses the principle of conservation of energy to describe phenomena.

Student S2 is the only one in this context who has descriptions in category D. For example, S2 when referring to the collision, *"the system has lost energy – the form of energy has been changed and the environment has gained a certain amount of energy from the collision"*.

Here again we have observed that the same context has been thematised differently by different students as they all showed different conceptions and inclinations towards certain conceptions.

c) **Study-provided context 3: an unfamiliar context where a negligible frictional force could be expected**

Table 6.5 Observed frequencies in context 3

Student	A	B	C	D
S1	7	1	2	0
S2	2	3	1	1
S3	6	3	4	0
S4	3	0	0	0
S5	5	0	0	0

In this unfamiliar context, all of the descriptions for students S4 and S5 are in category A, which is based upon intuitive deductions. Students S1 and S4 show a strong inclination towards category A, they have fewer responses in categories B and C. Again student S2 is the only one who has a description in category D. For example, student S4 when comparing the snowy surface to the wet one he said, "... *there are differences ...snowy road ... should be having more of the grasp than the wet road...*". Student S4 has not experienced a snowy road and creates an imaginative or intuitive context to enable him to describe the phenomena. In this case, it seemed difficult for him to move from the intuitive conception.

It has been obvious in this context that what is in the thematic field influences the theme, and hence the meaning.

6.3.1.3 Discussion on mappings of individuals and contexts

Table 6.1 gives evidence of patterns of shifts between and within contexts. The patterns of shifts are discussed in detail in the sections below. Category A is present in all the contexts for all the students. This could be evidence of the critical role that intuition plays in thematisation within and across contexts. This role is investigated to a certain extent when looking at intra- and inter-contextual shifts in the section below. Although variation in ways of experiencing the links had been noted in the examples given above and in Chapter 5, variation in ways of experiencing context is also evident. Adawi, *et al* (2001:1) in their paper "On context in phenomenographic research on understanding heat and temperature" discuss "context as experienced and interwoven with the experience of the phenomenon". They argue that to confuse the variation in ways of experiencing context of a study with the variation in ways of experiencing the phenomenon of study is to risk losing fundamental insights. They point out that the focus is on the ways the research participants experience the phenomenon, and the researcher experiences a variation in the ways in which the phenomenon is experienced, and "seeks meaning and structure in this variation" (Adawi, *et al*, 2001:2).

In this particular set of contexts provided, students S1 and S3 consistently did not move beyond classroom Newtonian dynamics. Student S4 is not only inconsistent, but also did not go beyond classroom Newtonian dynamics in all three contexts. Student S5 is also not consistent, but in context 1, went beyond classroom Newtonian dynamics. Student S2's descriptions are consistently present in all categories across the contexts. This could suggest looking more in depth at what conceptual links students presenting a descriptive profile such as that of S2 need have, to be

able to come up with a profile that can help in Newtonian dynamics teaching. The descriptions of such students could then be compared with that of students with profiles such as S4 whose descriptions were inconsistent and did not go beyond intuition and classroom Newtonian dynamics in future studies. Such comparisons are not, however, part of my study, but do represent a possible useful follow-on study.

It is observed here that intuition plays a great role by its existence in all the contexts. This has manifested through category A. The role of intuition here could possibly be attributed to the presence of friction in the contexts provided. Friction is a passive force, this kind of force arises and adjust itself in response to active ones, but it cannot increase indefinitely, it increases only to the point at which it reaches its limiting value. Friction can not easily be experienced directly, but its effects can be experienced. This concept has been known to be difficult to grasp (Arons 1990 and 1997, Salazar, *et al*, 1990).

Furthermore, the influence of context on manifested ways of experiencing or understanding is also constrained by the fact that a disproportionate amount of a particular category of description is captured. The study-provided contexts were planned by the researcher to introduce variance, but individuals in the study did not experience the intended contexts in the same way as the researcher did. In this study the assumption was that providing the different contexts, students would thematise the contexts in the same way as the researcher. This assumption has turned out to be false. Adawi *et al* (2001:4) have warned that it is important to distinguish between two different meanings of context, one, the *prepared context* as defined by the researcher and, two, the *experienced context*, as experienced by the participant. The distinct difference between the

prepared and experienced contexts has been highlighted by the individuals' responses in context 3, which was highly conducive to the use of intuitive deductions, as this is an unfamiliar context, which students had not experienced but could only imagine. Context 2 was significantly conducive to intuitive deductions, whilst context 1 is familiar and readily predisposed students to using category B which is textbook definitions and formulae. This could also be attributed to the fact that the interviews happened in the first half of the year. For example, when student S1 was asked in the first interview what he meant by the link "work done by force", replied, "*we know, it is known that work is force times distance, ...*". The student here did not attempt to describe the meaning of the link in his own words but instead used a textbook definition that was still fresh in his mind to describe the link.

Let us now look at the intra-contextual and inter-contextual shifts and see what role or influence does intuition have on conceptions within and between the given contexts?

6.3.2 Intra-contextual shifts

The intra-contextual shifts show the extent of variation at an individual level of ways of experiencing or understanding, which demonstrates how individuals moved from one category of description to another in a given context. Let us now look at examples of shifts within a given context.

6.3.2.1 Examples of intra-contextual shifts

Example 1

Student S1 in context 2.

Link(s): "force of friction reduced by road wetness"

I: ... you talk about force of friction reduced by road wetness. What do you mean by that?

S1₂¹: ... since it was wet it means there was lesser friction, that's what I mean. There was lesser friction compared to that (referring to first scenario) ... - *there was less grip for the men to try and overcome the* - I think if you had to compare the two scenarios, the men would be able to push a car easier in a drier place than in this wet road. That's what I mean.

He later said,

S1₂: ... when the road is dry I think it will be easier to push anything, okay, provided it was - I assume that you are wearing a proper gear, not something that is slippery, okay?

I: Now, about friction, is it going to be less or ...

S1₂: Yah, the friction is going to be higher on a dry ground which will help you push the thing easier, *because friction is what we use to walk*, is what we use to overcome a lot of things, so if it's wet there's very less friction which means *there's greater resistance or greater problem that you're faced with*.

I: ...you say it's a force of friction reduced by road wetness that is creating problems for the four men. Can you elaborate more about that?

S1₂: ... so if it's wet, the friction is reduced, hence *the grip is reduced and then you'll have greater problems*.

Table 6.6 below represents the above sequence of shifts.

Table 6.6 *Sequence of intra-contextual shifts by S1*

Sequence	Aspect focused upon	Couching	Category of description
1 st	Friction on men's feet	Intuition (<i>there was less grip; wearing a proper gear</i>)	A
2 nd	Friction and the surface	Application (<i>friction will be higher ... because friction is what we use to walk</i>)	C
3 rd	Resistance	Intuition (<i>there is greater resistance or greater problem that you're faced with; the grip is reduced ...</i>)	A

Although the interviewer is trying to lead the individual to focus on friction's magnitude, the interviewee does not seem to see the intended context but instead creates his own context by focusing on resistance. When the student is prompted, a new theme or central focus emerges from the thematic field. This supports what phenomenography's 'anatomy of awareness' tells us – that different people thematise the same context differently.

Example 2

In context 1,

I: What do you mean by "minibus exerts equal and opposite force on men"?

S3₁: As they are pushing, the minibuss is also applying a force on the men, and it is

¹ Subscript 1 denotes interview 1 and subscript 2 denotes interview 2

- equal to the one that the men applied on it.
- I: Is the minibus also pushing the men?
- S3₁: Not necessarily pushing, but what I can say, eh ..., it is not like pushing it is trying to to ... resist the force that these guys are applying on it.
- I: Does it succeed in resisting?
- S3₁: No, because it is being pushed and it moves, it means the men have been overpowering it.

The above sequence of shifts is represented in table 6.7 below.

Table 6.7 *Sequence of intra-contextual shifts by S3*

Sequence	Aspect focused upon	Couching	Category of description
1 st	Applied force	Classroom language (... and it is equal to the one that the men applied on it)	B
2 nd	Resistance	Intuition (men have been overpowering it)	A

Student S3 states Newton's 3rd law of motion without focusing on all aspects of this law, and hence interprets it the way he experiences it, hence, he describes it as, "the men have overpowered the minibus". Again we see an illustration of context being thematised differently from the researcher's context. When prompted S3 changes focus and hence the change in meaning.

Example 3

In context 1,

Link(s): "object in motion has momentum" and "momentum has velocity and has mass"

- I: What do you mean by "momentum has velocity and has mass"?
- S3₁: Hmm ..., this is a definition of momentum.
- I: And we just have to accept that?
- S3₁: Yes that is momentum. Since these cars are colliding we talk of momentum before and after collision and in this case momentum is not conserved.
- I: Why is it not conserved?
- S3₁: Because the velocity of minibus before is not equal to velocity of coupled cars after. The velocity will be reduced after collision.
- I: What reduces it?
- S3₁: Since the taxi has mass and minibus as well, if minibus travelling say with 50km/hr and is 50 kg in mass and colliding with say another 50 kg then definitely the velocity will be reduced now the mass will be 100 kg.
- I: So are you saying with more mass the less the velocity?
- S3₁: Yah, but in this scenario, in this particular problem, not necessarily always the case, *smaller is faster*.

Table 6.8 below represents the above sequence of shifts.

Table 6.8 Sequence of intra-contextual shifts by S3

Sequence	Aspect focused upon	Couching	Category of description
1 st	Momentum	Textbook definition	B
2 nd	Principle of linear momentum	Application of principle of linear momentum	C
3 rd	Mass and velocity	Intuition and common sense (<i>smaller is faster</i>)	A

Student S3 mentions a textbook definition and uses the principle of linear

momentum to explain the links he has made between two concepts. He however, creates a situation or context within which to operate, he gives an example of a 50kg bus travelling in 50km/hr to make sense of the link from this situation or context. The individual here creates an intuitive context or associated context within which to operate. This is in line with Marton and Booth's (1997:83) argument that "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".

Example 4

In context 3, student S1 when comparing the wet scenario with the snowy one said,

- I: ... Part A [wet surface] and Part B [snowy surface], do you see them as being different, ... how different are they?
- S1₂: Yab, they are different in a sense that I think that mainly what is playing a role here, is the conditions. ... all in all I think the physics principles have to be applied differently in dealing with the situations, but it comes to the point of applying the physical concepts differently because of the conditions themselves, ...
- I: In this scenario B [wet], which concepts, physical concepts do the snowy condition affect?
- S1₂: It affects friction, and if it affects friction it affects the whole scenario, ja, I would say it affects the whole scenario. ... there is very less friction on the situation [snowy], on the two situations in the second part [wet] and in the first part [dry] there's greater friction as compared to them.

He later said,

- I: ... if we were to increase the number of men in a snowy weather do you think we would be able to make ...
- S1₂: ... I'm making a lot of assumptions. I would say that probably I'm also overlooking a lot of other problems that might crop up. ... if you have seen a situation where a car gets stuck in the mud, you cannot expect to take that car out of the mud if you don't try and put something that will increase some sort of friction. I've seen it in some parts where you find that people bring as much as like stones, or even trunks of trees to try and increase the friction because the mud will be offering very less friction, you see. So, I might be overlooking such, er, er, minute, er, details that we would need to look into.

The above sequence of shifts is represented in table 6.9 below.

Table 6.9 *Sequence of intra-contextual shifts by S1*

Sequence	Aspect focused upon	Couching	Category of description
1 st	Friction and conditions	Intuition	A
2 nd	Implications of friction	Application	C

The student created his own context, he changed the context from snowy surface to muddy surface, because he has experience of muddy surfaces and was able to give a description of a phenomenon in that context. In the process of this contextual association, experience has played an important role in determining which aspects of a phenomenon were brought into focal awareness, and which remained in the thematic field.

Example 5

S2 in context 1

- I: How do the four men exert force on stationary bus?
- S2₁: The force is the regular push or pull, in this case it's a push, the simplest explanation of a force is a push or pull.
- I: Is friction a push or a pull?
- S2₁: It's a very simplistic or very elementary description of a force which I came across at school, I can't describe friction as a push or pull.
- I: What do you mean by "stationary minibus moves due to force by Newton's second law"?
- S2₁: The force I refer to is the force exerted by the four men, that is the force that makes the object move, by Newton's second law, is to describe that this is the force that causes the object to move, that is, Newton's second law will be the relationship describing how that force applied in minibus will cause the change in its motion.

Later in the interview S2 said,

I: How does Newton's second law relates acceleration and force?

S2₁: That is, if you apply a force you will get acceleration, those are proportional, you gonna get acceleration if there is a resultant force, but if it is only applied it does not necessarily mean you get acceleration, for example, when pushing a wall and wall does not move.

I: Is Newton's second law applied here as well?

S2₁: Definitely.

The above sequence of shifts is represented in table 6.10 below.

Table 6.10 *Sequence of intra-contextual shifts by S2*

Sequence	Aspect focused upon	Couching	Category of description
1 st	Force	Classroom textbook definition (<i>force is a push or pull</i>)	B
2 nd	Applied force and change in motion	Application Newton's second law	C
3 rd	Force and acceleration	Created a conceptual framework	D

S2 gives a definition of force as given in schools. He contextualises this definition to that of school physics, and forms a contextual association with school physics. He however, realises when probed further that this definition is a simplistic one that was given at school and cannot really be used to explain the phenomenon at hand. This positive progress shown by the student when probed can suggest that the student's thematic field is similar to that of the researcher's. It could also suggest that the researcher's probe led the student towards a positive direction.

6.3.2.2 Discussion on intra-contextual shifts

Examples given in section 6.3.2.1 above have shown that the prepared context, that is, study-provided context can be experienced in different ways by different individuals. These examples have also shown that there is evidence of movement from one conception to another within a given context as individuals change their focus, either spontaneously or by being prompted. The tables representing sequences of intra-contextual shifts above have also indicated that there is evidence of regression during these shifts. What is interesting is the fact that each time regression occurs, regardless of which category an individual is in, the move goes back to the intuitive level – category A. There is also evidence of positive progress, example given from S2 interview.

Student S2 however, shows a different trend. He shows evidence of positive progress and no regression. The mappings of student S2 and the categories have shown that student S2 has all the four categories in each context (see Table 6.1). This could mean that student S2 is capable of appropriately choosing focus at any time. It could also mean that his understanding of context is being built up from his own intuition and classroom physics until it becomes part of the gestalt. If we look at the example given above from S2's interview, it is clear that he is aware and conscious that certain definitions work well in certain areas and not in others. When asked what he meant by "four men exert force on stationary bus" he said,

"the force is the regular push or pull, in this case it's a push, the simplest explanation of a force is a push or pull".

When probed further, "is friction a push or a pull?" he replied,

"It's a very simplistic or very elementary description of a force which I came across at school, I can't describe friction as a push or pull".

It would have been interesting though to see how the student would have responded if the interview continued with questions on how friction could be described. The probing in this example could possibly have contributed to making the student aware that this definition of a force is not totally true.

6.3.3 Inter-contextual shifts

The data has shown in the previous section that some students constituted more than one conception for a particular context. I have shown how students shifted from one category of description to another within a particular context. This kind of shifts we called intra-contextual shifts. I will now look at the shifts from one category of description to another as students moved from one provided context to another. The shifts from one category to another across the given contexts suggest that we cannot pin down a student to a category, as each student described each link with the help of whatever concepts and principles that were at their focal awareness at the time.

6.3.3.1 Examples of inter-contextual shifts

Example 1

In the first interview, which was on context 1 student S1 gave the following link.

Link(s): "friction caused them to stop" and "force on minibus and taxi caused them to accelerate with opposite direction to their motion"

I: How did friction cause them to stop?

S1₁: *Friction always opposes motion*, right, so in this case the two cars accelerated in the opposite direction to their motion.

I: What do you mean opposite direction, to what?

S1₁: Remember when these guys were pushing they let it go and the minibus collided with the taxi pushing it forward and remember there is no external force at the moment they start moving but there was external force at the moment the bus hit the taxi. Friction was the only force acting on them and *it always opposes motion*, then it causes the two cars to stop at some instance.

In the next interview, which was in context 2, student S1 said friction enables us to walk. Student S1 was comparing the first scenario where the road was dry with the second scenario where the road was wet.

Link(s): "force of friction reduced by road wetness"

I: ... you talk about force of friction reduced by road wetness. What do you mean by that?

S1₂: ... since it was wet it means there was lesser friction, that's what I mean. There was lesser friction compared to that (referring to first scenario) ... - *there was less grip for the men to try and overcome* the - I think if you had to compare the two scenarios, the men would be able to push a car easier in a drier place than in this wet road. That's what I mean.

He later said,

S1₂: ... when the road is dry I think it will be easier to push anything, okay, provided it was - I assume that you are wearing a proper gear, not something that is slippery, okay?

I: Now, about friction, is it going to be less or ...

S1₂: Yah, the friction is going to be higher on a dry ground which will help you push the thing easier, because *friction is what we use to walk*, is what we use to overcome a lot of things, so if it's wet there's very less friction which means *there's greater resistance or greater problem that you're faced with*.

I: ...you say it's a force of friction reduced by road wetness, that is creating problems for the four men. Can you elaborate more about that?

S1₂: ... so if it's wet, the friction is reduced, hence *the grip is reduced and then you'll have greater problems*.

Later in the interview when asked to compare context 2 and context 3 student S1 said,

- I: Okay, um, now, um, Part A [wet] and Part B [snowy], do you see them as being different, and if they are, what is the difference and, um, that is, how different are they?
- S1₂: Ja, they are different in a sense that I think that mainly what is playing a role here, it's the conditions. In general, I would say it is the condition but all in all I think the physics principles have to be applied differently in dealing with the situations, but it comes to the point of applying the physical concept differently because of the conditions themselves, the way they, er, er, present themselves.
- I: In this scenario B, which concepts, physical concepts do, um, the condition, the snowy condition, affect here?
- S1₂: It affects friction, and if it affects friction it affects the whole scenario, ja, I would say it affects the whole scenario. Because if you look from where it begins, if you compare it with dry conditions, I think the men overcame the car – overcame the inertia of the minibus very easily, you know, if you were to maybe look at the very same four men in the snowy weather, you'd find that probably it would take them much more time and it will take much more energy on their part to overcome that thing, and this is created by the fact that there's very less friction on the situation, on the two situations in the second part and in the first part there's greater friction as compared to them [referring to Part A [wet] and Part B [snowy]].
- I: Okay, um, if we were to increase the number of men in a snowy weather do you think, um, we would be able to make Part B ...
- S1₂: Those conditions. Um, of course, assuming that the gears will be having its proper and stuff, I think we were to do that it is possible, I won't say it was – I wouldn't know the situation, you know, but I'm assuming, I'm making a lot of assumptions. I would say that probably I'm also overlooking a lot of other problems ... car stuck in the mud, you cannot expect to take that car out of the mud if you don't try and put something that will increase some sort of friction.

Table 6.11 below illustrates the sequence of shifts

Table 6.11 *Sequence of inter-contextual shifts by S1*

Sequence	Aspects focused upon	Couching	Category of description	Context
1 st	Friction and motion	Classroom textbook definition	B	1
2 nd	Friction on men's feet	Intuition	A	2
3 rd	Friction and the surface	Application	C	2
4 th	Resistance	Intuition	A	2
5 th	Energy	Intuition	A	3

Student S1 is regressing as he moves from one context to another, in this case, from a familiar context to a less familiar one. Student S1 creates his own context to operate from, by focusing on different aspects. This example illustrates again the distinction between the theme and the thematic field. In each instance as shown in the above table the individual's experiences of physics phenomena are seen to depend on which critical aspects of the phenomena are brought into focal awareness.

Example 2

Student S5 in context 1

- I: What do you mean by "friction opposes motion"?
- S5₁: Since these men are applying a force in whatever direction then there is obviously a force in the opposite direction which is friction, opposing motion even when they have stopped applying force, that is, after releasing, the two cars will move for some time and stop. It is friction which is causing them to stop because the surface is not smooth and also wind resisting the motion.
- I: Is wind resistance friction?
- S5₁: You may say so because it is force acting on opposite direction.
- I: Is every force that is acting in opposite direction friction?
- S5₁: Not every force but every force that opposes applied force is friction.

Student S5 in context 2.

- I: Okay. Now what do you mean by rainwater opposes motion?
- S5₂: I mean because the surface is not clear, there's water, then motion will be opposed by the rain.
- I: How is the motion opposed by the surface?
- S5₂: Because of the water that's on the surface, that's – whatever, on the car, whatever.
- It's what I'm trying to say, correct, because there is water on the surface. It's not like when there's nothing on the surface and it's only cars just moving, so there is water. Maybe the water it might be in an opposite – it might be flowing in an opposite direction to the motion of the car. So, the motion won't be the same as – I mean, when there wasn't rain on the surface.

- I: Okay. What do you mean by the rainwater increases friction? How does it increase friction?
- S5₂: By the fact - by the mere fact that the motion will be opposed. That means there'll be greater, I mean, friction on the surface. Not on the surface exactly, but - there'll be much force opposing motion which I call, I mean, friction, I mean.

Later in the same interview when comparing the 3 given contexts, he said,

- S5₂: I think the greatest friction would be on the water surface.

Later in the same interview in context 3, S5 said,

- I: What do you mean by snow on the surface decreases friction. How does it decrease friction?
- S5₃: Because the road is slippery, it means less friction, whatever.
- I: So, when we have snow on the road is slippery and we have less friction?
- S5₃: Yes.
- I: Okay. Now, what do you mean by snow on the surface increases motion. How does it increase motion?
- S5₃: Because there's less friction so motion won't be opposed, so it may - whatever.

The table below represents the sequence of shifts.

Table 6.12 *Sequence of inter-contextual shifts by S5*

Sequence	Aspects focused upon	Couching	Category of description	Context
1 st	Friction and motion	Classroom textbook definition (<i>friction, opposing motion</i>)	B	1
2 nd	Rainwater and motion	Intuition (<i>motion will be opposed by the rain</i>)	A	2
3 rd	Surface	Intuition (<i>road is slippery</i>)	A	3

Student S5 created his own context, where water is flowing in one direction and the car moving on the other direction, in order to describe a phenomenon. When friction was not brought to the fore the individual retreated to intuitive deductions.

6.3.3.2 Discussion on inter-contextual shifts

We have seen again here, the crucial feature of the importance of recognising and appreciating context appropriately. Again the distinction between the researcher's prepared contexts and the individuals' experienced contexts has been noticed. There is again evidence of regression as students move from a familiar context to a less familiar one as created by the researcher. It has been shown here as well that when regression occurs, the move is always back to category A – intuition.

One reasonable explanation for these kinds of shifts may be that, as was illustrated earlier, in less familiar contexts students created their own thematic fields from imagined synonymous contexts. Often these imagined synonymous contexts would seem to be drawn from domains of familiarity – things and places they are familiar with. Here, the influence of intuition towards contexts or domains of applicability is evident. In other words, from this study it would seem that intuition is the most significant influential factor in thematisation -- the way students interpret contexts. The students in this study attempted to make what they found 'unfamiliar' to them familiar, by drawing on a *relevant structure* constituted for a situation deemed to be a synonymous situation.

6.4 Findings and Discussion

The study has shown that there are intra and inter-contextual shifts. It was also evident that the change in focus resulted in a change in meaning. The influence of context in the shifts has been observed. The distinction between the researcher's thematisation of context and that of the participants' thematisation has also been noticed. The influence of intuition on the thematisation of contexts has also been observed. In most cases students did not move beyond intuition and classroom physics, which could possibly be a result of the way context was thematised. In many instances, intuition seemed to determine which aspects of a phenomenon were brought into focal awareness, and which remained in the thematic field. This finding has been supported by Ueno, Arimoto and Fujita's (1990) study which suggested that the difference between intuition and Newtonian dynamics lies in how intuitively motion is discerned as a dimension of variation whilst Newtonian physics takes objects at rest as the frame of reference.

The influence of contexts on ways of experiencing or understanding concepts has been noted and reported by other phenomenographic studies. Linder's (1989) study on understandings of physics graduates and more recently Pong's (1999) study on understandings of economics concepts showed that students focused upon different critical aspects of the physics and economics phenomena across and within different interview-generated contexts. Thus, in different contexts, students constituted different conceptions. Although this study is on understandings of conceptual links between Newtonian dynamics concepts, its findings are in line with Svensson's (1989), Linder's (1989) and Pong's (1999) studies on students' understandings of physics and economics phenomena, which suggested

that it is very difficult, if not impossible, to ascribe an 'all time' conception of phenomena to a particular individual. Pong (1999) suggested that conceptions are dynamic states of awareness. It has been repeatedly shown in the data that when individuals focused on certain aspects of the situation or context, a certain conception ensued.

The influence of context as thematised by individuals in the study is well observed, as well as the influence of intuition on the thematisation of contexts. In most cases the individual's thematisation of context was related to prior experience or knowledge. I will call it *intuitive context* or better still *a process of contextual association through relevance structure linking*, to distinguish it from the predefined context in the study. For example, student S1 associated snow with mud as he had not experienced snow, but has seen how people walk in snow on television and associated that movement with people walking in mud, and hence thematised the provided context of a snowy road as that of a muddy road when describing the phenomena.

The variation in contexts introduced in the study did not extend the students' focal awareness, instead it seemed to provide a basis for the shifts in focal awareness. Linder (1989) and Pong (1999) share this observation. Similar to this study, both studies showed that students expressed both inter-contextual and intra-contextual understandings without any 'mindfulness' (Pong, 1999) that they were doing it. Linder and Marshall (2001, in press) on "Reflection and phenomenography" argue that Linder (1989) and Pong's (1999) studies have suggested that variation is a necessary but not sufficient condition for developing a more complex structure of awareness, hence they introduced the notion of 'mindful conceptual dispersion' to emphasise conceptual dispersion with awareness of contextual appreciation. They continued to say that the way

something is thematised in physics “depends very much upon being mindful of the required contextual appreciation” (Linder and Marshall, 2001:11).

The contextual shifts have shown that a shift in what was focused on resulted in a shift in meaning. This result is similar to Pong’s (1999) finding that when an individual student focused on certain aspects of the situation or context a certain conception was constituted. Both findings support the theory of the structure of awareness, whereby “qualitatively different ways of experiencing something can be understood in terms of the differences in the structure or organisation of awareness at a particular moment or moments” (Marton and Booth, 1997:100).

When learning to experience and express understanding, it is important that students identify the significance of context influences, otherwise context will be taken for granted and complicate the process of learning (Svensson, 1979; Linder, 1993; Ramsden, 1997). Linder (1993) has argued that in science education more attention has to be paid to students’ way of distinguishing between contexts. In this study, context was predefined by the researcher, and often students used prior experience to create an intuitive context or contextual association to contextualise their descriptions. This result is similar to those described by Wilson and Sperber (1985), who, in their study, “On choosing the context for utterance-interpretation” found that the context-selection activity is marked by intuition. Similar results have been reported by Wistedt (1994) and Prosser (1994).

Although the contexts were predefined, the individuals thematised the contexts differently from the researchers’ contexts. In their paper “On

context in phenomenographic research on understanding heat and temperature” Adawi, *et al* (2001:1) argue that “the experienced context, the context as created and understood by the researcher, and the relation between these are relevant to varying degrees and in varying ways at different stages of the research project”. Thus individuals created their own contexts when responding to the questions during the interviews. The researcher has consciously led the students to focus on certain aspects of the phenomenon, in order to lead them in a certain direction, thus assuming a change in context.

The most significant aspect of phenomenography is that the process of obtaining the ‘pool of meaning’ involves a deliberate lifting of the descriptions out of their contexts. In Chapter 5 a phenomenographic process was followed which yielded variation in the ways of understanding the phenomenon. However, Marton and Pang (1999:5) when discussing recent development of phenomenography, stated that “to experience something in a particular way, there is always a discernment of the whole from the context”. They further state that in order to “discern something from its context, we have to assign it a meaning and see it as a particular thing” (Marton and Pang, 1999:6). The variation, which was created by the predefined contexts, seemed to have been taken for granted, as both the researcher and the individuals thematised the contexts differently.

The differences in the contexts as thematised by both the researcher and the individual emerge as an educationally critical aspect of learning. Educators should pay more attention to contexts as identified or created by students. The study has shown that the contextual variation as created by researchers is not necessarily similar to the contextual variation as seen by students. Intuition seemed to have played a major role in creating contextual variation for the students.

The implications of the variation in context is that educators often take for granted that students will thematise the context in a similar manner in which educators assume. Educators have to be aware that students always carry their own experiences, and they often use these experiences to delimit a theme from a context. This has been highlighted from the interviews where students moved forward from one category to another and then moved backward again. These backward and forward moves in conceptualisations pose a challenge to physics teaching.

The studies on the experience of learning in Newtonian dynamics have shown that it is often taken for granted that students hold Newtonian conception (Johansson, *et al*, 1985). We have seen in this study and other studies that students are capable of constituting multiple conceptions, as Svensson (1989) suggest that students are capable of 'fitting meaning given to aspects that they focus on' (see also Linder, 1989 and Pong, 1999).

Linder (1993) in his paper "Challenge to conceptual change" challenged conceptual change models which include as a goal, having a student giving up one conception and adopting an alternative. Mortimer (1995) has drawn on these ideas to extend the challenge, by drawing an overview of a model to analyse conceptual evolution in the classroom based on the notion of a conceptual profile. This model differs from conceptual change models in suggesting that it is possible to use different ways of thinking in different domains.

Mortimer (1995) in his paper "Conceptual change or conceptual profile change?" argues that the differences in epistemological profiles in each

concept is strongly influenced by the different experiences each person has had, by their culturally different roots, and by opportunities that an individual has had. That the same students who performed well in familiar tasks about force and motion reverted to pre-Newtonian reasoning of 'motion implies force' in non-familiar questions is an indicator that students have a profile of conceptions, as their previous beliefs were not replaced but coexist with the new view. Even a student who uses Newtonian reasoning in non-familiar questions would have this profile. The difference is that this student *seems to be conscious* (own emphasis) of the best occasion to use each sector of the profile. He or she could apply the pre-Newtonian reasoning in appropriate contexts, for instance, in everyday life (Mortimer, 1995). This type of phenomenon is realised in this study as well, as I observed students move from one conception to another, and showing positive progress in some instances and regression in other. The crucial feature here is the importance of understanding the context of a particular physical situation, implying what is relevant and what is not in this particular situation. That is, how to appropriately choose focus at any time and what procedures to implement. Linder (1993) argues that conceptual change from a phenomenographic perspective is achieved by changing one's relationship with a context. By that he means being able to perceive different contexts differently, and by doing so being able to change one's relationship with a specific context.

Newtonian conceptions are often seen by students as different from everyday experiences. This observation is supported by Wolpert's (1993) book on "The Unnatural Nature of Science". This is part of a wider theme: the existence in physics of effective or phenomenological theories, see Hartmann's (2001) paper on "Effective Field Theories, Reductionism, and Scientific Explanation". One often has a situation where a fundamental theory is awkward or difficult to apply to specific situations,

and an effective theory applicable to that situation, which should at least in principle be derivable from the fundamental theory, is much more useful in practice. Its domain of applicability will be less than that of the fundamental theory, but it will be simpler to apply within that domain of validity and will give correct results rapidly.

Specific examples are effective field theories in nuclear and particle physics, for example

- The Euler-Heisenberg theory of photon-photon scattering,
- The Fermi theory of weak interactions,

[See Hartmann² for a detailed discussion]. Equally,

- Newtonian gravitational theory was once thought to be fundamental theory of gravity; it is now known to be an effective theory valid under certain circumstances (slow motion and weak gravitational fields) when General Relativity has a good Newtonian limit, and is widely used as the effective theory of gravity in that context, e.g. in astrophysics. However,
- the Galilean theory of gravity close to the surface of the earth (i.e. a uniform acceleration of all bodies due to gravity, which in turn is derivable from Newtonian theory) is a good enough theory in most engineering applications (e.g. constructing a building or designing an aircraft or an elevator). One does not need the underlying Newtonian theory (or General Relativity) for this purpose.
- the apparent motion of the sun round the earth as experienced daily in the 'rising and setting of the sun' – a view where the sun moves round the earth on a daily basis (this view being embodied in those

² S. Hartmann: 'Effective Field Theories Reductionism, and Scientific Explanation'. *Studies in History and Philosophy of Modern Physics*. 32(2), 267-304 (2001).

everyday expressions for what is in reality the effects of the rotation of the earth); and

- the effective Aristotelian physics that replaces Newtonian physics in many everyday circumstances. It is the latter that is of interest here.

The experimental data of how students learn show that even when students have moved on to a more fundamental understanding of physics concepts and applications, they may revert immediately to a less fundamental position. For example, student S3 in the interview on conservation of momentum, said,

“... the velocity of the minibus before is not equal to velocity of the coupled cars after. The velocity will be reduced after collision”.

He later explained what he meant by “velocity will be reduced” by giving an example showing that the combined mass of the bus and taxi will be greater than that of the individual car, and because the combined mass is greater the velocity will be reduced. He ended the interview by saying,

“smaller is faster”.

One possible hypothesis is that this is because they have not really grounded the new ideas and so retreat to the more familiar: the ‘aha’ experience does not have solid roots. A second hypothesis is that this happens because even after they develop deeper understanding, it pays them to keep the less fundamental effective theory going, rather than abandoning it in the face of the new view, because it often works better in practice, or at least is simpler to apply and more easily gives the desired results. Possibly this only remains true until one is an expert, when this may no longer be the case; but some of the examples above, for example, the setting of the sun, suggest that even for the expert it is useful to keep a

simple incorrect effective theory going (even physicists talk about the setting of the sun!).

Wolpert (1993) argues that science is generally counter-intuitive and against common sense. In most counter-intuitive situations students tend to fall back on intuitive knowledge which makes sense to them when describing a phenomenon. A similar observation has been made in the study. Context 3, which turned out to be unfamiliar to more students than anticipated, had one student discern it from context 2, meaning that he saw similarities in people walking in snow in movies with the way one walks in mud, and he thus created a context within which he conceptualised conceptual links in context 3. The student formed a contextual association which helped him to experience a phenomenon in a certain way. The individual's context was what he experienced as being relevant for making sense of the situation, and as Adawi, *et al* (2001:4) put it, "this being interwoven with the experience of the phenomenon under consideration". They continue to say that "the phenomenon is thus experienced against and interwoven with an experienced context" (p.1), what they refer to as 'experienced context of the individual'.

According to Marton (1981), in order to learn, one needs to experience variation. Educators need to ensure that students experience variation by providing contextual variation that is necessary for meanings to emerge. It is however, inappropriate to assume that ways of experiencing can be entirely achieved through context variation alone. In the study we saw that the variation created by predefined contexts was not experienced by all students, hence these individuals could not learn within those contexts: they had to identify or create their own intuitive or experienced contexts to make sense of the conceptual links.

Pong (1999) in his study on students' understandings of economics concepts and Linder's study (1989) on students' understandings of physics concepts gave details of how students made sense of a particular phenomenon in different contexts, that is how the situation or context was thematised. In both these studies different contexts were generated during the interviews and students focused upon different critical aspects of phenomena and in this way variation in the students' way of experiencing these phenomena was introduced. For example, Linder and Marshall (2001, in press) wrote:

"if learning is about developing a more complex structure of awareness of a phenomenon, then introducing variation is a necessary, but not sufficient, condition. What is also needed is reflection on, or mindfulness of, this variation in order to develop explicit contextual appreciation".

Linder and Marshall (2001:11)

Educators should therefore observe and understand these intuitive or experienced contexts. Detailed implications for the teaching and learning of Newtonian dynamics will be discussed in the next Chapter.

Chapter 7

Conclusions and Pedagogical Implications

7.1 Introduction

In this final Chapter the findings of the study are drawn together and implications are considered, both for theoretical development and for teaching practice. Over and above summarising the contribution to the body of knowledge on student learning of Newtonian dynamics in higher education, this Chapter aims to relate the study and its findings to the relevant literature, and to propose directions for further research.

7.2 Summary of findings

Phenomenographic and theoretical findings are presented in this section. The educationally critical aspects from both findings are identified and discussed. The study was looking at the variance in the ways in which students experience or understand conceptual links between basic Newtonian concepts. The study went further in also looking at how the different ways of understanding conceptual links evolved. For analytical purposes the phenomenographic results have been described separately from the theoretical results, as the former analysis is done at a collective level, and the latter at an individual level.

In this study I focused on and thematised certain aspects of the content and put other aspects into peripheral awareness by providing contexts within which the students were to draw their concept maps. The design principally involved creating an everyday scenario thematised into three qualitatively different domains of applicability (see Chapter 1) for the exploration of inter-conceptual understanding of Newtonian dynamics.

The aim was to create contextual variation that would potentially facilitate as wide a discernment of critical aspects of the content as possible. The students were asked to draw concept maps set in these contexts. The concept maps were used to create a semi-structured interview protocol, which formed the basis of subsequent interviews with students about what they had written and drawn on their individual concept maps. The interviews were transcribed and they formed a 'pool of meaning'.

7.2.1 Phenomenographic findings

From a phenomenographic analysis as detailed in Chapter 4, I found that there are four interesting qualitatively different ways that students experience conceptual links in basic Newtonian dynamics concepts. These four qualitative different ways are represented by the four categories of description as a characterisation of ways of experiencing conceptual links (see Chapter 5). These categories of description were discerned from the interviews in terms of their meaning (referential aspect) and structure in terms of background to descriptions; what descriptions drew on; and nature of discourse or couching.

The different categories of description represent a hierarchy of increasing complexity and specificness of ways of experiencing conceptual links. The increasing complexity is based on logical specificness in that the world of physics was discerned and the conceptual links were recognised in a specific form. The students experienced links as *cause-effect* relationships. The various categories of description of the conceptual links identified in the empirical study differ from each other and from the desired way of experiencing conceptual links in Newtonian dynamics. Cope (2000:166) argues that such differences "lie in combinations of the number of dimensions in variation, the particular values within the dimensions of variation and the richness and strength of relationships between dimensions of variation". The differences are portrayed as being educationally critical where they are seen to be significant in the light of the desired way of experiencing conceptual links.

7.2.2 Educationally critical differences between categories of description

In this section categories of description are summarised and differences highlighted. As discussed earlier, in phenomenographic studies, categories of description characterise a way of experiencing, understanding, conceptualising, seeing, etc. some phenomenon. Cope (2000) argues that the differences between categories of description are, therefore, critical ones and contribute toward educationally critical aspects of a deep understanding of the phenomena.

Category A - Conceptual links are cause and effect relationships based upon intuitive deductions.

In this category, descriptions are drawn from intuition and common sense. The links are made up of everyday experiences, meaning those aspects of the conceptual links which are simultaneously in focal awareness consist of intuition and common sense. The focus is on the everyday world in a generalised form and the description of what is focused on is in everyday language. For example, the focus in most cases (see Chapter 5, Section 5.2.3) is on the surface of the road, which determines the ease, or difficulty, with which the men walk or push the car (see Appendix C for more examples).

Category B – Conceptual links are cause and effect relationships based upon textbook definitions, formulae and laws

In this category, descriptions are couched in a mixture of common sense and of recalling textbook definitions, formulae and laws. The links are textbook definitions, formulae and laws, meaning those aspects of the conceptual links which are simultaneously in focal awareness consist of textbook definitions, formulae and laws. The focus is on what has been learned and taught in the classroom. The description of what is focused on is in a mixture of vague and textbook description. In this category the

world is seen in a specific form, as the world of introductory physics while in Category A, the world is seen in a generalised form (variation 1).

Category C - Conceptual links are cause and effect relationships based upon application of laws and formulae

In this category, descriptions are drawn upon formulae, definitions, laws, and dependencies in relationships or formulae. The links are application of definitions, formulae and laws, meaning those aspects of conceptual links which are simultaneously in focal awareness consist of application of definitions, formulae and laws, or application of dependencies in relationships or formulae. The nature of the focus is recollection and application of definitions and laws. The descriptions of what is focused on are abstract with an introduction of symbolic description, and take on an interpretative value. It is in this category that abstraction appears for the first time, and formulae are used to relate general situations to specific cases (variation 2). This category is inclusive of Category B in that it also includes recollection of definitions, laws and formulae for application, while in Category B definitions, laws and formulae are only statements. Unlike in Category B, in this category taught physics is viewed through recollection and application of definitions and formulae.

Category D - Links are cause and effect relationships based upon integrated physics explanations (beginning of formal and systematic thinking)

In this category, descriptions are drawn by establishing a conceptual framework to consider a situation; the careful selection of concepts, definitions, laws, and formulae as a way to give conceptual meaning to a situation or phenomenon. The links depict the appropriate Newtonian way of thinking about dynamics meaning that those aspects of conceptual links that are simultaneously in focal awareness, consist of the establishment of a conceptual framework to consider a situation from, before the selection and application of formulae and laws. In this category, unlike all the

others, discourse and experience is about physics -- an abstract scheme of general understanding that can be applied to understanding and determining outcomes in specific contexts (variation 3). In this category a conceptual framework is established by mindfully taking the context into account before selecting and applying principles and formulae (variation 4). In this category beginning of formal and systematic thinking occurs for the first time (variation 5).

7.2.3 Discussion on educationally critical aspects from phenomenographic results

The qualitative differences between the categories of description are depicted as variations – five of which were discerned. The different categories of description represent a hierarchy of increasing complexity and specificity of ways of experiencing links between basic Newtonian concepts. The increasing complexity is based on logical specificity in that the world of physics was discerned and the conceptual links were recognised in a specific form.

Category A – cause and effect based on intuitive deductions coming from everyday experiences; and Category B – cause and effect based on textbook definitions, laws and formula, primarily reproducing what has been taught and as such can be argued to be generally rather unproductive in terms of making sense of physics. Category C – cause and effect based on application of formulae and laws can be argued to depict a combination of memorisation and abstraction, which representing what the literature calls ‘surface’ learning, on the one hand. On the other hand, Category D – cause and effect based on integrated physics explanation -- is essentially about seeking conceptual meaning or understanding, what the literature calls ‘deep’ learning. The existence of variation in the way conceptual links in basic Newtonian dynamics were experienced extends the existing research-based characterisations of different approaches and levels of understanding Newtonian dynamics in a useful way for teaching practice

(see Section 7.4). The different levels of understanding are summarised in Table 7.1 in Section 7.3.

7.2.4 Findings from the theoretical analysis

7.2.4.1 Introduction – the notion of *mindfulness of context*

Since there is contemporary theoretical discussion emerging in phenomenographic circles regarding the role that a person's state of *mindfulness of context* plays in the constitution of his/her experience of some phenomenon (for example, Linder and Marshall, 2001, in press, Pong and Marton, 2001, in press), I decided to begin my intra and inter-contextual investigations with a statistical analysis to see if any statistically significant correlation could be discerned between categories of description and the study-provided contexts. The statistical analysis yielded little information I could build on beyond some evidence of significant correlation at the individual level. This outcome led me to qualitatively look at the distribution of categories of description at an individual level, within and across the study-provided contexts. This qualitative mapping revealed some interesting patterns, which prompted further exploration by looking into intra-contextual and inter-contextual shifts with the associated variations that had emerged from the data. This path of investigation led me to make a contribution to what Marton and Pang (1999) characterised as new phenomenography theoretical concerns: "What is a way of experiencing a phenomenon?" and "how do different ways of experiencing something evolve?" (Marton and Pang, 1999: 2)

The influence of contexts or situations on manifested conceptions has been witnessed and reported by other phenomenographic studies (Dahlgren, 1979; Linder, 1989; Svensson, 1989; Pong, 1999). The theoretical development of the phenomenon as it relates to higher education learning in physics was introduced by Linder (1993). He characterised the phenomenon of intra and inter-contextual shifts as 'conceptual dispersion' and argued that conceptual dispersion was in part due to specific contexts

not being part of focal awareness development in the teaching of physics. Linder and Marshall (2001, in press) use a combination of Linder's (1993) argument and Pong's (1999) results to argue that experiencing variation is not sufficient for learning, but that contextual appreciation is also necessary, and that consequently the concept of mindfulness ought to be included in the phenomenographic 'anatomy of awareness'. And it is here that my study is able to contribute further to this theoretical development in phenomenography. In my study the influence of context was examined closely. Both inter-contextual and intra-contextual shifts were looked at (see Chapter 6) and the analysis could be characterised as yielding an unpredictable set of explanations for the given set of contexts. This makes discussion regarding the role of contexts difficult beyond illustrating the capability of people to draw upon multiple ways of making sense of things in order to explain them in different contexts. According to Linder, Marshall and Nchodu (2001) this suggests that effective physics learning should be portrayed in terms of learning to experience certain patterns of variation – the kind of experience which only a reflective searching for critical aspects to focus on can generate.

I planned the study-provided contexts to introduce variance. In some instances individuals in the study did not experience the intended contexts in the same way as the researcher. This was highlighted by the individuals' responses in an unfamiliar given context (see Chapter 6). An unfamiliar context, context 3, was highly conducive to the use of intuitive deductions, a less familiar context, context 2, was significantly conducive to intuitive deductions whilst a familiar context, context 1, readily predisposed students to using classroom textbook definitions and formulae.

When moving from a familiar context to a less familiar context, the trend was that students moved from a higher category of description to a lower category. This kind of movement was not unexpected as seen in less familiar contexts; students created their own intuitive or associated contexts within which they operated. Students made what was unfamiliar,

familiar, by using whatever experiences they deemed similar to what they were confronted with. It was also evident that there were low responses on higher categories as we moved to unfamiliar contexts. Students were moving forward and backward as they moved within and across study-provided contexts. The contextual shifts have shown that a shift in what was focused on resulted in a shift in meaning. The influence of intuition in the thematisation of contexts was also observed. This influence contributed to the variation of context.

The shifts from one category to another within and across the given contexts suggest that one cannot pin down an individual to a category. This seemed to occur because the students described each of their concept map links with whatever concepts and principles the different contexts brought into their focal awareness at that time. Yet the kinds of discernments made were not found to be contextually dependent. This outcome can be seen to support Linder and Marshall's (2001, in press) notion of a lack of mindfulness of contextual influence. However, I believe further detailed characterisation is needed. If we consider how physicists use effective and fundamental theories (see Chapter 6), I believe that a case can be made that the phenomenon of conceptual dispersion is best characterised as sets of everyday life 'effective theories'. And because they are everyday life-based they are constituted with little or no contextually related mindfulness. Then the contextual influence in understanding may be seen as being an outcome of discerned *contextual* variation. In other words learning is not just about variation in critical aspects in terms of the parts, but it is also about variation of wholes as defined by context. In this way understanding cannot be seen as an intrinsic part of a person, but as something that one experiences and expresses through contextual appreciation. Where everyday life has led to taking the contextual appreciation for granted and to the formulation of 'effective theories' then the teaching of 'fundamental theories' explicitly requires two things – firstly a continuous focus on context and secondly, using this contextual focus an explicit exploration of when and why 'effective theory' may be valid and when not (this second aspect is further

discussed in Section 7.4, *Implications for introductory physics teaching practice*). The importance of context is explored further now in relation to domains of applicability and implications for teaching practice.

7.2.5 Educationally critical differences between domains of applicability

The way of experiencing variation in context was found to include a number of educationally critical aspects. The differences between study-provided contexts and the intuitive contexts generated by students are critical ones and contribute toward educationally critical aspects of a deep understanding of the phenomena (variation 6). Adawi, *et al* (2001, in press) when discussing the differences between the researcher's context, the collective context and the individual's context, in their paper "On context in phenomenographic research", argue

"Our consideration of the context of the individual – comprising the interviewer's knowledge about the personal and educational background of the interviewee, the prepared context, and the interview discussion that has gone before – give the interviewer a tool to distinguish the theme from the thematic field at specific and critical points in an interview, in order to encourage an elaboration on the thematic field which can later give grounds for understanding the interviewee's experience of the context".

(Adawi, Berglund, Ingeman and Booth EARLI, 2001:10)

As described earlier, the study-provided contexts were thematised in three scenarios with varying degrees of abstraction with changes in theme-content made up of everyday experience and everyday intuitional content. These different *domains of applicability* discussed in Chapter 1 can thus be said to have thematised the given scenario as follows (in increasing abstraction):

a. A normal sunny day

In this study-provided context, the implicit implication is a familiar everyday situation where normal frictional conditions exist. Those aspects

of the context simultaneously focal in awareness consist of normal friction.

b. A rainy day

In this study-provided context, the implicit implication is a less familiar situation where reduced frictional conditions exist. The critical difference between this and the first context lies in the magnitude of friction on both surfaces (variation A, different numbering to indicate that the variation was created by the researcher).

c. A snowy day with roads covered with ice and snow

In this study-provided context, the implicit implication is an unfamiliar situation where negligible frictional conditions exist. The critical difference between this and the previous contexts lie in the magnitude of friction on all surfaces (variation B).

There is yet another context, which we called intuitive context or experienced context, generated by students themselves, which is different from the study-provided contexts (see variation 6). We have observed the influence of intuition in the generation of these experienced contexts.

7.2.6 Discussion on educationally critical aspects from theoretical results

The variation introduced into the study was the variation in friction implied by the different surfaces. In Chapter 6 I described how on the one hand, if friction was not brought into focal awareness, then the situation was likely to be experienced in an Aristotelian force-causes-motion way. For example, student S4 in the interview, when asked what he meant by “applying a force”, he replied, “*by applying a force, ... these men because they cause a movement on the minibus ..., that is why I say they applied a force*”. According to the student the force is in the form of men, and as

they push the minibus they apply a force and it is this force that causes the minibus to move. On the other hand, if friction is part of the thematisation, the situation was likely to be experienced in a Newtonian way, with force causing a change in motion (see also, Johansson *et al*, 1985 and Svensson, 1989).

The influence of intuition on the variation of context is indicative of the importance of intuition in learning. Educators should be aware that intuitional knowledge plays a vital role when students thematise contexts. Therefore when introducing variation in context teachers should aim not only at setting their teaching in ways which introduce variation, but also in ways which help students to become mindful of context as an interpretative framework.

There are educationally critical aspects of a phenomenon which are necessary for developing a scientific understanding, or experience of a physics phenomenon. Linder and Marshall (2001:8-9) state that in phenomenography, learning is about "changing those aspects of the phenomenon that are present in the theme, and the role of teaching, then, would be to focus on the educationally critical aspects of a phenomenon, and in doing so, widen the space of variation for the learner". The context variation that I brought into the study widened the space of variation for the interviewees with the aim of effectively turning them into students. Thus friction was intentionally brought into the students' focal awareness, however, variation on its own was not enough to establish the conditions for effective learning. While students recognised the role of friction in the different contexts provided, their descriptions indicate that they did not understand its appropriate role in the different contexts. Thus my study has provided strong supporting evidence that the aspects of the phenomenon that physics students pay attention to -- bring into focal awareness -- turn out to be very much a function of the nature of their appreciation of the contextual setting for the phenomena. Therefore, the aim of effective teaching should not only be to introduce variation, but also to ensure that the context of teaching is recognised and understood.

7.3 Assessment of the theoretical framework

7.3.1 Levels of understanding sought as a consequence of relevance structure

Marton and Booth (1997:111) state that phenomenography is a research orientation which attempts to identify, formulate and tackle certain types of research questions about learning and understanding in an educational environment. Learning is seen as “a change in the learner’s capability of experiencing a phenomenon in the world around them” (Marton and Pang, 1999:11). Marton and Pang (1999:11) poses a question, “how can we bring different ways of experiencing something about?” Put another way, as a physics teacher how can one deliberately introduce variation into our teaching in order to promote more effective learning? The argument is, “The principle of architecture of variation is considered as a thread that brings the teacher’s and the learner’s awareness into contact” (Marton and Pang, 1999:13).

From the phenomenographic analysis I found four qualitatively different ways in which students experienced, understood, apprehended and made sense of conceptual links in Newtonian dynamics. These four categories of description discovered were found to be hierarchical and logically related.

From the outcome space (i.e. categories with their logical relationships), two different ways of ‘approaching’ making sense of the conceptual links are characterised as two levels of understanding sought as a consequence of what phenomenography characterises as *relevance structure* -- what past experience says is needed – what is called for – to make sense of things. I make this characterisation because I want to argue that the students’ past teaching experiences and its relationship to the kinds of contexts I provided in my study provide the basis for what the students decided were the parts of the given research-contexts should be seen to be more, and what parts less, relevant. (It is in this sense that I talk of

'approach'). Broadly speaking two levels of sought understanding may be identified for the students involved in my study -- the need to search for parts to reproduce classroom physics, and the need to search for parts to use in a world of physics. Table 7.1 summarises this classification as follows:

Table 7.1 *Two levels of understanding sought as a consequence of relevance structure*

Levels of understanding sought as a consequence of relevance structure	Categories of description as a characterisation of a way of conceptualising conceptual links	What the conceptual link is seen as
Superficial understanding – reproducing what has been taught from school	A. Links are Cause and Effect relationships based upon intuitive deductions	An intuitive connection describing cause and effect
	B. Links are Cause and Effect relationships based upon textbook definitions, formulae and laws	A connection representing definitions and symbolic representation (physics formulae) in describing cause and effect
	C. Links are Cause and Effect relationships based upon application of laws and formulae	A connection representing application of laws and formulae in describing cause and effect
Meta- understanding – seeking meaning (beginning of formal and systematic thinking)	D. Links are Cause and Effect relationships based upon integrated physics explanations (beginning of formal and systematic thinking)	A connection representing conceptual meaning in relation to context in describing cause and effect

The difference between these two levels of understanding sought is framed by the background to the conceptions. The first level mentioned in Table 7.1 shows that the background was classroom introductory physics. Students were reproducing and recalling what has been taught in the classroom. The second level mentioned, however, shows a beginning of a move from taught physics to the world of physics. This level is still different from the desired physicists' approach to learning. However, the second level is likely to lead to the development of more complex ways of conceptualising conceptual links in Newtonian dynamics.

7.3.2 Perception of context

The arguments initiated by Linder (1993) and refined by Linder and Marshall (2001, in press) and by Pong (2000) and again by Pong and Marton (2001, in press) that experiencing variation is not sufficient for learning, but that mindful contextual appreciation is also necessary are supported by the findings of this study.

The importance of the 'context of experience' can be seen when consideration is given to being confronted with an unfamiliar context. Linder and Marshall (2001, in press) argue that

"When learners encounter a novel, complex or confusing phenomenon 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".

(Linder and Marshall, 2001:19)

An example of such reflective learning was presented in my study when a student looked for a similar context that he had experienced in order to thematise the given unfamiliar context. He did this when faced with the unfamiliar description of a road full of snow. He had experienced muddy roads, and had seen on television that people walking on snow walk the same way as one walks on a muddy road. So he then 'mindfully' used the muddy road experience to create a relevance structure to explore questions about a snowy road.

7.3.3 Conceptual change and multiple conceptions

The study has shown that students have multiple conceptions. This has manifested through the presence of different categories of description within and across the study-provided contexts for each individual student. Students moved from one conception to another. If they only had one conception, they would not be able to shift from one to another.

This outcome is similar to that reported by Pong (2000) in his PhD study on students' conception of the economic phenomena of pricing. This kind of evidence supports the conclusion that educators have to guide students in using conceptions in an appropriate way for a given context, or domain of applicability. This way I believe we will not be met with resistance, as we will not be asking students to abandon their conceptions but to use them in particular situations.

The presence of multiple conceptions in students brings a challenge to one of the most popular contemporary depictions of learning: conceptual change (for example of popular models of conceptual change see Hewson, 1981; Nussbaum and Novick, 1982; Posner *et al*, 1982; Osborne and Wittrock, 1983; and Brown and Clement, 1987). It is the conclusion of many studies framed in a constructivist perspective that students' prior conceptual knowledge influences all aspects of students' processing of information. Although phenomenography has no such cognitivist view it does propose that students bring certain relevant structures to a learning situation and that these learning structures mediate the constitution of understanding. From this point of view widening the variation in contextual appreciation seems a natural objective to strive for and I would argue that the nature of relevant structure is a fundamental attribute in generating variation in the domains of applicability. Thus one aim of science teaching must be to get students to appreciate the boundary conditions for different domains of applicability as a way to enable them to draw on appropriate relevance structures for a given context.

7.4 Implications for introductory physics teaching practice

The educational implications of this study are multi-pronged. One is to highlight to educators the variation depicted in ways students conceptualise conceptual links between basic Newtonian dynamics concepts. As students were moving from one conceptualisation to another, we looked at the track they went through. The move from one conception to another has been shown to be attributable to changes in

focus. Although the focus was predefined in the provided contexts, students identified or created their own intuitive or associated contexts within which they operated. It is evident that as educators we should not take for granted that the contexts we have provided will lead students to conceptualise phenomena in an assumed way. The implication of this variation was that “for learning to take place, critical aspects of the content and pupils learning should be discerned simultaneously by teachers against a backdrop of experienced variation of the aspects concerned” (Marton and Pang, 1999: 12).

Arons (1990) suggests in teaching introductory physics, it is most effective to develop variation by contrasting two situations (for example, block on a floor and block on an accelerated cart) when the concept of the static coefficient is first being developed. Extending the context for the same concept will be conducive to learning and understanding.

Now that as educators we are aware of the variation in the way students make links or form relationships between Newtonian dynamics concepts, we can now bear in mind in our lectures that these are the possible variations in understanding that can exist in our classes and have to take these variations into account when preparing our lectures. Also educators have to realise how unfamiliar contexts or unfamiliar domains of applicability can influence the way in which students conceptualise links between Newtonian concepts.

As educators we should ourselves appreciate the contexts and teach our students to appreciate context before we can use variation in contexts. We need to make our students recognise and understand the different contexts that they have to operate from, by ensuring familiarity of all contexts concerned. We should not as educators assume that students have the same thematisation of contexts as we do (see Svensson, 1979; Linder, 1993; Ramsden, 1997 on ‘context taken for granted’). The use of the unfamiliar context in the study bears testimony to this.

The relationship between focus and meaning suggests that educators should pay more and closer attention to the structure of the aspects of the conceptions expressed by their students in the learning situation as well as those expressed in the intended content of the curriculum. This relationship will help educators to understand individual differences in terms of the differences in the structure of awareness in their encounters with phenomena.

The implication for physics teaching is that we might recognise students' experiences as 'effective theory' for everyday life observations (see Chapter 6 on effective and fundamental theories), and instead of trying to **replace** such effective theory by the 'fundamental theory' (the correct physics), so that the former is considered a misconception in physics context, rather accept that both will run parallel even after the new view is understood, and concentrate on **showing when and why the effective theory will be valid, and when not**. This is a function of context. Thus:

they don't have to abandon their prior learning: they have to learn when it is appropriate to use it. The way to do this is to learn the broader theory, and then to discover the contexts when the prior learning gives valid results, and when it does not.

All the conceptions found in the study were based upon cause and effect, which is really what Newtonian dynamics is all about. Effective theory gives a view of cause and effect in a specific context, whilst the fundamental theory gives a view of cause and effect in a more general context. The effect theory develops into a more fundamental theory when it is made applicable to more general circumstances, and this is usually arrived at by generalising a theory to cover a wider set of contexts e.g. Newtonian gravitational theory covers the fall of apples to earth and the motion of planets in the solar system, and Galilean effective gravitational theory covers the first not the second. However, in each case it is an effective theory of cause and effect. Thus, for students to develop their effective theories into fundamental theories, teachers will have to help

them make their effective theories applicable to more general circumstances by introducing variation in contexts as a way of extending sometimes students' limited contexts, and also helping students to appreciate extended contexts.

We have seen in this study students moving from one concept to another and moving back again, this is evidence that there is a possibility of students who respond to two contexts, namely, formal academic and everyday life, by a two-track mode of cognition, with switching between them. Mortimer (1995) in his paper "Conceptual change or conceptual profile change?" argues that the existence in science of classical and modern views related to several concepts, is a strong indication that we cannot talk about a scientific view as opposed to a common-sense one, as this scientific view is not unique. Marton (1981) argues that a conception of a certain aspect of reality accepted as the scientifically correct view is not something given, something which is to stand for all time. He says historically, there have been other dominant conceptions taken as correct and it is not unreasonable to think that there will be others in the future. He continues to say common-sense conceptions held by today's students and judged wrong by science frequently turn out to be identical to conceptions accepted previously in history as scientifically valid ways of thinking. We have learned from the history and the development of science that scientific theories may be accepted by the scientific community in a certain period, and these theories may also appear as intuitively acceptable to the layman, and yet one may discover later, in the history of science, that the theory contradicted facts, previously known, or was rejected on logical grounds, previously not taken into account. Intuitively, space appears to be non-isotropic (as it appeared to Aristotle), consequently the absolute, continuous, homogeneous and isotropic space of Newton is difficult to accept intuitively.

For example, in the case of Aristotelian physics, the implicit statements derived from daily life experiences dominated by friction are:

1. A body stays at rest unless pushed.
2. A steady force keeps a body moving at a steady speed.

While in Newtonian physics,

1. A body stays at rest unless acted upon by an unbalanced force
2. A body will continue moving at a steady speed unless acted upon by an unbalanced force

That is, a body at rest or a body moving with a steady speed will stay in that state unless an external force is introduced.

The Aristotelian intuitions will indeed be true in many cases provided the body is not pushed too hard and is indeed friction-dominated, as opposed to motion in the air (by a ball thrown horizontally, for example, or an object that is dropped and freely falls) on the one hand, and motion on the earth in circumstances where friction is small on the other, as in the case of slippery mud, an ice-covered surface, a highly polished floor, or wheeled vehicle with very good bearings. The Aristotelian law is good as long as friction is significant and almost constant, and the acceleration is small. With appropriate signs, when pushing an object horizontally,

$$F_{\text{total}} = F_{\text{experienced}} - F_{\text{friction}} = m(dv/dt)$$

and so

$$F_{\text{experienced}} = F_{\text{friction}} + m(dv/dt)$$

$$\Rightarrow F_{\text{experienced}} \approx \text{constant}$$

$$\text{when } (dv/dt) \approx 0 \text{ in the sense that } (dv/dt) \ll F_{\text{friction}}/m$$

$$\text{and } F_{\text{friction}} \approx \text{constant.}$$

Thus the need is for

- a. showing how historically Aristotelian effective theories were developed into Newtonian fundamental theories for dynamics, and exploring highly illustrative contexts to

show that particular effective laws are not always true, and that some other more fundamental laws provide a more general explanation, which applies also in those circumstances; but with the addition of

- b. A derivation of a given effective law under specific circumstances where it holds, showing why and when that effective law will give a good description.

Thus, the teaching strategy can sanction the use of the effective law, provided the circumstances are right. This will validate both the students' daily experience (as expressed in the effective law) and the more fundamental theory, valid in a wider range of circumstances. The two-theory strategy – which the students almost certainly will use despite our best teaching efforts – can in this way be legitimised if understood in this way.

7.5 Conclusions

The study was on an appropriately small scale for its theoretical framing, thus no claims to generalisability are made in the traditional statistical way. In this study I was not sampling people but sampling variations on 'ways of experiencing or conceptualising' conceptual links. From this argument, I can, thus, make a 'naturalistic generalisation' (Stake, 1978) that there is a possibility of finding these kinds of variations in the way in which conceptual links between basic Newtonian dynamics concepts are conceptualised or understood in an introductory physics classroom (see issues of validity and reliability in phenomenography detailed in Chapter 3).

However, the concept of variation in ways of experiencing conceptual links in Newtonian dynamics was found to have enough potential to justify the educationally critical aspect of variation in learning. In addition, the variation of context was found to be a necessary critical

aspect of variation in learning, but not a sufficient one. The context has to be recognised and understood. Together with these aspects there are possibly other educationally critical aspects that need to be considered in order to promote better learning, but are not covered in the present study.

The study has generated an understanding of student conceptual links in Newtonian dynamics, which has strong implications for practice. These implications are fundamentally directed at the context in which the study took place. It is for the reader to consider the transferability of particular findings to other comparable contexts.

Variation on its own is not enough. We need to bring in the domain of applicability in terms of effective theories. These theories are not 'alternative conceptions' or 'misconceptions' as they are commonly referred to in most science education studies dealing with student understanding, but they are essentially 'effective theories' in a specific domain of applicability. When the context is removed, or when there is a lack of mindfulness or appreciation of the contexts, these theories fall away or become muddled and the importance of the domain of applicability in variation as a critical factor in the teaching and learning of physics emerges, as it did in this study.

7.6 Further research

Having considered the contributions of the research reported in the thesis to student understanding of conceptual links in Newtonian dynamics, the development of phenomenographic research approaches and student learning in higher education in general, some suggestions for future research are presented as follows,

- a. Extend the current study to further investigate the approaches of understanding that emerge from the categories of description discovered. In particular, it will be helpful to build up a library of similar

detailed interviews where the dynamics of flow between the different categories of description can be discerned and classified in relation to context. This will enable the results of the present study to be tested in a wider context and extended in appropriate ways where necessary.

- b. Investigate further evidence that introducing variations in context leads to an understanding of context and hence of concepts and appropriate focus. In particular, build up a library of studies where the effective theories in various fields (Newtonian physics, fluid flow, electricity, and economics, for example) are related to context and to the underlying fundamental theory, investigating how appreciation of context may help lead to an understanding by the student of when the fundamental theory may safely be replaced by an appropriate effective theory. Maybe certain types of questions or examples will help students to appreciate context in desirable ways. The teaching community should be provided with specific guidelines in terms of questions posed, and focus in relation to issues of teaching dynamics, e.g. focus on friction and momentum; presenting contexts where one or other dominates.
- c. Extend the current study to investigate the correlation between the concepts selected for each context and the categories of description discovered.

The product should be a set of guidelines to help teachers discern what stage in the categories has been achieved by

an individual, and suggestions of context variations that may help the student discern the next level. Furthermore, and most interestingly, it would be useful to investigate what cultural variations occur in this process, and how an understanding of the effect of these cultural variations may help discern the best contextual settings to propose for problems placed before classes of varied cultural origins.

University of Cape Town

APPENDICES

University of Cape Town

APPENDIX A

CONCEPT MAP PROBLEMS

Problem 1

A minibus is being pushed by 4 men. When it starts moving they let go and it accidentally collides with a stationary 10-seater taxi. The minibus drags the taxi with it and they both stop a few metres away. Given this scenario what concepts and/or principles do you think about? Draw a concept map about these concepts and link them together, clearly stating the nature of the relationship. Please do not put down the equations or translations of equations.

This exercise will help you and me to see how you understand the whole scenario, and how you understand the links you make between the concepts. That is, this will give me the propositional knowledge that you have about the whole scenario and the Newtonian dynamics concepts involved in this case. Please take this exercise as an educational one as it will indicate to you how you have experienced and learned these concepts.

NB: remember you can have more than one link between concepts.

Problem 2

- a) On a rainy day (wet road) 4 men are pushing a minibus. When it starts moving they let go and it accidentally collide with a stationary 10-seater taxi. Given this scenario what concepts and/or principles do you think about? Draw a concept map about these concepts and link them together, clearly stating the nature of the relationship. Please do not put down the equations or translations of equations.
- b) On a snowy day (road full of snow) 4 men are pushing a minibus. When it starts moving they let go and it accidentally collide with a stationary 10-seater taxi. Given this scenario what concepts and/or principles do you think about? Draw a concept map about these concepts and link them together, clearly stating the nature of the relationship. Please do not put down the equations or translations of equations.

APPENDIX B

CONCEPT MAPS DRAWN BY STUDENTS

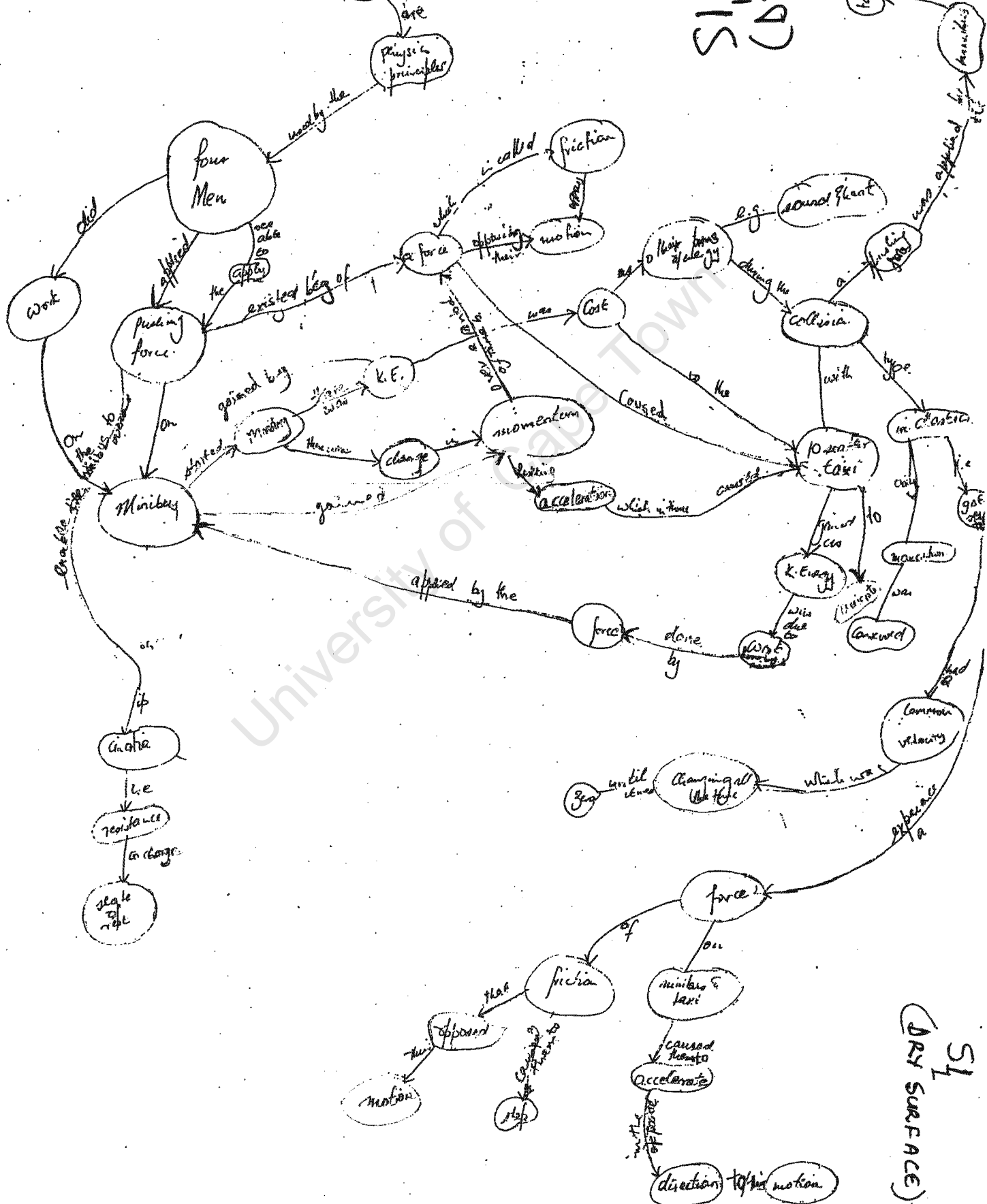
Concept maps were drawn by students for problems 1, 2a) and 2b). The maps show the links students made between Newtonian dynamics concepts. The maps are attached here, as follows:

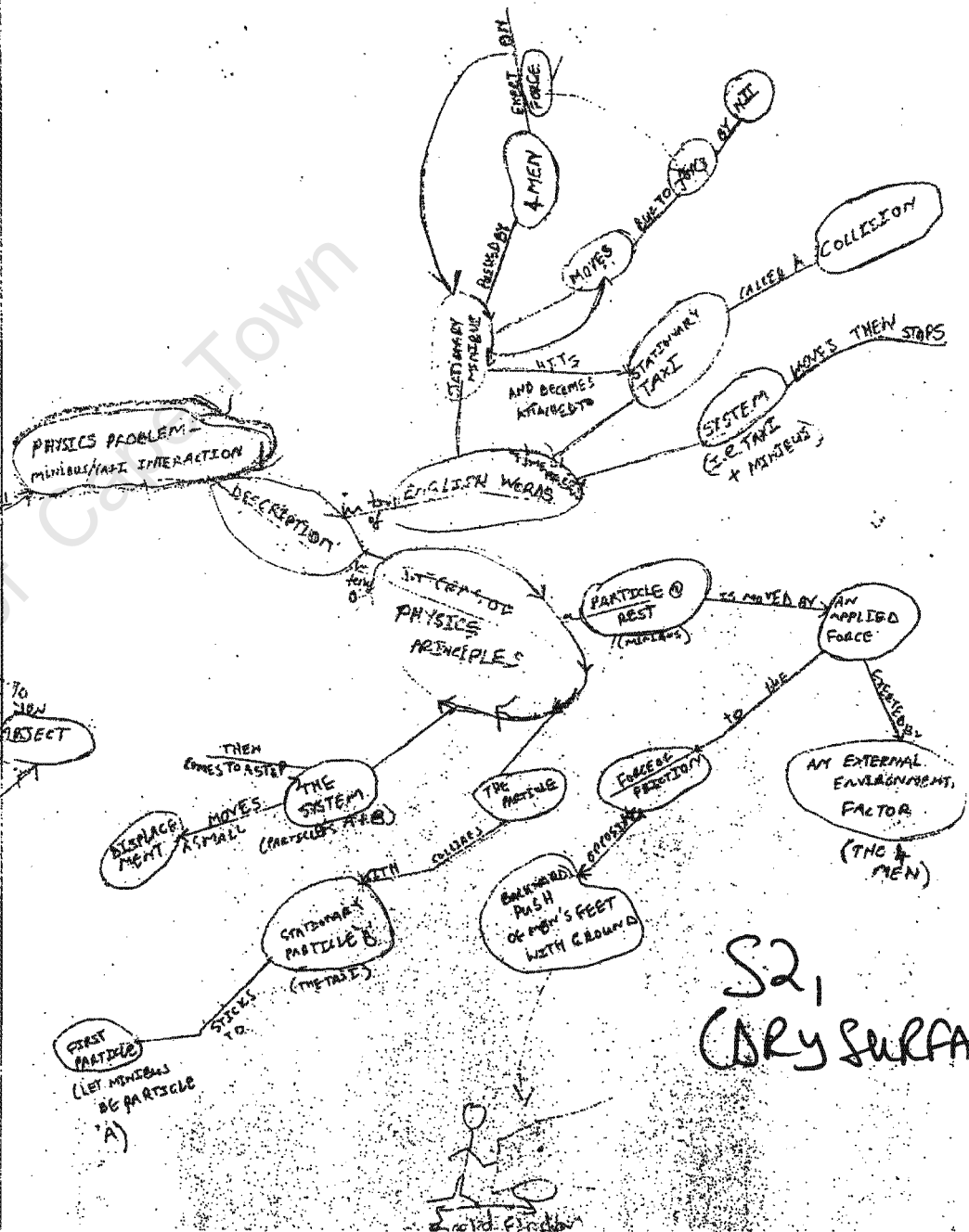
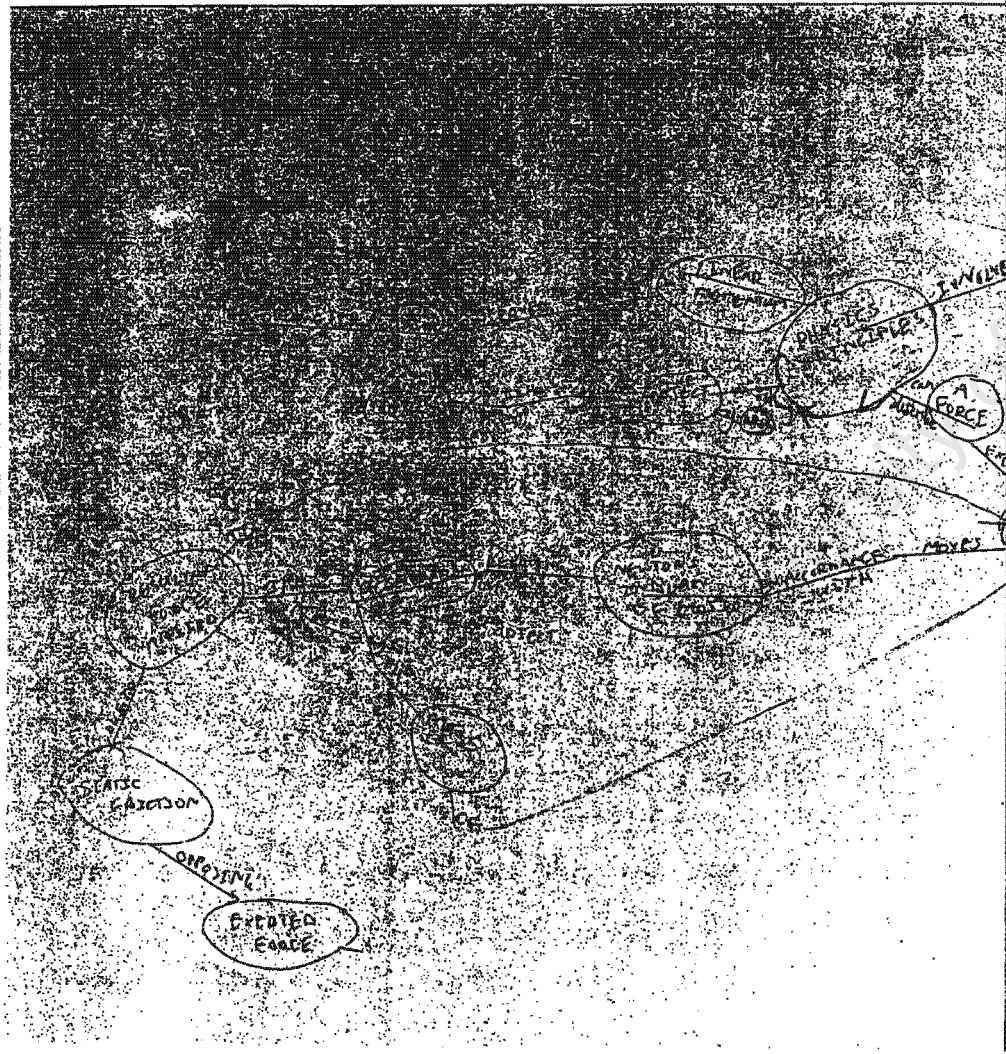
Map S1₁, Student 1, Dry Surface;
Map S2₁, Student 2, Dry Surface;
Map S3₁, Student 3, Dry Surface;
Map S4₁, Student 4, Dry Surface;
Map S5₁, Student 5, Dry Surface;
Map S1₂, Student 1, Wet Surface;
Map S1₃, Student 1, Snowy Surface;
Map S2₂₊₃, Student 2, Wet and Snowy Surfaces;
Map S3₂, Student 3, Wet Surface;
Map S3₃, Student 3, Snowy Surface;
Map S4₂₊₃, Student 4, Wet and Snowy Surfaces;
Map S5₂₊₃, Student 5, Wet and Snowy Surfaces;

The Newtonian dynamics links made by students in their maps formed the basis for the interviews.

NEWTONIAN MOTION

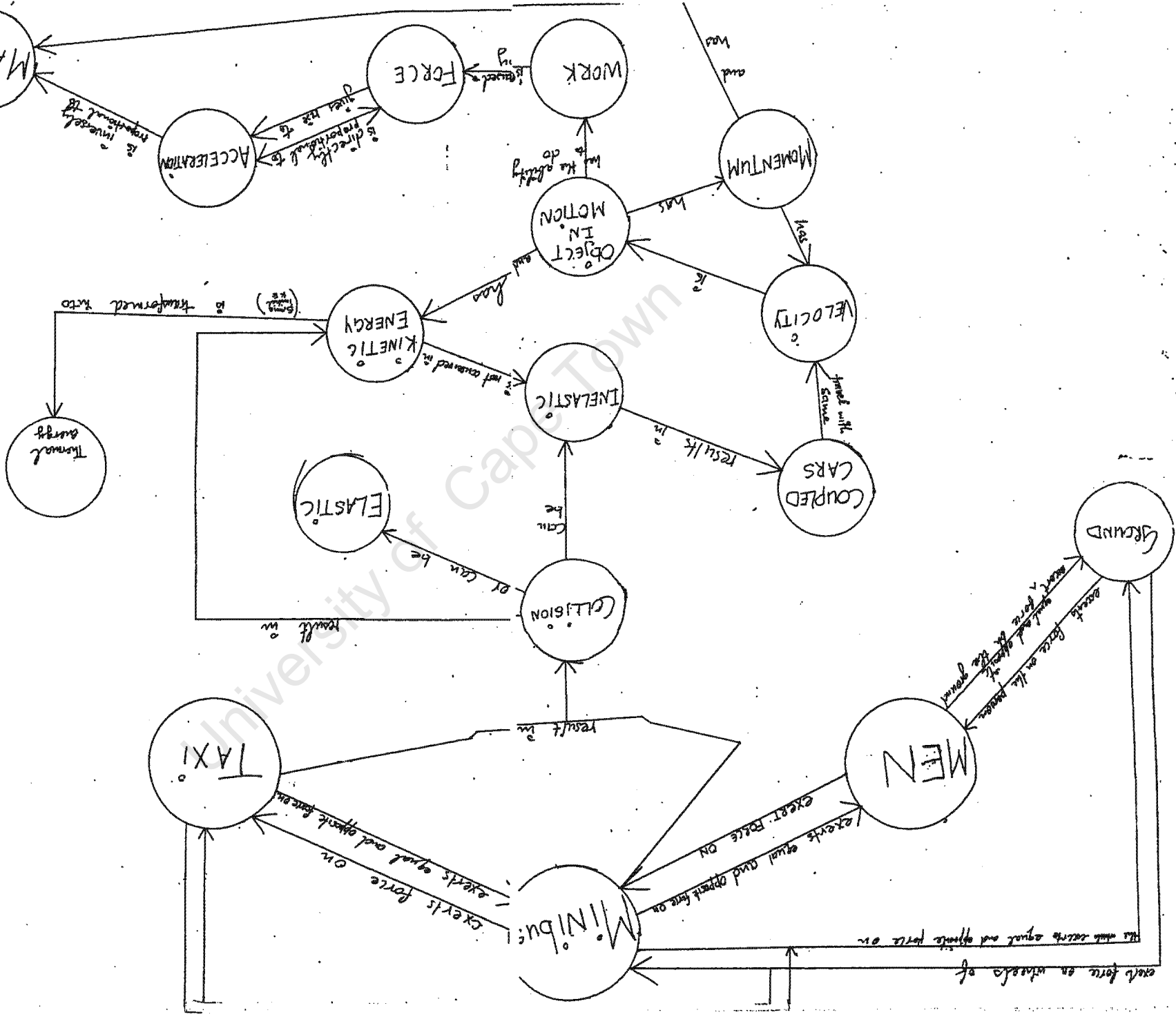
SI (dry surface)

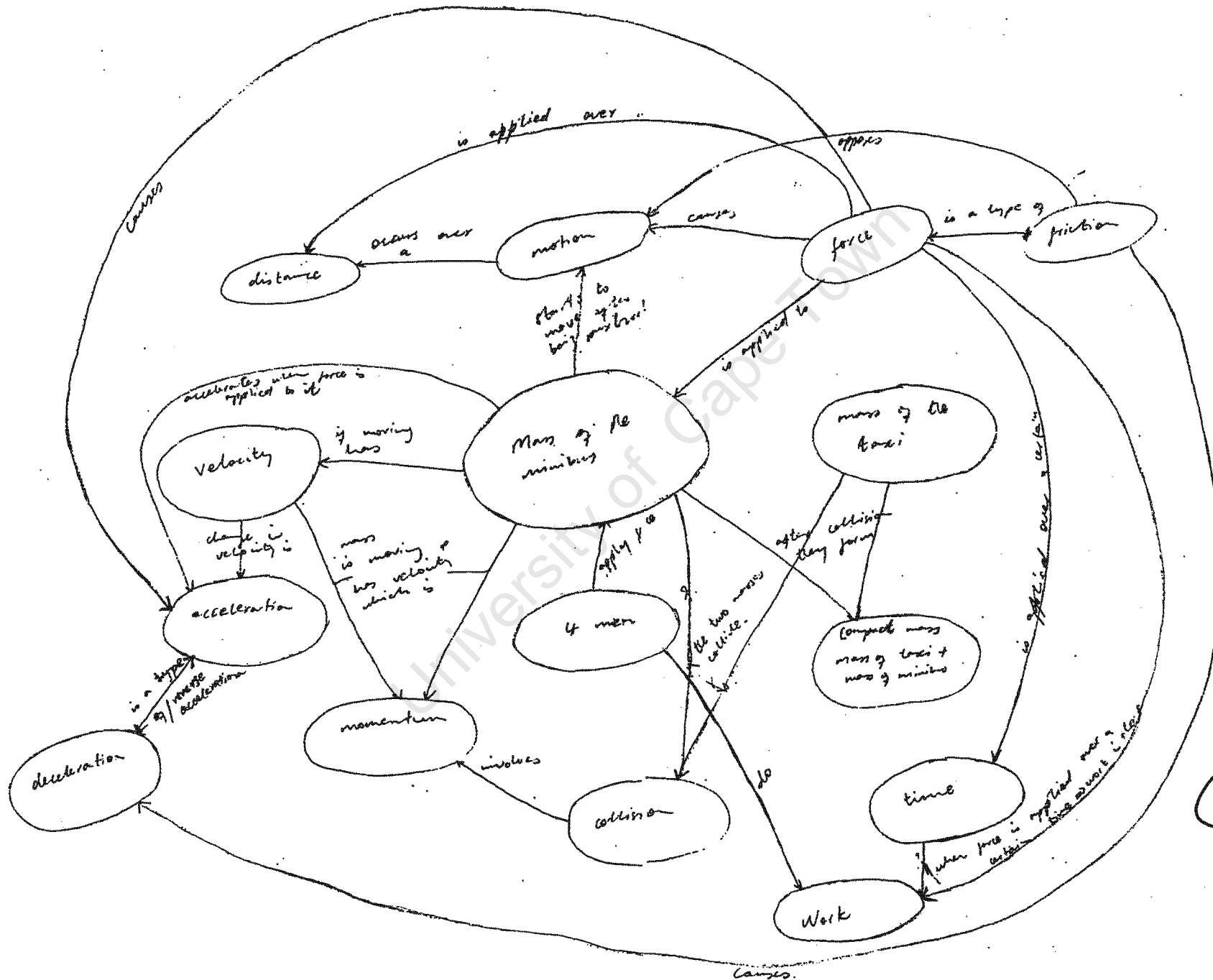


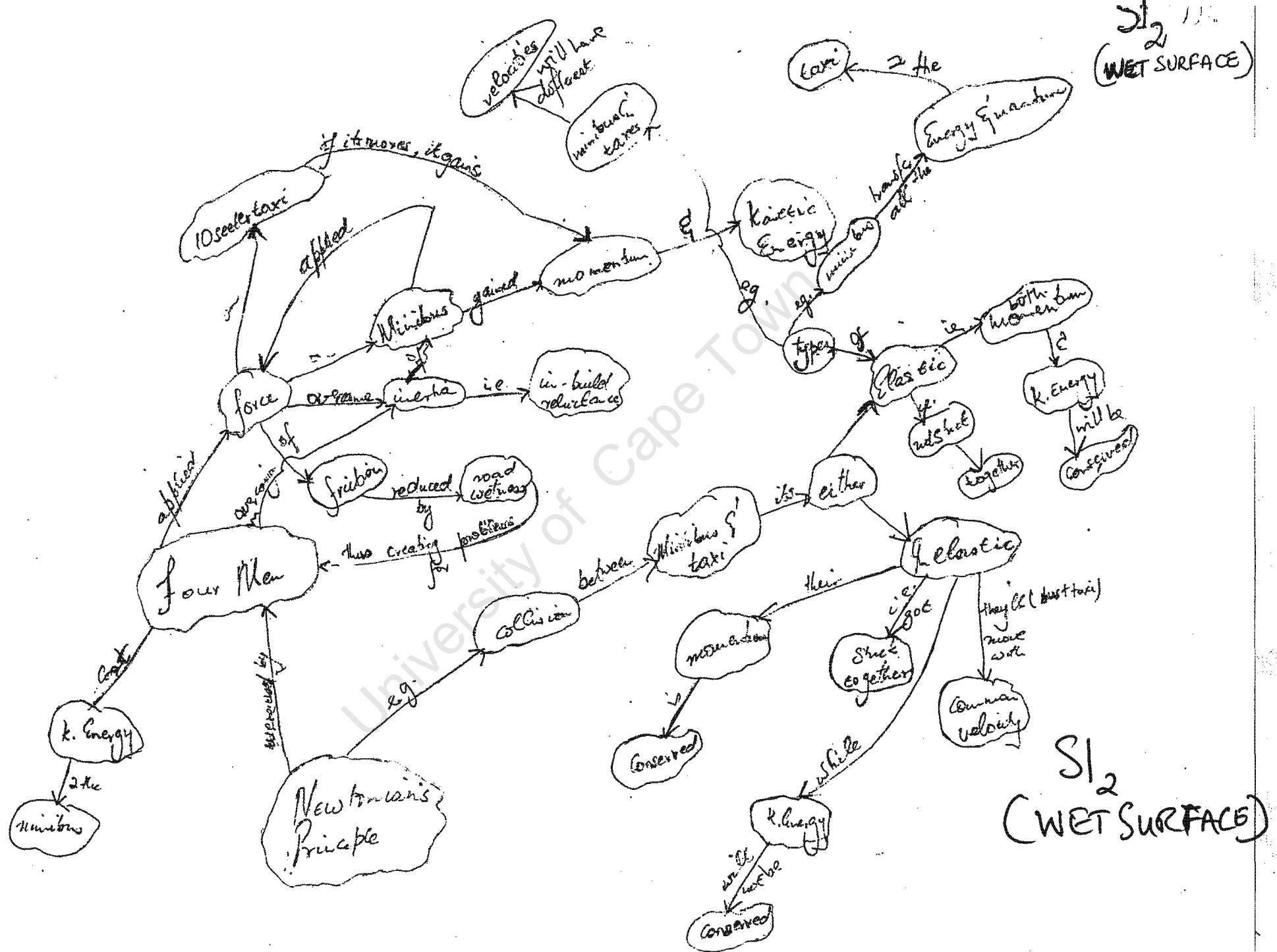


S3
1
(DAY SURFACE)

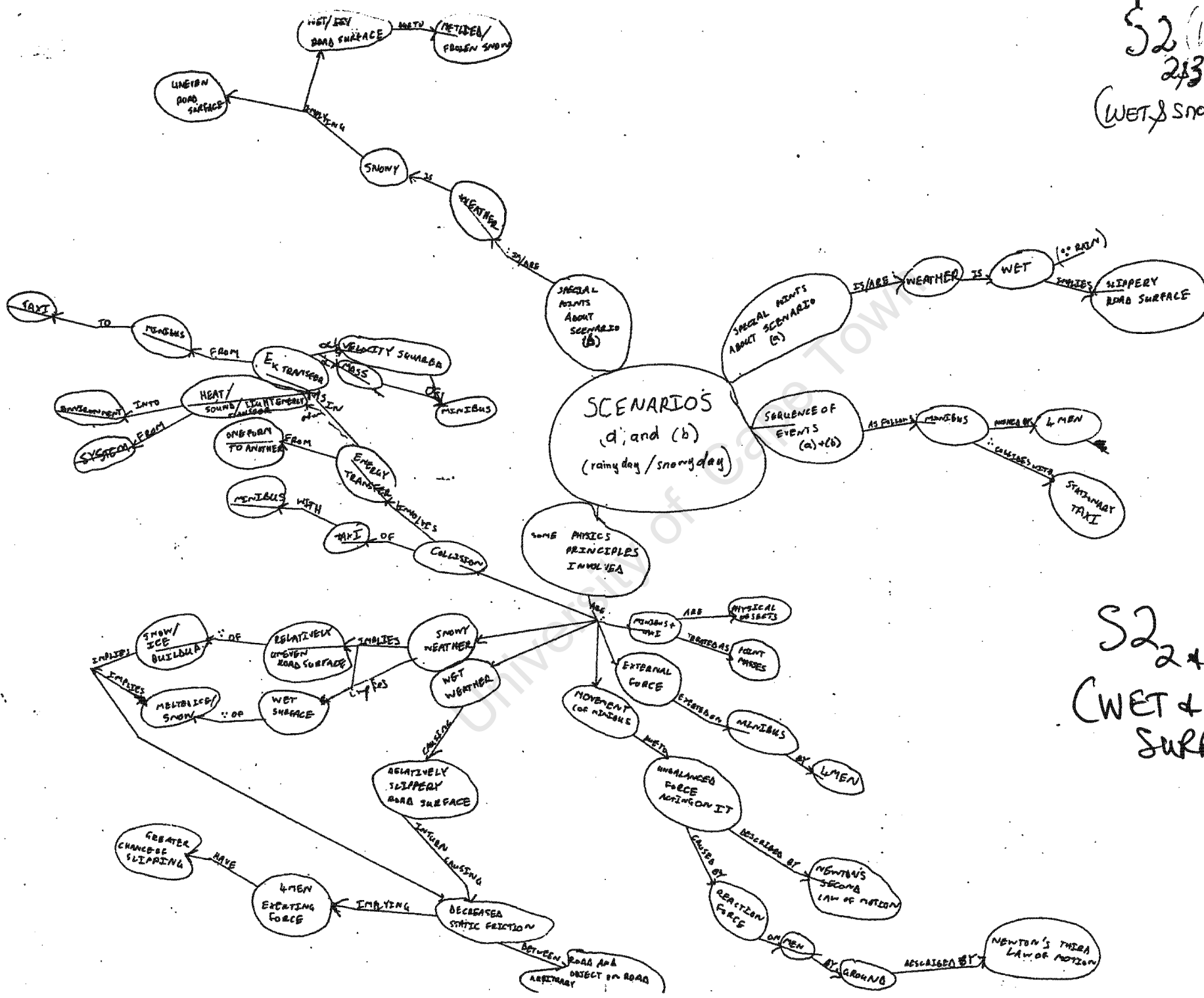
S3
1
(DAY SURFACE)

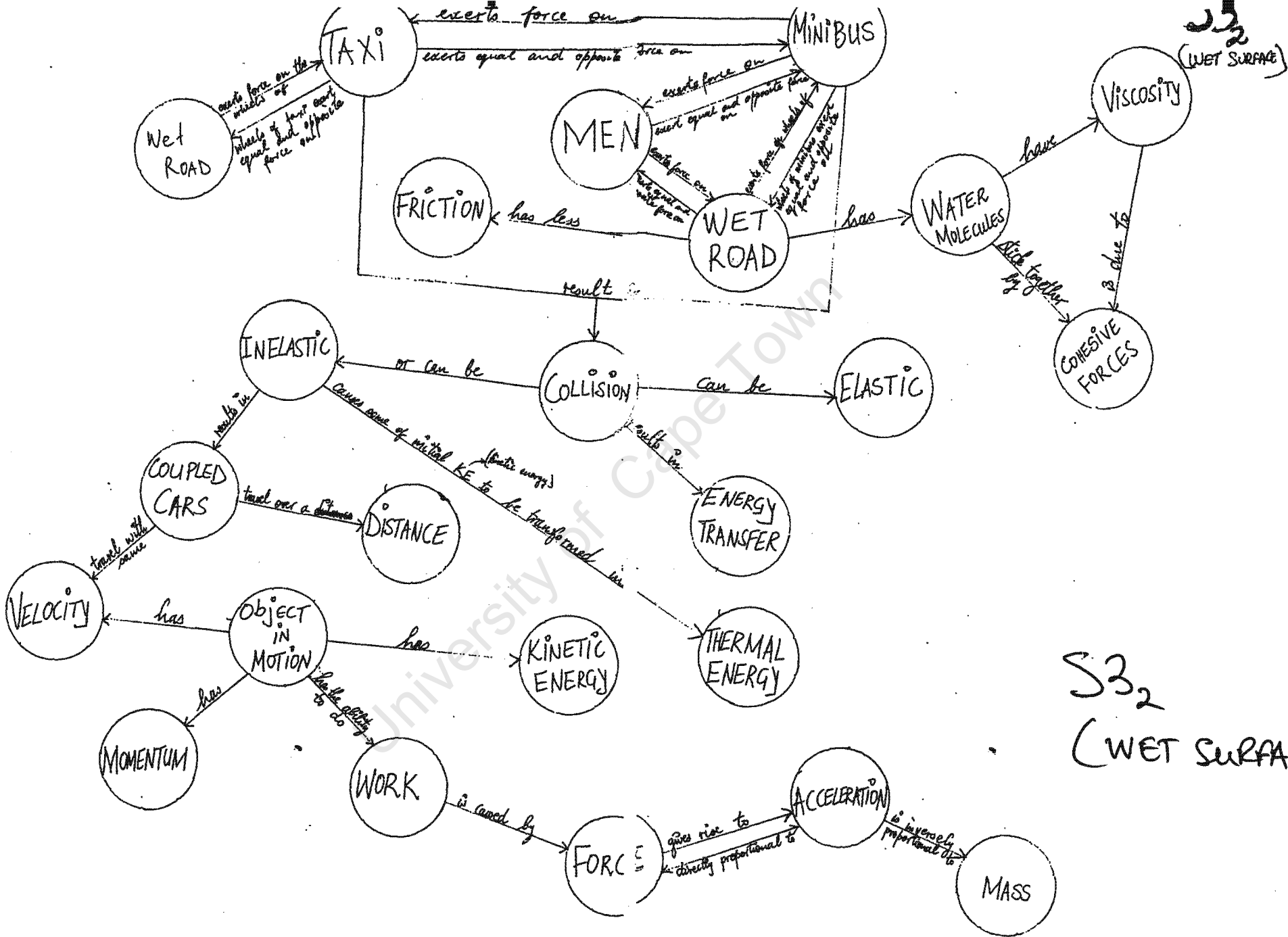




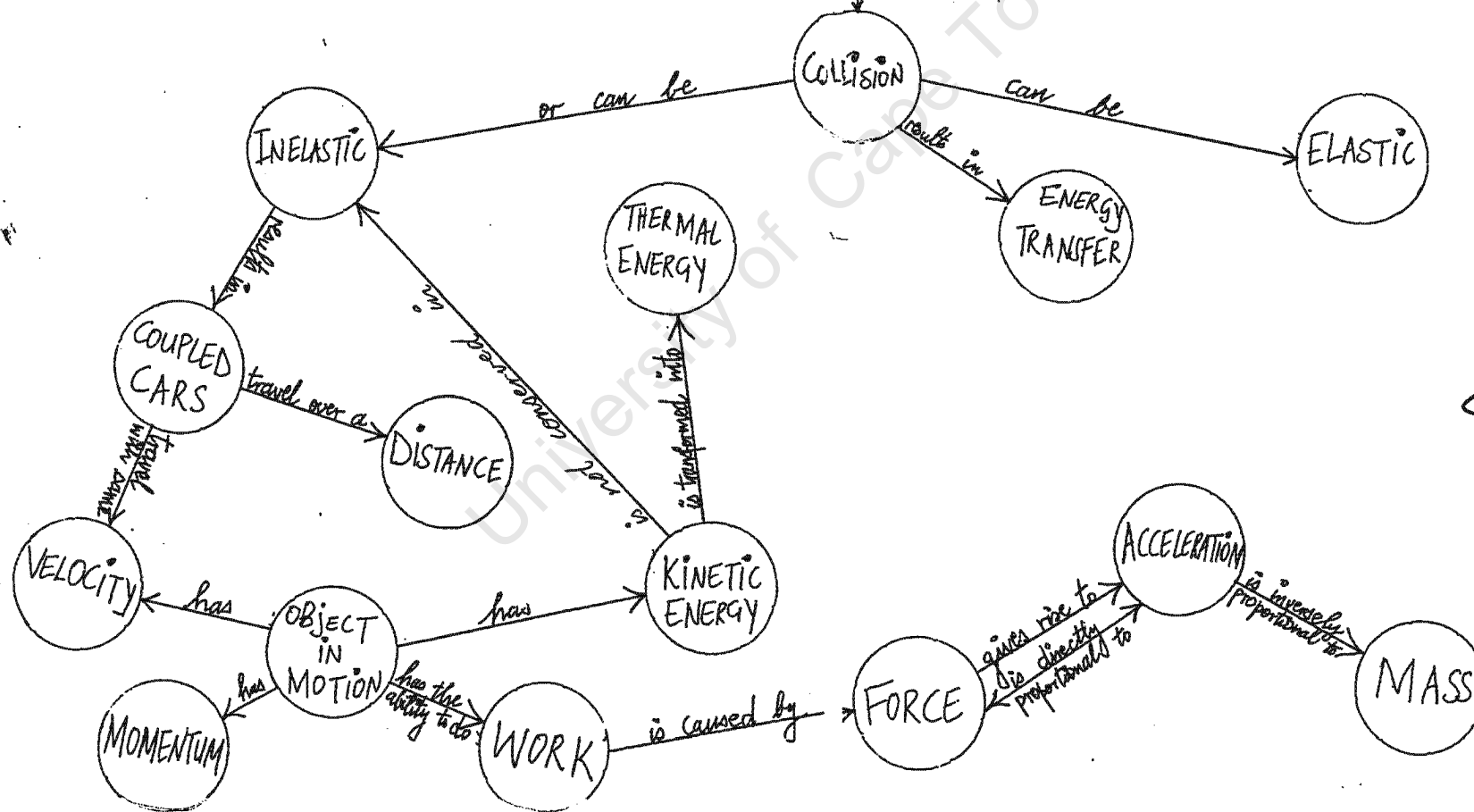
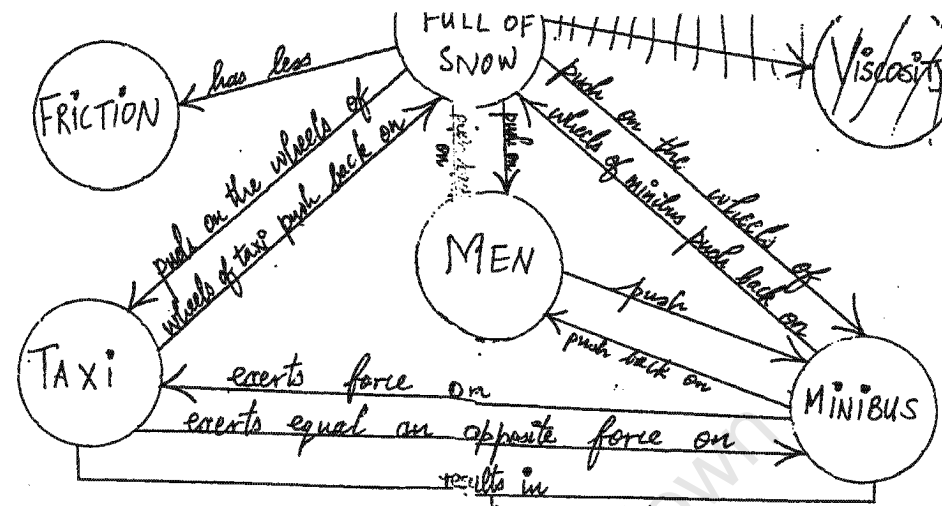


\$2 (WET & SNOWY SURFACE)
243



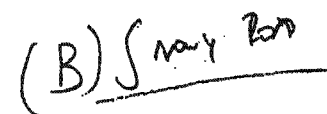


S3₃
(SNOWY SURFACE)



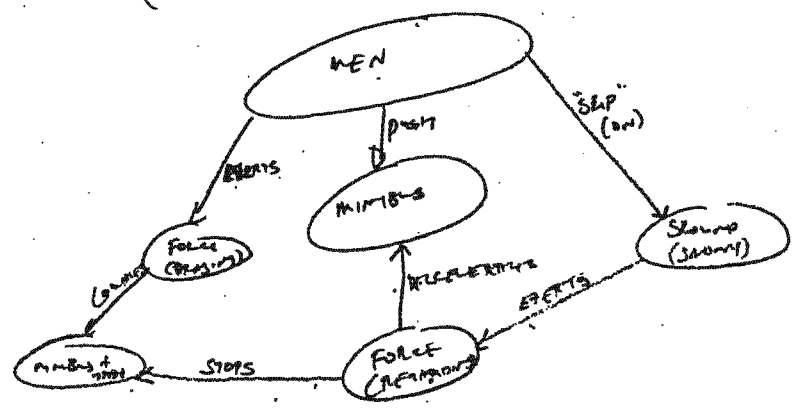
S3₃
(SNOWY SURFACE)

(WET & SNOWY SURFACE)



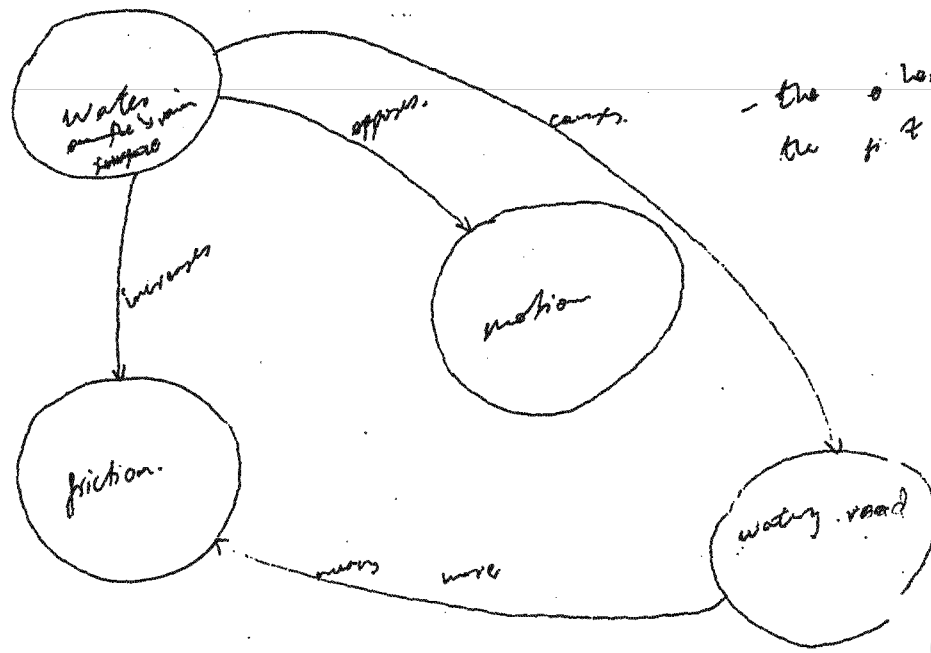
S4₂₊₃

(WET & SNOW SURFACES)



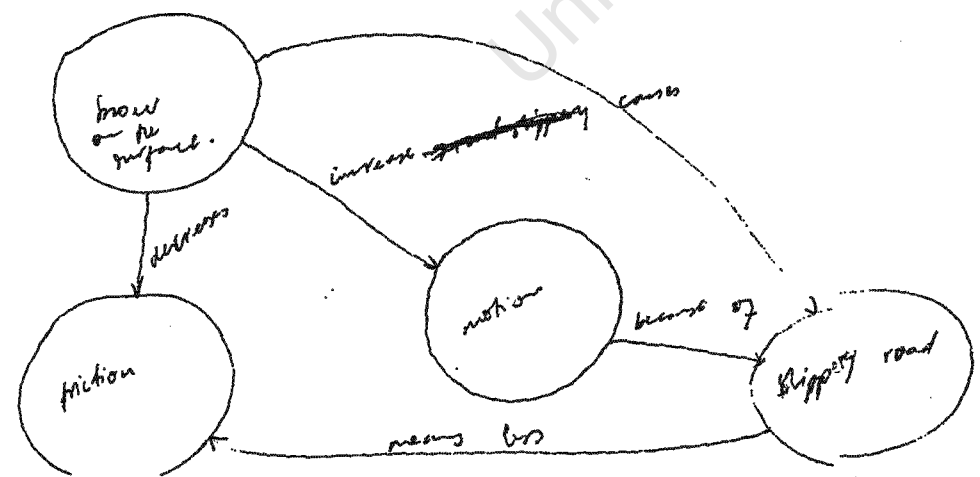
S5_{2/3} 11/7/2011
 (WET & SNOWY SURFACE)

- the other concepts are illustrated in the p. 4 map.



(b)

S5_{2 & 3}
 (WET & SNOWY SURFACES)



APPENDIX C

Interview transcripts on links drawn in concept maps

Interview transcripts are given here for the interviews based on the maps drawn. The first set of interviews was on the first concept map, that is, for dry surface. The second set of interviews was for the second and third concept maps, that is, for the wet and snowy surfaces respectively.

The interviews are attached here as follows:

The first set of interviews:

- S1 is for dry surface, student 1
- S2 is for dry surface, student 2
- S3 is for dry surface, student 3
- S4 is for dry surface, student 4
- S5 is for dry surface, student 5

The second set of interviews:

- Tape S1 Side A is for wet surface and part of snowy surface, student 1
- Tape S1 Side B is for snowy surface (continued), student 1
- Tape S2 Side A is for wet and snowy surfaces, student 2
- Tape S3 Side A is for wet surface, student 3
- Tape S3 Side B is for snowy surface, student 3
- Tape S4 Side A is for wet surface, student 4
- Tape S4 Side B is for snowy surface, student 4
- Tape S5 Side B is for wet and snowy surface, student 5

The interview transcripts formed a 'pool of meaning' for this study. Interview excerpts are used as examples in Chapters 5 to illustrate the categories of description and in Chapter 6 to illustrate the intra and inter-contextual shifts.

INTERVIEWS ON CONCEPT MAP 1

S1 (1 hr)

- I: Why did you include Newtonian motion in your map?
S: The problem is based on Newtonian motion.
I: What makes you think that it is based on Newtonian motion?
S: In this problem we are dealing with movements of things and why they are moving.
I: Why do you describe these movements as Newtonian motion?
S: Because we are dealing with forces, and forces generally are based in Newtonian Motion.
I: What makes you think that the four men did work?
S: Because they pushed the car over a certain distance, even though they let go after it has started moving, they applied a force in a certain distance, and work is a product of force and distance.
I: What do you mean by "four men applied pushing force"?
S: I was trying to describe a kind of force they were applying, they could be dragging but in this case they are pushing, we know that force is a push or pull and in this case they applied a push.
I: You say we know that force is a pull or push, what do you understand by that?
S: It means a force can be applied in two ways, either by pushing or pulling.
I: Do you think these are the only two ways that force can be applied?
S: mm.... Generally, I will say so, if I'm pressing on this table (points to the table) I use the word press but I am actually pushing it down, even when a helicopter takes off, it pushes down to be able to lift up or take off, generally, I would say yes it can be applied in two ways.
I: Using your example of pressing on the table, is the table also applying any force, if yes, what kind of force is this?
S: In the case when the table is not moving yes the table is applying a force according to Newton's third law, I would say it's a push in this case, it is pushing back
I: What do you mean by friction opposes motion?
S: Can I make an example?
I: yes.
S: In the case of the four men when they are pushing the car there is a force which is opposing their motion as they are pushing the car, it is a form of a grip for these guys without it they would slip and hence they would not be able to push the car.
I: Will I be right to say that friction enable the men to push the car?
S: yes.
I: What do you mean by Kinetic Energy gained by the minibus
S: (silence)
I: or how does it gain Kinetic Energy?
S: By virtue of its movement, Kinetic Energy is the form of energy that comes into play by virtue of motion.
I: What do you mean by momentum results in acceleration
S: (silence), how can I put it , ... I would say, ... since we know that momentum is the product of mass and velocity, if we look at the velocity of the minibus before they applied the force to it, it was zero, hence momentum is zero, after applying the force the momentum of the car changed to a certain value. If you look at that situation momentum changed from zero to a certain value at a certain period and this results in a force.
I: What results in force?
S: The rate of change of momentum.
I: and so,
S: and so, force is directly proportional to acceleration, hence I can conclude that momentum resulted in acceleration. In a shorter way, I can say velocity changed from zero to a certain value in a certain period, and the rate of change of velocity implies there is acceleration in that motion.
I: What do you mean by a force caused a 10-seater taxi to accelerate, how does it

- cause it to accelerate?
- S: The force was applied by the minibus on the taxi, the pushing force again, so if that is the case, there was a rate of change of velocity from 0 to velocity v in that period, resulting in acceleration.
- I: How did friction cause them to stop?
- S: Friction always opposes motion, right, so in this case the two cars accelerated in the opposite direction to their motion.
- I: What do you mean opposite direction, to what?
- S: Remember when these guys were pushing they let it go and the minibus collided with the taxi pushing it forward and remember there is no external force at the moment they start moving but there was external force at the moment the bus hit the taxi. Friction was the only force acting on them and it always opposes motion, then it causes the two cars to stop at some instance.
- I: What do you mean by Kinetic Energy due to work?
- S: The minibus applied a force on taxi and did some work, so that work was converted into Kinetic Energy.
- I: How was it converted, and what makes you say that?
- S: Work done by minibus on taxi changes the Kinetic Energy of taxi from zero to a certain value and the taxi started moving and we know Kinetic Energy is a form of energy gained by virtue of movement.
- I: What do you mean by "work done by force"?
- S: I mean the force that was exerted by the bus on the taxi did work on the taxi.
- I: How does the force do work?
- S: We know, it is known that work is Force times distance, when it is applied it causes an object to change its state from rest to motion and also that work amounts in change in Kinetic Energy, therefore, the force does work.
- I: What do you mean by pushing force enables bus to overcome its inertia?
- S: Pushing force applied by the guys (silence), it is obvious that the minibus on its own will not move, assuming the engine is not turned on of course, by them applying the force they enabled the bus to overcome that reluctance of change of state.
- I: What do you mean by "Kinetic Energy lost during collision", explain how it is lost.
- S: It is lost by ..mm.., take the case that when the minibus had x K.E., when it collided with taxi, the fact that the taxi was stationary, it had zero K.E. and as a result of collision taxi gained K.E. and there is no way it could have gained the K.E. from somewhere except that the bus lost some of K.E. to it.
- I: In your map you mention that when stuck together after collision, they have common velocity changing all the time until it is zero, what caused the velocity to change and how does it get to zero?
- S: It is caused by the friction which was opposing their motion, it gets to zero when they stop moving.
- I: How do they stop moving?
- S: Friction experienced is the same all the time like a falling object experiences 10N/kg force on it and this force increases by 10 constantly all the time, so if you look at object falling by the time it hits the ground the force would be much greater than when it dropped, it is evident if you look at the velocity change, i.e. the rate of change of velocity means there is acceleration which implies that there is a force. I'm saying then that the moment they are together they experienced friction which will increase until it reaches a maximum that will cause the motion of the two objects to cease. Another analogy, if you take a marble and drop it on a sandy soil, the depth of the penetration would vary with height, i.e. if you drop it from a higher level by the time it hits the sand it will have a greater force than when dropped from a lower position because the force (i.e. gravitational force) builds over a period of time.
- I: What do you mean by momentum was conserved?
- S: It means the momentum that the two cars had before is equal to momentum after in magnitude.
- I: What makes them to be equal?
- S: That's the principle of Linear conservation of momentum that we were taught.
- I: Do you believe in this principle? Do you think this is true in everyday life?
- S: I don't think I've really seen it work, ...mmmm ... Okay, I remember I did a Lab practical on Linear airtrack, which can be applied to real life situation.
- I: Do you have anything that you would like to say on top of what we have discussed so far.

- S: No, nothing.
I: Thank you.

S2 (45 mins)

- I: What do you mean by “an applied force due to force of friction”? What do you mean by “force of friction opposing backward push of men’s feet with ground”?
- S: My point was the men applied a force on the object and the object is able to move only because there is friction which is opposing the men’s applied force and the resultant force will be the sum of those two forces, and this resultant force will be the force that will enable the object to move.
- I: What makes the system to come to a stop?
- S: That is due to the force of kinetic friction opposing the motion, please note that kinetic friction is in opposite direction to forward motion and causes it to accelerate negatively, I don’t want to use the name deceleration, deceleration does not exist in physics, I mean if going forward is positive, then it is accelerating negatively.
- I: How does it come to a stop?
- S: In terms of Newton’s second law, the acceleration is due to the resultant force, and there is only one force acting on the object which is force of friction, that is, friction is the resultant force in this case.
- I: How does the four men exert force on stationary bus?
- S: The force is the regular push or pull, in this case it’s a push, the simplest explanation of a force is a push or pull.
- I: Is friction a push or a pull?
- S: It’s a very simplistic or very elementary description of a force which I came across at school, I can’t describe friction as a push or pull.
- I: What do you mean by “stationary minibus moves due to force by Newton’s second law”?
- S: The force I refer to is the force exerted by the four men, that is the force that makes the object move, by Newton’s second law, is to describe that this is the force that causes the object to move, that is, Newton’s second law will be the relationship describing how that force applied in minibus will cause change in its motion.
- I: What makes you think that this problem involves physics principles?
- S: Definitely it does, we are dealing with parts of dynamics because we are looking at what actually causes particles to move as they do, not so much how they move but why they move.
- I: What physics principles are you referring to?
- S: We are looking at what causes things to move, which is Newton’s laws of motion, other principles could be conservation of linear momentum, physics of collision, inelastic collision i.e. not bouncing each other, and this implies that Kinetic Energy is not conserved, mechanical energy is not conserved, because there is a non-conservative force acting i.e. friction, and energy is another principle.
- I: What do you mean by “linear momentum is conserved in the collision”?
- S: The definition of momentum is mass $\times$ velocity of the object concerned, when we say Linear momentum is conserved in this particular example, objects collide, they have initial velocity before collision, and final velocity after collision which may or may not change, so the product mv before is equal to mv after regardless of whether it is elastic or inelastic collision.
- I: What do you think happens when one object collides with another?
- S: That is to let the reader know that when one object collide with another, is another physics collision. Do you want a description of a collision?
- I: yes.
- S: When two particles interact with each other one might be moving another stationary, or both could be moving, that’s movement relative to one another if they are moving but stationary in relation to one another then there is no collision that can occur.
- I: What do you mean by “a force exerted on object”?
- S: Much the same as expressed earlier, the force applied by four men on the object, that’s the force I’m referring to here.
- I: In this problem when you say, “object moves in accordance with Newton’s second law of motion” what do you mean? Give an example and refer to this particular problem.

- S: The object will move in a manner described in Newton's second law, it moves in accordance, or in a manner that will be predicted by Newton's second law. We have a resultant force which is equal to the sum of all forces acting on the object, e.g. force applied by the four men and friction, now Newton's second law will describe the motion, it will say that the acceleration is proportional to the resultant force applied to the object and inversely proportional to the mass of the object that is, if there is more mass acceleration will be less.
- I: What do you mean by "resultant force applied due to static friction"?
- S: When the guy is applying the force, the force applied is backwards, i.e. pushing backwards on the ground in his feet, static friction between his foot and ground will act forward and the sum of those two forces (applied and static force) will cause the resultant force.
- I: What do you mean by "static friction opposing exerted force"?
- S: Static friction opposes the exerted force, any force of friction opposes motion of the object, opposes means acting on opposite direction in this case, opposite direction to exerted force.
- I: How does Newton's second law relate acceleration and force?
- S: That is, if you apply a force you will get acceleration, those two are proportional, you gonna get acceleration if there is a resultant force, but if it is only applied it does not necessarily mean you get acceleration, e.g. when pushing a wall and wall does not move.
- I: Is Newton's second law applied here as well?
- S: Definitely.
- I: Is there anything that you would like to say to clarify what you have said in this interview?
- S: Minor thing on physics principles – energy in its broadest sense is conserved, one thing I forgot to point out.
- I: Thanx.

S3 (55 mins)

- I: What do you mean by "men exerts force on minibus"?
- S: They are applying eh ..., they apply force on the minibus by pushing.
- I: So, can I say that pushing it means applying a force?
- S: Yah.
- I: What do you mean by "minibus exerts equal and opposite force on men"?
- S: As they are pushing, the minibus is also applying a force on the men, and it is equal to the one that the men applied on it.
- I: Is the minibus also pushing the men?
- S: Not necessarily pushing, but what I can say, eh ..., it is not like pushing it is trying to to resist the force that these guys are applying on it.
- I: Does it succeed in resisting?
- S: No, because it is being pushed and it moves, it means the men have been overpowering it.
- I: What do you mean by "coupled cars travel with same velocity"?
- S: Well, as the minibus collides with the taxi the resulting collision is inelastic, they are stuck together and as they are stuck together their velocity will be the same.
- I: What do you mean by "momentum has velocity and has mass"?
- S: Hmm..., this is a definition of momentum.
- I: And we just have to accept that?
- S: Yes, that is momentum. Since this cars are colliding we talk of momentum before and after collision and in this case momentum is not conserved.
- I: Why is it not conserved?
- S: Because the velocity of minibus before is not equal to velocity of coupled cars after. The velocity will be reduced after collision.
- I: What reduces it?
- S: Since the taxi has mass and minibus as well, if minibus travelling say with 50km/hr and is 50 kg in mass and colliding with say another 50 kg then definitely the velocity will be reduced now the mass will be 100 kg.
- I: So are you saying with more mass the less the velocity?
- S: Yah, but in this scenario, in this particular problem, not necessarily always the case, smaller is faster.
- I: What do you mean by "Force gives rise to acceleration"? How does it give rise to acceleration?

- S: In this case, force is applied on minibus as it is applied on, the minibus moves, and it accelerates as it moves.
- I: What do you mean by “acceleration is directly proportional to force”? Also, what do you mean by “acceleration is inversely proportional to mass”? Give an example.
- S: From the definition of force $F = ma$, from this definition it is clear that if force is increased then acceleration will be increased and if acceleration is increased $a = F/m$ from here acceleration is inversely proportional to mass, force will be increased as well.
- I: What do you mean by “object in motion has kinetic energy”?
- S: Every object that is in motion has kinetic energy, if it did not have kinetic energy it would not move.
- I: What do you mean by “object has momentum”?
- S: Because the object in motion, when we talk of object in motion we are talking about the velocity because the object is moving and the object itself has the mass and those two things mass and velocity they make momentum.
- I: What do you mean by “kinetic energy is not conserved in inelastic” collision?
- S: Again it will be from the definition of kinetic energy, that is $K = 1/2mv^2$, so the velocity before is not equal to velocity after collision, so the kinetic energy will not be conserved because the velocities are not the same. In our case the masses are different because afterwards is coupled mass.
- I: What do you mean by inelastic collision “results in coupled cars”? And what do you mean by inelastic collision?
- S: Since cars stick together an inelastic collision occurs when two cars stick together.
- I: What do you mean by elastic collision?
- S: Elastic collision is when two objects don’t stick together after collision.
- I: What do you mean by “work caused by force”? How does force cause work?
- S: For work to happen or to be performed there must be a force applied on an object.
- I: What do you mean by “object in motion has the ability to do work”?
- S: Because the object, since the object is moving, it means force has been applied on object so the object is doing work as it moves or it can do work as it is moving since it has power.
- I: Where does it get power from, what do you mean by power?
- S: Power is the rate at which work is being done.
- I: Where does the object get power from?
- S: It was pushed then they collided and stuck together as coupled cars. It comes from the fact that it is moving and if it is moving it has power, I can’t explain further.
- I: Do you have any questions you would like to ask me or anything that you need to clarify concerning this interview?
- S: What do you make of me from this interview?
- I: Like I told you before I am conducting this interview so that I can understand the linkages you made in your concept maps. I just want to make sure that I understand what you mean.
- S: I left some things out, like friction, energy transfers, for example, in collision, heat as a result of energy transfer. I thought my map would be too big. There is also reaction force on the men’s feet, may be I should go and add them.
- I: (map given back to student to make additions) Thank you for your time, we’ll meet again when you are through with the additions.

(Next interview 10 mins – after a short break)

- I: How does kinetic energy transform into thermal energy?
- S: Moving objects have kinetic energy and so, when the minibus hit the taxi initial kinetic energy is converted into thermal energy, that is, when the minibus hit the taxi there is heat produced which is heat or thermal energy
- I: How does the ground exert force on the men?
- S: It pushes on the man, the man is pushing on the ground and the ground is pushing on the man thereby giving him motion, that is making him to move.
- I: How does the ground exert force on the wheels?

- S: Same explanation as with the men, it causes the wheels to move.
- I: What do you mean by the cars "exert equal and opposite force on the ground"?
- S: It is the wheels not the cars I'm referring to, let me add it to the map (modification done on map).
- I: How do the wheels exert "equal and opposite force on ground"?
- S: That is action reaction pair, the wheels of the cars exert force on the ground and the ground is also pushing on the wheels, so as a result a car moves, the wheels move.
- I: Is there anything else that you would like to add to this interview?
- S: The wheels will move because of friction on wheels, that is, friction of wheels on the ground is not so strong it is overpowered by eh... since the car is moving, how can I put it, if friction was more, then the wheels won't move, so the wheels move because friction is less and coming back to first interview, the question where you asked me "Does it succeed in resisting"? Remember these guys are pushing the minibus and the minibus is also pushing back, so remember the question was, Does the car succeed in resisting? And my answer was no, what I exactly meant was the friction. Since there is friction between wheels and ground that friction is not so strong that it resists motion of wheels or car, that is why the minibus is moving. The thing is, it does not succeed in pushing back according to Newton's 3rd law of motion because the men get tired as they are pushing so it means the car is also pushing back at them.
- I: Thank you for your time.
- S: I think I'm happy now I have been thinking about my answer all this time.
- I: If you are happy, I'm happy. Thank you.

S4 (50 mins)

- I: What do you mean by "men exert a pushing force"?
- S: I mean they apply a force on the minibus.
- I: What do you mean by applying a force?
- S: (silence) by applying a force, (silence) from the problem given, these men because they cause a movement on the minibus or they moved the minibus, that is why I say they applied a force.
- I: What do you mean by "pushing force accelerates minibus"?
- S: It is exactly what I've said before it is that pushing force exerted by the men that changed the speed of the minibus and that is what we call acceleration. The reason I thought of that is because the minibus moves on its own after they have stopped pushing until it reaches the taxi.
- I: What do you mean by "minibus exerts retarding force"?
- S: By that I mean when minibus, by the time it moves on its own there is a force that is, may be I'll call it ground force, when they release it that ground force or retarding force because it is produced by the ground will reduce the speed of minibus or decelerate it.
- I: Is it the minibus or the ground?
- S: Basically it is the ground force that causes this on minibus.
- I: How do the men produce power?
- S: The fact that they have exerted a force on minibus and minibus is moving implies that, may be we should cancel this link, (silence), because it implies that power is involved because (silence) I can't remember the definition of power (silence).
- I: Should we cancel the link?
- S: No, wait a minute (silence) in this link I thought of literally exerting power, what came into my mind was imagining those men struggling to get the minibus to move and ultimately getting it to move they must have applied more power on it to get it moving.
- I: How does the power move the minibus?
- S: I think basically when explaining that they produce power, it is power in the form of men, I'm referring to the power produced by these men, I'm referring to men because this power is in the form of men since they produce it.
- I: How does the minibus produce speed?
- S: By moving.
- I: How does speed produce momentum?
- S: As minibus moves that results in momentum and when speed changes momentum will change as well somehow speed will affect momentum.
- I: What do you mean by "momentum causes kinetic energy"?

- S: Again the fact that the minibus is moving and momentum is changing that will affect kinetic energy or change in kinetic energy.
- I: How will it affect kinetic energy?
- S: If momentum reduces kinetic energy will also reduce because they both depend directly on speed.
- I: How does the minibus gain kinetic energy?
- S: As it moves and like I have explained the relationship between speed and kinetic energy, as it gains speed it will gain kinetic energy.
- I: What do you mean by "taxi gains momentum"?
- S: I mean taxi starts moving we have a change in momentum, I mean the same thing as when I say producing momentum.
- I: So is producing and gaining momentum the same thing here?
- S: No, disregard that one, here I mean, this is during collision there is loss of momentum on minibus which gives a gain in momentum on taxi.
- I: What do you mean by "minibus loses momentum"? How does it lose momentum?
- S: By having its speed reduced when colliding with the taxi.
- I: What reduced its speed?
- S: The taxi when they collide.
- I: What do you mean by "power accelerates taxi"?
- S: In this regard of the power produced by minibus since after collision both cars are stuck together which means power produced by minibus caused movement of taxi.
- I: What do you mean by "minibus exerts dragging force"?
- S: Dragging force refers to the force exerted by minibus on taxi to get taxi moving.
- I: What do you mean by "dragging force couples minibus and taxi"?
- S: It is after collision because like I said what I mean by dragging force, it is the result of that force that we have the minibus and the taxi stuck together.
- I: What do you mean by "dragging force accelerates taxi"?
- S: Same explanation as retarding force, that force exerted by minibus that causes movement of the taxi.
- I: What do you mean by "taxi produces retarding force"?
- S: Same as before it is the ground force produced or opposing movement of the taxi (see answer to the question "What do you mean by "minibus exerts retarding force"?)
- I: How does retarding force reduce coupled speed?
- S: Same answer as the one I gave to the question about "retarding force decelerates minibus", they ultimately stop and the speed has been reduced.
- I: What do you mean by "minibus and taxi transfers kinetic energy"?
- S: During coupling we have transfer of energy from minibus to taxi.
- I: Do you know what kind of energy is this?
- S: Kinetic energy.
- I: What do you mean by "kinetic energy changes momentum"?
- S: Same answer as the one given to question about "momentum causes kinetic energy", I think it is the wording problem again, I mean they will both be affected.
- I: What do you mean by "kinetic energy decreases minibus speed"?
- S: Again in coupling, I basically refer to minibus speed, the fact that the minibus shared its energy with the taxi, it means its speed will be reduced as this speed will be shared with taxi speed since they are stuck together.
- I: What do you mean by "minibus speed loses kinetic energy"?
- S: This relationship is, I was supposed to have referred to the minibus not minibus speed, I mean the minibus is losing kinetic energy since we have kinetic energy being shared. The speed refers to the earlier on link not the bottom one (point to the map) the same with the taxi relationship, but with taxi it gains kinetic energy since we have minibus transferring or sharing its kinetic energy.
- I: What do you mean by "kinetic energy increases taxi speed"?
- S: I mean energy that was shared between minibus and taxi since taxi was not moving and will start moving just after collision, hence that energy caused increase in taxi speed.
- I: Is there anything that you would like to discuss regarding this interview?
- S: I had a problem with what was expected of me initially in the interview I thought the links I made were very clear and didn't need any further clarification.
- I: Are you happy with how it went?
- S: Yes, I'm happy now, I know you did mention before the interview that I need to

make it clear what I mean by the links so that you give my own interpretation not what you think I mean. It was difficult when we started but now I see why you had to interview me.

I: Thank you for your time.

S5 (30 mins)

- I: What do you mean by "force causes motion"?
- S: 4 men are applying force to minibus and it starts to move.
- I: What do you mean by "force causes acceleration"?
- S: Since these 4 men are applying a force it changes the velocity of the minibus which is acceleration.
- I: What do you mean by "force is applied over a distance"?
- S: They are applying a force over a distance and the motion occurs over a distance.
- I: What do you mean by "friction opposes motion"?
- S: Since these men are applying a force in whatever direction then there is obviously a force in the opposite direction which is friction, opposing motion even when they have stopped applying force, that is, after releasing, the two cars will move for some time and stop. It is friction which is causing them to stop because the surface is not smooth and also wind resisting the motion.
- I: Is wind resistance friction?
- S: You may say so because it is force acting on opposite direction.
- I: Is every force that is acting in opposite direction friction?
- S: Not every force but every force that opposes applied force is friction
- I: What do you mean by "force is applied to mass of the minibus"? Similarly, what do you mean by "4 men apply force on mass of the minibus"?
- S: I would say they are applying force, since the minibus is stationary obviously there are forces acting on it which are balanced, the men would apply another force which will request the minibus to move, that is, adding another force that will cause motion, which is unbalanced, that is, at rest implies balanced forces and from rest to motion implies unbalanced forces
- I: What do you mean by "change in velocity is acceleration"?
- S: That is, it is not moving at a constant velocity because it is stationary first then it moves until it collides, and moves and stops, obviously the velocities are different in those stages.
- I: What do you mean by "deceleration is a type of acceleration or reverse acceleration"?
- S: Deceleration is when it is moving up to a point where acceleration is zero, it decreases in the negative direction.
- I: How does "collision involve momentum"?
- S: Since a moving mass has momentum, it is going to impact on the momentum of the other car when they collide. Collision depends on the velocities of the two cars, a moving mass that has velocity has momentum by definition.
- I: What do you mean by "4 men do work"?
- S: Because they are applying force over a certain time.
- I: What do you mean by "friction causes deceleration"? How does it cause deceleration?
- S: I mentioned it before that friction acts on the opposite direction, since the cars will stop because of friction the acceleration will decrease which is deceleration and it will obviously decrease to zero.
- I: What do you mean by "motion occurs over a distance"?
- S: Since there is movement, that is, motion and it covers some distance.
- I: Can I ask you what motion is?
- S: It is when something that has mass moves.
- I: Do you have any questions that you would like to ask me or any thing that you would like to clarify concerning this interview?
- S: No, may be later, I don't have any thing now.
- I: Thank you.

INTERVIEWS ON CONCEPT MAPS 2 AND 3

NB: Side A of the cassette is interviews for concept map 2 and side B is for concept map 3, except for student S1.

CASSETTE S1 SIDE A

- I: I've brought your older map. If there's anything that you want to refer to, you can use it, okay? Okay, we can start now. Um, before we start, um, I'm going to ask you to expand on the links that you have made. I've noticed that you've drawn the two maps and there are some links which are similar. I'm not going to assume that they mean the same things, I'm going - I'm still going to ask you the same question when I get to the other one, okay. What do you mean by four men lost kinetic energy to the minibus? I think you can refer to your map.
- S: Er, how can I put it? Yes, I say - I know what you mean. Ja, I understand what you mean. They, um, I'm saying the four men lost, er, their kinetic energy to the minibus in a sense that for them to have pushed the car, er, for them to push the car they had to gain some certain speed or some certain movement, change of speed. There had to be some change of speed from them being stationary whilst they are trying to push the car until they are able to move, so once they started moving, the car started moving and then they let the car move on its own, so in that sense I mean the energy that they had gained, they gave it to the, er, to the minibus.
- I: Okay. Which Newtonian principle were used by four men in overcoming inertia? It's this part I think.
- S: Ja. Um. Okay, I would say the - the Newtonian principle that they used was, er, er, I think Newton's law - Newton's law of motion, the second one, ja.
- I: Okay, and the last part of it where you say, er, Newton principles used by the four men in overcoming inertia, what do you mean "in overcoming inertia"? What do you mean by that?
- S: I mean, er, inertia, it is defined as an in-built reluctance of anybody to change a state of rest or motion, you know what I mean? So, those men aided the minibus in overcoming it's state of change, of that state it was in, because the minibus was stationary, so they helped it in overcoming that, er, state of inertia.
- I: Okay, um, a follow-up to that, you talk of - about inertia of minibus, what do you mean by the inertia of the minibus? That's this part here.
- S: Ja, that's what I'm - I've just - that is what I've just said about the minibus, that the four men, if you look at the four men of, er, the four men used the - used Newton's principle to overcome the inertia of the minibus, that's where the thing is going to, so I'd answered that question.
- I: You might have answered this one as well, but, er, you need to tell me, um, what do you mean by force overcame inertia? This part here.
- S: Okay. Er, what I mean, it will be just elaborating on what I've said about inertia. Those men applied a force and it is due to that force that aided them in overcoming the inertia, in helping the minibus overcome the inertia.
- I: Okay, thank you. Um, now the other part of your map you talk about force of friction reduced by road wetness. What do you mean by that?
- S: Okay, if you look into the first map that I did for you, the situation in that one, it was a normal day, there was no rain and stuff like that, so since it was wet it means there was lesser friction, that's what I mean. There was lesser friction compared to that, because there was lesser, um, um - now what's the word - there was lesser - there was a less grip for the man to try and overcome the - I think if you had to compare the two scenarios, the man would be able to push a car easier in a drier place than in this wet road. That's what I mean.
- I: Okay, you say less friction, where? When the road is wet or before?
- S: No, when the road was dry, like in the first scenario, the first - the very first one,

- when the road is dry I think it will be easier to push anything, okay, provided it was - I assume that you are wearing a proper gear, not something that is slippery, okay?
- I: Now, about friction, is it going to be less or ...
- S: Ja, the friction is going to be higher on a dry ground which will help you push the thing easier, because friction is what we use to walk, is what we use to overcome a lot of things, so if it's wet there's very less friction which means there's a greater resistance or greater problem that you're faced with.
- I: Okay, um, I guess you have answered this question but let me just ask it again. You continued to say, um, this reduced, er, force of friction creates problems for the four men - I think it's this other part - you say it's a force of friction reduced by road wetness, thus, ja, thus creating problems for the four men. Can you just elaborate more about that?
- S: Yes. It is exactly what I've just said, that, er, if you - if you're pushing something in a dry, in dry conditions, it's going to be easier, provided you're wearing a proper gear to push whatever you're trying to push. There's greater friction, and friction helps you overcome whatever the inertia of that body you're trying to push, so if it's wet, the friction is reduced, hence the grip is reduced and then you'll have greater problems.
- I: Okay, we can move on, um, what do you mean by the minibus gained momentum and kinetic energy?
- S: Okay. As the minibus started moving, it had a velocity and, er, if you compared the momentum before there was the force applied, it was zero for the minibus because velocity was zero and momentum is a product of mass and velocity, so after these men started pushing the car, it gained a certain velocity, hence it gained momentum and also kinetic energy, in the same sense it's energy which it gained due to - by virtue of movement. So, if you are moving you've gained those two and, if you look at the scenario prior to the men pushing the car, the quantity of velocity was zero, hence the two quantities, momentum and kinetic energy, was zero until these guys started pushing the car, the minibus.
- I: Okay, um, are you going to use the same, er, explanation for that when you say the 10-seater taxi, if it moves it gains momentum and kinetic energy. Is it the same explanation that you've just given for the minibus?
- S: It should be the same, yes.
- I: Okay. You also mention that in elastic collision, both momentum and kinetic energy will be conserved. What do you mean by this?
- S: Um, how can I put it? By principle, an elastic collision, it is said that it is where two bodies collide and they continue to move after the collision, you know? So, both - if you had to calculate the kinetic energy the bodies had before they collided, or, ja, if you had to calculate the kinetic energy for the bodies before they collided and the kinetic energy afterwards, it should be the same, hence that's what I mean by, er, conserved, because there's no energy lost and there's no momentum loss, I would say. I don't know whether it's a proper word to use.
- I: Okay. You give two scenarios of elastic collision. One is that minibus and taxi will have different velocities. What do you mean by this?
- S: Um, what I mean by that, since we know that elastic collision, both bodies after colliding, they continue to move, hence they will have different velocities, even if one body was the one which was moving prior to the collision, after they collide if it is an elastic collision then they should both move at different velocities. Okay, let me just add something, why am I saying that, because they would be sharing the velocity that the first body had before it collided with the other body. So they will share it, hence they have to have different velocities, they can't have anything greater or less.
- I: Okay. Um, the other scenario you state that minibus transfers all the energy and momentum to the taxi. What do you mean by that?
- S: Okay. Okay, if you look at what I said in my map, I said that, er, in an elastic collision there are two possibilities that can take place. It's either the two cars move after they collide in different velocities, which I've addressed, or they knock each other - when they knock each other, another car moves and then the other one stops. What I'm trying to say is that there are two possibilities. The car that knocks the minibus might transfer all the energy and its momentum to the other one, it is still an elastic collision because they're not getting stuck to one another. What is happening, all the energy's transferred into - into the other car. I will make you an analogy; if you play pool and you hit one - the white ball hits another ball, er, I would say maybe head on, though it's spherical, it's not easy to say, but probably hits it in the centre of the sphere, in a straight shot, usually what will happen, the

white ball will stop and then the other ball will continue, so thus meaning all the kinetic energy and the momentum that the white ball had prior to the collision will be transferred to the other ball. That is what I'm trying to say.

- I: Okay. Um, what type of collision, I mean, inelastic or elastic, do you think will happen in this scenario? I mean in wet weather like this one?
- S: Er, for me it depends on the collision. Well, I haven't had experience of seeing a lot of them, but I would say it depends on the situation, you know. You could have, er, you could have a car, let's say maybe if one car comes from the east, the other one comes from the west, and they knock each other at the robot and one car might move the other way, the other one may move the other, but probably if maybe one car hits the other one from the back, maybe they might get tangled and move at the same velocity, because one thing for sure, they will move if it's wet, I think, there will be some movement after the collision, you know, that's why I think it should happen.
- I: Now, er, what do you mean by in inelastic collision the taxi and the bus' momentum is conserved in an inelastic. That's what you said.
- S: What I'm saying is that, er, the moment - why am I saying - momentum is always conserved, to start with, in any collision, er, so in this case, I mean it's only energy which will not be conserved, but the momentum will be conserved. It means the momentum of - of the minibus would be equal to the momentum of the sum of the two because they would have been stuck together, so you'll have to get the sum of the two to get the velocity of - the new velocity of the two cars, and if you compare that magnitude of the momentum after the collision, it should be equal to the momentum of the minibus prior to the collision.
- I: And why do you say the kinetic energy, in this case, will not be conserved?
- S: Okay, it is - I would say, it is by principle that if, er, a collision is, er, inelastic, kinetic energy is not conserved, er, I don't know how to put it but, er, I think by principle that's what I know I know.
- I: Okay, um, what do you mean by um, in an inelastic collision they will move with common velocity, what do you mean by that?
- S: As I said, er, in, I think in question 12 that, er, the minibus knocks the taxi and once they are stuck together they should have a certain common velocity to move it, no matter how small it is, but they will have a common velocity, and that velocity multiplied by their sum of - by the sum of the mass of the two should give you, er, the momentum of the minibus prior to the collision, so what I mean that they will have the common velocity, they should move at the same speed because they would be like one body now.
- I: Um, okay, you say in inelastic collision the two objects will be stuck together. Will I be right to say in any collision where the two objects are stuck together, we have an inelastic collision?
- S: I would say you are right. I would say you are right.
- I: So, will the elastic collision be the opposite of that?
- S: Er, I would say probably up to an extent you could say that, but maybe situations would differ if you look at it maybe more closely, maybe there will be so many things that you have - other factors that have to come into play, but probably in general, I would say yes.
- I: Um, I'll ask this one, okay. What do you mean by both momentum and kinetic energy will be conserved in an elastic collision?
- S: What I mean is that the momentum if you were to be able to calculate or have something to measure probably, er, what can I say - the speed - to know the speed of the car before - to know the speed of the minibus before it collides with the taxi, and be able to calculate the speed of both the two bodies, er, after collision, the minibus and the taxi respectively, you'll find that if you were to add the quantities after - after collision, meaning the momentum for the two bodies, the minibus and the taxi, and, er, and compare it with the total momentum of the minibus prior to the collision, they will be the same. And that same principle should apply to the kinetic energy.
- I: Okay, um, and this particular problem, um, what do you think, um, the type of collision would be? Would it be an elastic one or an inelastic one?
- S: I think I've tried to answer some question more related to this one. Like I said, it depends on the situation. Collisions happen in different, er, scenarios, you know. In a robot, you might find that the car might collide with another car from behind, probably there - for me, the chances there are that maybe if it's a really - how can I put it - if the car which hits the car from the rear was travelling at a high speed there should be an inelastic collision, but if you look at a situation where maybe one

car comes from the east, another one's coming from the west, they are trying to beat the robot together, I won't think it would be an inelastic collision, whether it's wet or what.

I: Um, do you see this particular problem different from, um, the one that you had before, and if you say they're different, how different are they and what is that difference?

S: Er, that's fine. Oh, okay.

I: Look at your previous map, or you can look at the problem.

S: Okay. Okay, let me look at the problem. Well, after looking at the previous problem, I would say there is some difference, in a sense that the scenario, the conditions at which this, er, occurrence is taking place, they are different, and, er, I think even if you look at the principles of physics, er, you - you - you - you cannot apply distinctly the principles that we applied in the first problem without maybe, er, how can I put it, sort of like looking at this problem - problem 2 - a bit differently because they are not the same and this one is a more - it's more - I would say it's a more simpler way. In this one you have to - I had to think more, I had to try and, er - I don't know what's the word, but I had to try and scrutinize the problem more closely, I would say, you know. I don't know whether that's the right word.

I: Okay, now that you say they are different, um, what sort of impact does this difference have on the physical concept that you have mentioned in your maps?

S: By impact, what do you mean? Do you mean in terms of how I think or in terms of what - I'm not getting that.

I: Okay, um, more or less you have, um, similar, um, physical concept in both maps. Um, my question is basically on, er - how can I put it - I actually mean, um, if you use, um, I'll just pick on any of the concept. If you use force in the first map, the force that you are using in the second map, is it the same force - would you interpret it as being the same thing? I mean, does the concept change a little bit or - that's what I'm asking.

S: The concept might have not changed, I don't think it has changed. It's just that, er, the scenario was a bit different so I had to apply the concept in a more different way, and maybe in a more, er, detailed way. I don't know whether it's - but I don't think detailed way is the right word, but I think I had to apply the principle in a more different way than in the first problem.

I: Can I ask - if you don't know how to answer it's fine. How - in a different way, how, what do you mean by that different, what is that different way that you have - that's what I'm asking?

S: Okay, I will make you an example. For instance, I said there are four men applied a force that overcame the inertia of that car. If I look at the problem more closely, in both instances the four men applied a force to overcome the inertia of the minibus, right, but I - when I understood the problem, from the fact that you said it was wet, it meant the force that they applied, if they were to do the same - if the situation had to be applied on both scenarios, both wet and dry, you'd find that if we are to gauge the force, I don't think the force that they'd applied in wet conditions would be the same as the force they applied in the dry conditions. That is what I mean.

I: Okay. Um, is there anything else that you feel I need to know, any assumptions which are not so explicit that I'll need to know when I look at your map?

S: No, I would say no.

I: Okay, thank you for your time and then we'll do the next one.

S: Okay, fine.

Interview on Snowy Surface starts here

I: Okay, the second map, which is about the snowy weather, what do you mean by minibus continued to gain momentum after collision because of less friction?

S: [Indistinct] said it continues. Okay.

I: You say it continued to gain momentum.

S: The minibus, okay - this comes from [indistinct].

I: Collision, because of less friction.

S: Oh, okay, I can see that. Did I mean that. Since I assumed that it is an elastic collision - ja, since I think I was answering here for an elastic collision, ja, or even whatever the collision was anyway, I think it continues to gain momentum in a sense that, er, if - I haven't been to any snowy countries as such, but from the physics that I've learned, is that if you look at the first problem that we had, due to the friction that the dry ground or the dry road offered, the car has to stop somewhere because it's got tyres that have - what is it - what is the word for tyres when they are printing

tyres - I don't know whether it's the right way to have those lines, you know, ja. If you look at that, that those tyres offer some friction on towards the ground, so if a car collides with another it will continue to move up to a certain extent, to stop, you know, but in a situation where people have pushed it, I think, though it is moving, though it is moving and it has some momentum, it is more - it's slipping as it's moving, so it will continue to gain momentum. That is what I meant.

I: Um, what do you mean by friction greatly reduced by snowy weather, I mean by snowy road, ja?

S: Okay. What I meant by that is that it is - it is - it is known that, er, snow is - it's - it's - it's - it's water so it's more water frozen, so if something stamps on a snowy surface the water underneath that thing sort of melts or something like that, so that doesn't offer a lot of resistance to the movement of anything, so hence it will reduce the friction and it will - it can cause - that's what causes slipping, I think.

I: Okay. What do you mean by friction reduces the grip of the four men?

S: Ja. What I mean is, if - if - if - if - if - if friction is - ja, I see, ja. If friction is greatly reduced, then there will be no - the grip that the men - because for the men to push the car they've got to have a grip, and a grip I think it's more of a general word to describe the interaction between the person and the ground in trying to overcome or in trying to push or when they are walking, you are gripping against the land, so that's what the men were doing, they were trying to - to - to overcome or to - to push the car, to push the minibus, hence the grip was smaller or was greatly reduced by the snowy weather or conditions.

I: Okay. You continue in your map to say that it makes it hard for the four men to overcome inertia of minibus. What do you mean by that?

S: What I meant by this is that, er, er, if - if - if, as I had put it, friction is a very important physics principle, or an every day thing that you might overlook because without it we can't walk or do anything, so if - if - if, as I've said in the first few questions that I've answered, that the snowy weather was, er, er, er, introducing a situation where there was less and less friction, so if you look at the two problems, the very first one I did for you was that the men had to overcome this minibus' inertia, and if you were to consider the force that they applied and the grip, you'd find that it was more easier because there was greater friction in the first part of the problem than now, so it made it harder for them because without friction they cannot push the car. I would make an instance that if you look at - if they were to wear something like, er, er, let me say those bath slippers, you know, those old plastic bath slippers, you know, those ones, ja, if they were to wear that I don't think they would be able to push a car in a snowy condition, but probably in a dry condition they will. Which brings back to one thing, that friction will play the role. It is more of a key factor in the whole scenario.

I: So they have to wear, like rubber boots?

S: Ja, [indistinct] or boots or something like that.

I: Now, what do you mean by minibus gains greater momentum and kinetic energy? What makes it gain greater momentum, do you think?

S: Okay. Is it getting finished? Okay, I will try and be brief. What I meant by minibus continues to gain, as I say, I think question one said something about what do I mean by a minibus gaining momentum, it is more or less the same principle, as I said, if these guys push the car, that's my assumption, because the problem said they managed to push the car after all, although the conditions were snowy, so if they managed to push the car the car will start moving and as it starts moving, since the conditions are snowy, it should start slipping and if - if you were to experience - if you have been in a situation maybe where, like in the [indistinct] if you are trying to go down a muddy place and you are trying to walk down, once you slip there you just go down, you slide. So, it should gain momentum - greater momentum than what it started with, you know.

I: Okay. Um, you continued to say that hence greater impact on 10-seater taxi, what do you mean by this? Hence, it will have greater impact?

S: Ja, I mean that if you were to compare, er, er, because what I kept on relating this situation to - is it getting finished? Okay. What I kept on relating the situation to was the previous problem. I tried to, even though I didn't have the chart though, but I tried to imagine the previous problem and then I tried to make that my point of departure, that if you were to look at the situation, let's say the situation would have happened at the same condition - not the same conditions as such, but you were to have maybe the same distance where the ...

END OF CASSETTE S1 SIDE A

CASSETTE S1 SIDE B

- S: Okay, so, as I was trying to answer that question, I was saying that I kept on relating the second problem to the very first one I did for you, in the sense that if you were to look at the situation in the same way that, let's say the minibus was at the same distance - the distance between the minibus and the 10-seater taxi was the same on both occasions, there you'd find that in the dry conditions, the collision - the momentum gained by the minibus before it hits the 10-seater taxi would be lesser, so will it be with the kinetic energy, but in a situation where the car gains momentum and then it starts slipping because of the snowy conditions, the momentum and the kinetic energy should be greater, such that the impact would be greater if you were to compare the two situations.
- I: Okay, um, maybe you have explained this but I'll just ask it again. You also continue to say greater impact because of speed gained due to less friction. Do you need to clarify or should I take, um, your last answer as answering this question as well?
- S: Well, I can just make clarity on the point of less friction. As I was saying that friction is a key - is playing a key role, but you can see that here, if you were looking at a situation of trying to make the car move faster in snowy conditions after overcoming the inertia of the minibus would be an ideal situation to get the car to move faster, compared to dry conditions, you see. So, that is what I mean by saying it will gain momentum, so if you want something to move faster, that is why you find that, I think I've seen it on TV, people in Europe playing with those things called like sledges, moving on the snow. Probably if you had to take the same situation and there's no snow, no one would be able to move downhill without snow, there is no way, but as long as the mountain is covered by the snow, the snow reduces the hurdles that you might have to be faced with in the condition where there's no snow.
- I: Okay, um, another similar question. What do you mean by when the minibus collides with the 10-seater taxi it gains greater both kinetic energy and momentum because of less friction?
- S: Okay, ja, this one it's similar to what I answered, I think it was question 6, about comparing the greater kinetic energy and stuff. What I mean, I was also relating the very same situation to the first problem. If you were to compare the taxi - the collision in that if it was because in this first problem, I think the collision was inelastic, isn't it, because they - the car dragged it, but I'm saying if you were to - this collision in the first problem were to be, excuse me, a situation of an elastic collision in the first situation, and if you were to compare the taxi's momentum or kinetic energy after the collision in dry conditions, it wouldn't be as great as that one because it will keep on reducing in dry conditions and in this situation it should be a slipping situation, unless the car or the minibus were to knock something head-on which was bigger than it, which will block it from moving. Otherwise, I think it can move on, you know.
- I: Okay. What do you mean by elastic collision have different velocities? Well, you had a similar link before but I don't want to assume it's the same.
- S: Er, in this case, I spoke of only, er, er, er, different velocity. I suppose you noted that because if you look at the first one I had two types of inelastic collisions, where there's different velocity and the other one, one stopping and the other one moving, but I still said both of them are elastic collision anyway, so in this one, why I would say there would be different velocities, I mean the - er, er, er, it should be - I think it would be because if you look at the fact that, er, by principle of momentum, the momentum of the - of the - of the - of the minibus before it collides with the taxi was a certain value. After they collide, they will move with different velocities. Hence it is an elastic collision. They have to have different velocities anyway, okay.
- I: Okay. What do you mean by inelastic afterwards have same velocity? This part.
- S: Okay. So, what I mean is that if - if - if - if it's an inelastic collision, suppose it is an inelastic collision, then I mean it will stick together, and they will continue - they will have a velocity that will be common to both of them. It will be like, as I said in the first, er, er, er, problem of the second, er, situation, it will be - it will be - it will be like the two cars have become one body, so they should have a common velocity.
- I: Okay, um, in this particular scenario, Part B, what type of collision do you think would happen?
- S: It's not easy for me to answer that one because like I've never been on snowy conditions, but if I use, er, my - my - my - my experiences with life and maybe TV and stuff, I think it also depends. It will depend on how the collision took place. If - if - if - if I go back to my first example that if probably it's in a robot and cars

hit each other, er, maybe side - one car coming from one, maybe hit each other at more or less 90°, the collision is very much likely for me it would be an elastic collision, but if you look at where a car hits another from behind or head-on, then I think that would be an inelastic collision.

I: Okay, um, now, um, Part A and Part B, do you see them as being different, and if they are, what is the difference and, um, that is, how different are they?

S: Ja, they are different in a sense that I think that mainly what is playing a role here, it's the conditions. In general, I would say it is the condition but all in all I think the physics principles have to be applied differently in dealing with the situations, but it comes to the point of applying the physical concept differently because of the conditions themselves, the way they, er, er, present themselves.

I: In this scenario B, which concepts, physical concepts does, um, the condition, the snowy condition, affect here?

S: It affects friction, and if it affects friction it affects the whole scenario, ja, I would say it affects the whole scenario. Because if you look at from where it begins, if you compare it with dry conditions, I think the men overcame the car - overcame the inertia of the minibus very easily, you know, if you were to maybe look at the very same four men in the snowy weathers, you'd find that probably it would take them much more time and it will take much more energy on their part to overcome that thing, and this is created by the fact that there's very less friction on the situation, on the two situations in the second part and in the first part there's greater friction as compared to them.

I: Okay, um, if we were to increase the number of men in a snowy weather do you think, um, we would be able to make Part B ...

S: To match them?

I: Ja, to match, ja, the first one.

S: Those conditions. Um, of course, assuming that the gears will be having its proper and stuff, I think if we were to do that it's possible, I won't say it was - I wouldn't know the situation, you know, but I'm assuming, I'm making a lot of assumptions. I would say that probably I'm also overlooking a lot of other problems that might crop up, you know what I mean? Probably maybe you might find the [indistinct] er, if you've seen a situation where a car gets stuck in the mud, you cannot expect to take that car out of the mud if you don't try and put something that will increase some sort of friction. I've seen it in some parts where you find that people bring as much as like stones, or even trunks of trees to try and increase the friction because the mud will be offering very less friction, you see. So, I might be overlooking such, er, er, minute, er, details that we would need to look into.

I: Okay. Is there anything that you'd like to add? Something that you think I need to know?

S: Well, I think I've - from what I did, I did okay for the interview and I don't see anything I would like to add, unless maybe you could have another question, I don't know.

I: Okay. I don't have any more questions, thank you for your time.

S: Thanks.

END OF RECORDING ON CASSETTE S1 SIDE B

CASSETTE S2 SIDE A

- I: Okay, like the first interview, I'm going to interview you about the links that you have made from your map. Okay, the first question is just out of curiosity. You have drawn one map for the two problems. Can I ask why?
- S: Um, well, when I considered the problems, um, I thought there were small differences in the scenarios and, um, I thought it would be adequate to, um, sort of include maybe a different, um, branch or two, um, for each of the scenarios and, um, that would be adequate to describe them, seeing as they were so similar. That's about the only thing I can say.
- I: Can you tell me what the differences are from the two problems?
- S: Well, um, I think the main one would be, um, the first case, um - it's got to do with the weather, if I remember correctly. Um, the one - the one involved, um, one involved snow while the other one I think was just muddy and wet, so, um, that's the main difference I picked up and, er, that's what I commented on and any concepts I could think of involving ice.
- I: Um, now you said you have snowy weather implies relatively uneven road surface or wet surface from the top of your map. Okay, um, what do you mean by the wet surface or the relatively uneven road surface implies decreased static friction between road and arbitrary object on the road?
- S: Well, snowy weather, um, what I thought of was a build up of, um, ice and snow, um, so compared to a normal road, um, which was perhaps only wet, um, you would have a build up of the snow, etc, and, um, well that would explain the - the unevenness, um, with regards to the - the decreased, um, um, friction. That would - that would just involve, um, the slipperiness, you know, would be increased, um, when the - when the ice and snow melted and, um, that would affect - affect how the men, um, would, um, push the - the vehicle, because, um, they would have a greater chance of slipping, you know, their feet exerting a force on the - on the - on the road surface, etc.
- I: You've actually answered my other question. Now, moving on, what do you mean by movement of minibus due to unbalanced force acting on it, caused by reaction force on man by ground?
- S: Okay, right. Um, that would be - that would be, um, just explaining sort of an application of Newton's second law, yes, um, if we add up all forces on a - on a body and, um, we see there's a resultant force then we're going to be able to comment and say that, um, the object is going to move in the direction of the unbalanced force. Um, I think, ja, okay, as regards to the reaction force, that would just - that would just be referring to the force, um, between the - the feet of the men and the ground, the reaction force would be actually what's - what's driving the - the, um, object forward.
- I: Okay, a follow up on that one, um, you say it is described by Newton's, that law of motion. How is it described?
- S: Right, ja, the reaction force is linked with the third law. Um, if you - if you put it, um, plainly, perhaps incorrectly, you can say that every - every force has its - has its reaction force. Um, that would be, um, if men apply a backward force on the ground with their feet, the reaction force would be a force in a forward direction, would be unbalanced and would cause the object to move forward.
- I: Okay. Um, what do you mean by minibus and taxi are physical objects, what do you mean by that?
- S: Well, for - what I mean by that is for convenience we, um, we can treat them as - as, um, sort of point masses, it's sort of an ideal way to treat an object in a physical situation like this, that perhaps wasn't needed but just to make things, um, more simpler.
- I: You do mention that you treat them as point masses. What is the significance of a point mass?
- S: Well, um, perhaps more in other situations than this one but, um, I thought, um, sometimes when a mass has got uneven dimensions, it has a bearing on the problem, so I just decided to mention that we could consider these as, um, as sort of one mass object, um, ja, I suppose it was perhaps not one of the more relevant points but, um, that was my reasoning behind that.
- I: Okay. It's sort of an assumption?
- S: Ja.
- I: Okay, so what do you mean by kinetic energy transfer is proportional to half velocity squared of the minibus? I think that's what you have here.
- S: Yes. Ja, in a collision, um, that would be that the two objects involved, the first one - the first one would transfer energy, okay, and, um, the energy it gained before the

collision was proportional to its velocity, half of the velocity squared. Um, that's just, um, that's just a known, um - that's just a known result which I cared to mention there.

- I: You also mentioned that, um, it is proportional to the mass of the minibus, what do you mean by that?
- S: Yes, um, the kinetic energy is proportional to mass and proportional to velocity, um, in plain terms, so the greater the mass, obviously the greater the kinetic energy it has and, um, the more it will transfer to the second object.
- I: Okay. Um, now, moving on to the other part, what do you mean by collision involves energy transfer from one form to another?
- S: Okay, besides from the - the - the main, um, potential to kinetic and vice versa transfers, we're going to get, um, transfer to heat, to light, etc. Um, it was just to emphasize that, um, in a collision, um, you're going to get transfer to all sorts of energy forms.
- I: Okay. What do you mean by kinetic energy transfer from minibus to taxi? What do you mean by that?
- S: Well, simply, um, what I mean is that the first object has - it's in motion which implies a kinetic energy that it possesses. Now, after the collision, we're going to be able to imagine that the second, um, object which was initially stationary, will now be in motion after the collision, and, um, the first one having, er, transmitted an amount of kinetic energy to the initially stationary one, that's what I meant by kinetic energy transfer.
- I: Okay, um, what do you mean by energy transfer as in kinetic energy transfer from minibus to taxi? I think it's this other part here. It's this part here. Energy transfer as in kinetic energy transfer from minibus to taxi.
- S: That, I think is much the same as the previous point, um, I think I was giving an example of the main type of energy transfer in the collision. I think it's similar to what I've just commented on, um, right before this.
- I: Okay. I think this one is also similar. You mention that energy transfer, as in heat, sound, light, energy transfer from system into environment. Maybe if you can just explain from "system into environment", because you have explained the other one.
- S: Okay. Um, what I meant to - what I meant to put across here is, um, that, um, the system has - has - has, um, lost energy in - the form of the energy has been changed and, um, the environment has - has gained a certain amount of energy from the - from the collision in the form of perhaps light, um, you might have a few sparks or whatever coming off, and - and in heat. Heat will be also another form of energy which will be released into the - to the sort of external agent or environment. I think that's what I - that's what I meant to say here.
- I: Okay. Um, you do mention, um, what you call special points about scenario A and special points about scenario B. Referring to special points about scenario A, can you tell me what is so special about it, what has - what - what - okay, you mention it's the weather and the wetness and the slippery road surface. What is - what is so special about those three points that you have put down there?
- S: Okay, um, going back right to the beginning, um, seeing as I was doing the map on the same, um, on the same sheet, I - I just wanted to point out what I found to be the main differences, um, so in describing the points about scenario A that I thought were different to that of B, um, it would be just the obvious ones, um, wet weather and, um, the implied slippery road surface. Um, the latter also being common to the second - er, to scenario B of course, but, um, that is - that is why I included this little branch.
- I: Okay. Um, you do mention that, um, there are differences between A and B. How different are they?
- S: Well, um, not a lot different in my opinion, um, which is - which is, um, why I actually used one - one page, um, for a short explanation. Um, very obviously the one had slightly different weather conditions to the other one, being, um, just wet. The other one having an amount of snow, um, occurring.
- I: Okay. Tell me, how does the weather impact, the wet one and the snowy one, impact on the problem as a whole?
- S: Okay, um, it's just a slight difference that I could think of, um, scenario A would have been, um, slippery due to the - due to the wetness. Um, scenario B would also have been, um, slippery but, um, it could have been icy, it could have had even more slippery conditions, um, which could have further implications, in that, um, the men could have had even more trouble trying to find a footing, um, trying to, um, push the object while in scenario A, while still being slippery, it could have been less slippery than perhaps in scenario B.

- I: Okay. Um, do you still remember the initial problem that we - we had before? I just want you to compare these two problems with the initial one that we had. Are they different, and if they are, how different are they?
- S: Gee, I'm going to have to, um - I'm going to have to have a glance at the old one. My memory doesn't serve me a hundred percent, um, do you want to know about how the problems differ, or how my maps differ?
- I: Not necessarily the maps, but I guess when you drew the maps there were certain physical concepts that came into your mind, so I just want to know if, when you were drawing this, when you were doing the first problem and when you do this last two problems, is the main physical concept that differ if you compare the two? Do you get my question?
- S: Ja, um, I think to answer your question properly, I'd have to remember more closely what the first problem was about, which I unfortunately - which unfortunately - let me just have a glance at it. Um, um, ja, it involves a collision, as in the first one. I think it's similar in - in the collision sense, um, that was the major concept which was similar. Um, the second, um, concept problem included a comment on the weather, which was a difference, so we had to, um, include that in our evaluation of drawing the map. Um, otherwise a lot was similar, um, I think.
- I: Okay. Um, I was going to ask you something, I've just forgotten what. Um, okay, is there anything, um, that you need to clarify, any assumptions that you made when you drew the maps that are not so explicit that you need to tell me about?
- S: Um, if I rack my brains I could perhaps come up with something. I think, um, this question's a bit more in depth, I'd have to, you know - I'd had to give this one a bit more thought. As in physics situations, you always make assumptions because physics we rely on assumptions to make life bearable, but, um, this is a tough one.
- I: But do you think the map as is, I will be able to interpret it, you know, like there is - everything is explicit, it's not something - isn't there anything that is hidden that I need to take into consideration when I - I look at the map?
- S: Well, I wouldn't say so. I don't think I've - I don't think that the detail is so great that you're going to come across doubts as to my reasoning. Um, it was a simple situation and, um, to mind no assumptions, um, I can't really think of any that you might, er, find misleading.
- I: Okay. Now, I've remembered my question. Um, what sort of collision do you think happens in the wet weather?
- S: Well, um, what - as opposed to dry weather or ...
- I: Yes.
- S: There, um - collision should be pretty much the same, um, there may be some - some slipping of - of the objects on contact, um, which would affect, um - what would it affect, er - I think it might affect some of the energy transfer. Um, but very similar, um, the collision would be very similar.
- I: Okay. Are you saying it would be similar to the first problem that we had?
- S: Ja, ja.
- I: And for the second part, the snowy weather, what sort of collision do you think would happen there?
- S: Also - also, um, inelastic in nature. Um, I think it would be very similar to the first, um, there might, er - there might be a bit more, um, a bit more, um, friction or, um, when a car's in the snow there might be a bit more, um - that's - I can't really think about much that's different.
- I: Okay. Thank you. Is there anything else that you need to tell me?
- S: Um, I can't say there's anything I can think of, um, thanks.

END OF RECORDING ON CASSETTE S2 SIDE A

CASSETTE S3 SIDE A

- I: Okay, are you ready? Um, like before, I'm going to interview you about the concept, the second concept map that you have drawn. Again, I'm going to ask you about the links that you have made so that I can get clarity. Now, what do you mean by minibus exerts force on taxi?
- S: Um, okay, it's the minibus collides with the taxi, um, it exerts a force, a force on the taxi, um, and the taxi as well exerts equal and opposite force on the minibus.
- I: What do you mean by that, by the minibus exerting force on taxi and taxi exerting an equal and opposite force on the minibus? What do you really mean by those two links?
- S: Um, the minibus is being pushed - where is it - is it the minibus? - ja, okay, the minibus is being pushed by me, right, so it's moving, it's being pushed so it collides with the stationary taxi and as it collides with the taxi it exerts a force on the taxi, it makes the taxi like move, it makes it move. So at the same time the taxi, the

stationary taxi exerts a force, the opposite force, on the minibus trying to retard its motion.

I: To retard the motion of the minibus or of the taxi?

S: The minibus, of course, the minibus if the one which collides with the stationary taxi.

I: Okay. Um, now you say the men exert force on wet road. What do you mean by that?

S: Um, actually what I meant is, um, the men exert a force, okay, on the wet road, the feet of the men, um, and the wet road as well, that's the same, it exerts equal and opposite force on the men, thus making the men move.

I: Okay, you go on to say that, um - let me see which one is that - okay, you say the wet road exerts force on the wheels of the taxi and again you say the wheels of the taxi exert an equal and opposite force on the wet road. What do you mean by that?

S: Um, the wheels of the taxi exerts a force on the wet road, um, ja, because the taxi, since it collides with the minibus, um, the thing that's going to make it move is the wheels. If it wasn't for the wheels, um, maybe it wouldn't move, but, okay, now since the taxi is, um - no, sorry about that - okay, the taxi moves because the wet road exerts a force on its wheels, on the wheels of the taxi. That's why it moves. And the taxi as well, exerts the same force, equal force on the wet road. That's the third law of motion, Newton's third law of motion.

I: Okay. You again say the wet road has less friction. What do you mean by that?

S: Um, since the road is wet, it has less friction, um, this means that, um, if your car is moving and maybe all of a sudden there is something that comes in front of it and you, um, you are forced to brake the car, then you're not going to have the car stopped, then and there. It's going to, um, drive some distance before it stops, because the friction will be less on the wheels because of the wet road.

I: Okay. You again say that the wet road has water molecules and these water molecules have viscosity. What do you mean by that?

S: Ja, the water molecules have viscosity. The viscosity is the internal friction of the water - of the water. Um, it's the friction, actually. It's the force that keeps the water molecules together. Ja, that's what I mean by viscosity. The water must have viscosity.

I: And you say that viscosity is due to cohesive forces. What do you mean by that?

S: Um, cohesive forces are, um, the forces that keep the water molecules together, that's what I mean by cohesive forces.

I: Okay, you mention that collision can be elastic or inelastic. Are these the only two types of collisions that one can have?

S: According to my knowledge, that's the only two I was taught about. I don't know whether there is another collision.

I: What kind of collision do you think happens in this problem and why do you think that way? That is, do you think it's an inelastic one or an elastic one?

S: Um, I would say the way I've drawn this - I drew this concept, I was looking at the collision being an inelastic collision.

I: Why did you choose an inelastic one? Is there a particular reason?

S: Well, not really. I just chose it to being an inelastic collision. Actually, it is inelastic since, um, um, we are dealing with, um, with, um, with cars here, two cars, um, because elastic collision is when the two things - like using two billiard balls, they just collide and then after the collision the other one goes its direction the other one goes another direction without actually, um, um, losing much of energy, like the kinetic energy. The kinetic energy before collision of the two balls would be the same, um, before and after the collision. But in the case of, um, these cars it won't be the same.

I: Okay. Are you saying the cars will stick together or are they going to bounce each other during collision?

S: Well, I wouldn't say they will stick together, you know what I mean, um, because we can have an inelastic collision, er, when the two cars are colliding, not because they have to stick together, you know what I mean? It can be inelastic but they won't be sticking together.

I: Okay. Can you tell me what you mean by an inelastic collision?

S: Inelastic collision? Um, inelastic collision is when the two objects, um, like they collide with each other and the kinetic energy before the collision is not equal to - okay, the initial kinetic energy for the collision is not equal to the final kinetic energy after the collision, that's inelastic collision.

I: Okay. You say collision results in energy transfer. What do you mean by that?

S: Um, what I mean is, um, in every collision there must be energy transfer. In this

- case, um, the energy that is going to be transferred is - it is thermal energy. Um, the reason why we're not having the same kinetic energies like before the collision, after the collision, is because some of the initial kinetic energy is transformed into the thermal energy, which is the heat energy.
- I: Okay. You go on and say that inelastic results in coupled cars. What do you mean by that?
- S: Um, I thought of the situation - oh, okay - I made up a situation. I just thought maybe if the cars, the two cars collide, they're going to stick together. That's what I came up with. I didn't - it doesn't really mean that they're going to stick, you know what I mean? But I just thought maybe they would stick together.
- I: Okay. Would I be right to say that you say if they stick together then you have an inelastic? Because you say inelastic results in coupled cars.
- S: Yes, you're right, I will say that.
- I: Okay. You say that coupled cars travel with same velocity. What do you mean by that?
- S: Oh, okay. Um, they travel at the same velocity because they stick together. The minibus collided with the stationary taxi and, um, the taxi, initially it was stationary, so what happens is the speed with which the minibus was travelling the time it collided with the taxi decreases and the speed of the taxi increases, so they will travel at the same velocity, um, to the, to the, um, to the end - what is it - to the end point, something like that.
- I: Okay. Would I be right to say that they travel with the same velocity because they are stuck together?
- S: They travel - ja, you're right. They travel at the same velocity because they'll stick together, they'll stick together.
- I: Um, you go on to say coupled cars travel over a distance. What do you mean by that?
- S: Um, they travel over a distance, okay, the taxi collides with the minibus, but I guess that the minibus is - as the men are pushing the minibus its velocity increases and it collides with the stationary taxi and as a result the velocity of the stationary taxi increases, so they go together with the same velocity and they will travel over a distance before they come to stop.
- I: Okay. You say an object in motion has velocity. What do you mean by that?
- S: An object in motion has velocity because if it didn't have velocity then it wouldn't be moving. It's moving because it has velocity.
- I: Okay. You continue to say an object in motion also has momentum. What do you mean by that?
- S: Objects in motion has mass and since it is in motion hence it has velocity and that's basically the definition of momentum.
- I: And what is this definition of momentum?
- S: Momentum is the product of the mass, um, and velocity.
- I: Okay. You again say the object in motion has kinetic energy. What do you mean by that?
- S: Object in motion has kinetic energy. Um, the kinetic energy is the energy of a moving object. Therefore, any moving object must be having kinetic energy.
- I: Okay. You continue to say the object in motion has the ability to do work. What do you mean by that?
- S: Um, it has the ability to do work, um, because it is moving, so what I mean is, um, if - if maybe it happens to - to - to - to - to - to - to collide with something else on its way, then it will do the damage on that thing, so it means it will be doing work on that thing.
- I: Okay, and you say that work is caused by force. What do you mean by that?
- S: Work is caused by force. Okay, um, for the work to - to - to happen, you know what I mean, there must be the work - the force involved in that, otherwise there wouldn't be work. That's what I mean by work is caused by force. There must be force before - before - before the work happens.
- I: Okay, how does the force cause the work? Let me rephrase it.
- S: Um, um, like, okay, if - okay, let me take this scenario, okay. The men are pushing on the minibus, so the men are doing work on the minibus. They're pushing the minibus with the force, so as a result they are doing work on the minibus.
- I: Okay. You say that force gives rise to acceleration. How does it give rise to acceleration?
- S: Um, force gives rise to acceleration because, um, the object that is being pushed starts from zero, right, it starts from rest then it is being pushed and the force is being applied, and as a result the object accelerates. That's what I mean by saying

the force gives rise to acceleration.

- I: Okay. You say force is directly proportional to acceleration and also acceleration is directly proportional to force. What do you mean by that?
- S: Um, um, as the force is increased, um, okay - let me get back to the initial, um, um, scenario here. We're having four men who are pushing the minibus. If the number of men were to be increased, maybe to be doubled, then we're having eight men who will be pushing on the minibus, so it means, um, there will be, um, um, greater force and the minibus will, as a result, accelerate faster than when it was only four men who were pushing on that minibus.
- I: Okay. Now, if - when you say acceleration is also directly proportional to force, what do you mean?
- S: Um, acceleration is directly proportional to the force. A fast moving object must have been given greater force.
- I: Okay. You also say acceleration is inversely proportional to mass. What do you mean by that?
- S: Acceleration is inversely proportional to the mass. Okay. Um, if the mass of the object is - is - is - is increased, then the acceleration will - will - will decrease as a result. That's what I mean by - by - by - by - by saying acceleration is inversely proportional to mass.
- I: Okay. I brought in your earlier map together with the problem. Do you find this current problem different from the first one and, if so, how different are they?
- S: They are - the only difference I see on the current problem, um, with the initial one is - is the conditions, the weather conditions. The initial problem didn't have, um, um, um, rainy conditions. This time men were pushing the minibus while it was raining, while the road was wet and in the initial case there wasn't something like that.
- I: So, um, do these weather conditions have any impact on the map itself?
- S: Um, the only thing - I think, if you check my last concept map, you'll find out that this one and the current one has, um, many - what is it - concepts coming up because of - of - of - of the conditions, the weather conditions, because I'm having the wet road and water molecules viscosity causing forces. That's what I'd added. And they are not there in the initial problem.
- I: Okay. Is there anything that you'd like to add, any assumptions that you have made which I'm not aware of, anything that you think you need to tell me so that I can understand your map?
- S: Um, the only assumption that - I think the assumption that I made is, um - is that the cars are coupled together after collision, that's the assumption I made.
- I: Okay, thank you. We'll take a short break and prepare for the next one.

END OF RECORDING ON CASSETTE S3 SIDE A

CASSETTE S3 SIDE B

- I: Okay, are you ready?
- S: Yep, ready.
- I: Okay, um, I'm going to make an assumption that, um, this map that you have is different from the Part A one. If you feel that there are some links which are exactly the same, which exactly mean the same thing as the first one, you'll just tell me. Okay. What do you mean by a road full of snow push on the wheels of the minibus or taxi?
- S: Um, road full of snow push on the wheels of the minibus, um, the minibus push on the wheels - the minibus - the wheels of the minibus push back on the road full of snow. This is - this is, um, the action, the reaction of the pair - the Newton third law of motion. All what it means is, or what it says is that, um, for every force - for every action there must be reaction, so in this case the road is pushing on the wheels of the minibus and the minibus as well pushes back on the wheels of - I mean, on the road full of snow, with the same and equal force.
- I: Okay. Um, I guess even these ones are the pair, but you'll tell me. The road full of snow push on men and the men push back on the road full of snow.
- S: That's exactly the action/reaction pair I have just explained on the road full of snow and the minibus.
- I: Okay. So, I guess the men push the minibus and minibus push back on men will also be the action/ reaction pair you are talking about?
- S: Exactly.
- I: Okay. You say the road full of snow has less friction. What do you mean by that?
- S: The road full of snow has less friction. Um, this takes us back to the problem number A where, in that case the road was wet. Um, when the road is - has snow on it or it has water, the friction on it is low. Um, this means that, um, a travelling car,

- when you suddenly stop it, it will - it won't like stop immediately, it will - it will, um, move, um, a certain distance, um, because of - of - of the friction on - on - on - on the road.
- I: Okay. You also talk about collision as being inelastic or elastic. In this particular problem, um, do you think it's inelastic or elastic?
- S: Um, it is an inelastic collision in this case, like in Part A.
- I: Okay, again did you choose inelastic just for the sake of it, or is there a reason behind choosing it to be inelastic?
- S: It is inelastic because - because of - of - of, um, the minibus together with the taxis - um, they are not like, um, like soft balls - you know what I mean - where you're going to collide and then the other one will take its own direction after that. These are cars, they are cars, big cars and as they collide you're definitely going to have an inelastic collision.
- I: Okay. Do you really think, when it's cars, it will always be inelastic? Haven't you seen any accident where two cars collide and they go different directions?
- S: Well, the reason why I'm saying this is an inelastic collision is because of, um, the kinetic energy. The kinetic energy before won't be the same as the kinetic energy after the collision. That's why - that's why - what's why, er, I say this is - this is an inelastic collision.
- I: Okay. What will make the kinetic energy before not to be equal to the kinetic energy after the collision?
- S: Because, um, some of the initial kinetic energy will be lost to other forms of energy. It will be converted to other forms of energy like the thermal energy, like I say in the first problem, so therefore it definitely won't have, um, the same kinetic energy initially and after the collision.
- I: Okay. So what do you mean by kinetic energy is not conserved in inelastic?
- S: Kinetic energy is not conserved in inelastic collisions. Um, this is because, um, the kinetic energy initially, when we [indistinct] the kinetic energy after, the cars stick together. Okay, in the first case we are looking - okay, before the collision, the minibus is - is - is - is moving alone, it's being pushed and it moves and then it collides with - with - with the stationary taxi, so as they go together, they are coupled, the mass will definitely increase. We'll have the mass of the minibus plus the mass of the taxi together, so definitely kinetic energy won't be conserved.
- I: Okay. You say inelastic results in coupled cars. What do you mean by that?
- S: Inelastic collision results in coupled cars. I assumed in this case, like in the first problem, that the cars stick together - they stick together when they collide.
- I: Okay. You say coupled cars travel with the same velocity. What do you mean by that?
- S: They travel the same velocity, um, because they're coupled. So, the velocity will be the same for - on both cars.
- I: Okay. You say coupled cars travel over a distance. What do you mean by that?
- S: They travel over a distance, um, because after a collision, um - okay, the minibus will collide with the taxi and as a result the cars - the two cars will move over a distance. It won't just be a collision and the cars not moving, they will definitely move over a distance, and they will stop eventually.
- I: Okay. You say that an object in motion has velocity and also has momentum. What do you mean by that?
- S: Object in motion has velocity because it is moving. It is moving. It has momentum as well, because it has mass and at the same time it is moving, there's mass and velocity. So that's why we're saying it has momentum.
- I: Okay. You also say an object in motion has kinetic energy, what do you mean by that?
- S: Object in motion has kinetic energy. Object in motion has energy, it has energy and that type of energy, we call it kinetic energy.
- I: Are you saying by the mere fact that it is motion, it must have kinetic energy?
- S: Definitely, yes.
- I: Okay. You also say an object in motion has the ability to do work. What do you mean by that?
- S: Object in motion has the ability to do work. Because, like I said, in problem number A, um, if it happens to collide with anything in front of it then it will do work on that thing, it will damage that thing.
- I: Okay. And you say work is caused by force, what do you mean by that?
- S: For work to happen, there must be force involved. Um, okay, I guess that the men are pushing on the minibus, the men are using force and as a result they are applying force to push the minibus and they are doing - they are doing work on the minibus

- as they're pushing.
- I: Okay. Um, you say force gives rise to acceleration. What do you mean by that?
- S: Force gives rise to acceleration because, um, the force is being applied on the minibus by men and as a result the minibus is moving and, as it moves it accelerates.
- I: Okay. You say force is directly proportional to acceleration and acceleration is directly proportional to force. What do you mean by that?
- S: Force is directly proportional to acceleration. Um, if you increase the force, acceleration is also increased, and if the acceleration is increased, the force as well will be increased, so the two must be proportional - directly proportional to each other.
- I: Okay. And you lastly say that acceleration is inversely proportional to mass. What do you mean by that?
- S: What I mean is, um, as you increase the mass of the object, um, acceleration will in - sorry, will decrease because, um, the object will be much heavier than in the first case where it didn't add any mass on that.
- I: Okay, and this particular assumption that you made, that the cars will be coupled after collision, I guess the mass will be increased. Does it necessarily mean that the acceleration will be reduced?
- S: Definitely, yes. Acceleration will be decreased because, um, the cars will - the speed of the cars, of the coupled cars, will decrease and eventually the two cars will stop, um, showing that the acceleration will be decreasing.
- I: Okay. Do you find this problem, this Part B, different from the one in Part A? If they are different, how different are they?
- S: The only difference is, um, if the road - the conditions as well, um, like I said in - before, just the snow and in the first problem is the wet road. Um, basically they are the same, so what I'm not sure about is - is - is - is, the problem itself didn't specify whether, um, um, the snow or the water, um, how much water was there, you know what I mean - whether there was too much water on the road, or the only - or whether the road was only wet, you know what I mean, because if you don't have too much, er, um, water on the road then we will have - we'll have - the cars will become able to move, but if you have too much water, then it will be difficult for a car to move on that - on that condition.
- I: Okay. So what kind of assumption did you make when you drew the maps? Did you assume that there was a lot of water on the road or less water?
- S: I assumed that there is just less water and there is snow.
- I: Okay. Now that you say that the differences on the conditions of the road, tell me, do those conditions have any particular impact on the physical concept, and which ones they are?
- S: I don't think there are any impacts. Um, the same thing happened in both cases, you've got less friction on both cases, less friction on the snowy - road full of snow and less friction on the wet roads, so they are basically the same.
- I: Okay. You're saying it will be the same friction on wet road and the same friction on the snowy road?
- S: Not the same friction. The friction will be less but not exactly, um, um, you cannot say they are equal, you know what I mean. You can't say the friction is 10 on this side, you cannot say it's 10 on the other side, you cannot say that.
- I: Okay. Which one would you say has got lesser friction?
- S: Hmm! Well, according to me that's the question I've been asking myself all the time. Um, I think the one that will have less friction, um, ai - okay, it's when the road is full of snow.
- I: Okay. Now can you compare those two problems, the Part 1 and Part 2, with the original map that we drew. What differences are there, if they are any?
- S: Um, the differences will be, um, like I say the conditions, the weather conditions. The concepts themselves, I think is as we can see them, they're - they're - they have everything in common, you know what I mean. The only difference is the initial stage when the car is being pushed. The one is being pushed on the snowy conditions, the other one is pushed on the wet conditions, and the other one, um, the weather is just okay, you know, there's no wet or rain.
- I: What can you say about the friction of the first problem as compared to the last two problems?
- S: The friction - you mean the friction on what? On the road? Okay. As compared to the first one, the friction on the road is too much, it was too much friction and the - so on the first - in the first problem, indicate if two cars collides, two cars collide, we're going to have - the cars will move over a distance but the distance will be

shorter because of the friction that will be retained in motion.

I: Okay. Are there any other assumptions that you have made, anything that you think - that you feel that I need to know about your maps?

S: Um, no, I think there are no further assumptions. The only assumptions are that the cars will be coupled, that's the only assumption that I think you should know.

I: Okay. Thank you for your time.

END OF RECORDING ON CASSETTE S3 SIDE B

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CASSETTE S4 SIDE A

- I: Okay, are you ready? You have stated in your map that other concepts that you haven't included in your second map are similar to the previous map. Er, would I take it that the links will be exactly the same and the meanings will also be exactly the same and, um, can you just briefly tell me which concepts you haven't included which you feel should be the same as the previous one?
- S: Um, with the first one, like the one with - where we had the wet road, um, the concept there which is force driving, for example, force - for driving - has a similar application with the last one and all the [indistinct] around it are the same, except that after coupling - after the taxi has coupled with the minibus, say the taxi was stationary, in the first place - in the first concept it was not stationary, they will expect the taxi physically to slip on and you will have the same [indistinct] of any transfer as it was previously.
- I: Okay, excuse me. I think that that - which one was stationary?
- S: I mean, with - the taxi was stationary in the second one and even in the first one, but the difference was that this time we have a slipping - we have a wet road.
- I: Okay. Now I'll just concentrate on the second map that you have, Part A of it - of the wet road. What do you mean by men exert force, which you call dragging. What is this dragging force?
- S: Um, this dragging force is actually the force that the men put on the minibus and hence the minibus will exert it on to - or will exert it to the taxi as a result. I call it a dragging force because this is a force that basically the minibus will be using to drag the taxi.
- I: Okay. Um, you also mention that men push the minibus. What do you mean by that?
- S: I was literally meaning pushing a minibus.
- I: Okay. You might have answered this one, but let me just ask it again. You say dragging force moves the taxi. How does it move the taxi?
- S: Er, like I said, that the force that the men exerted and which is exerted by - indeed, the force that is exerted by the minibus on the taxi, so by the force - dragging force moves the taxi [indistinct] that the minibus when - will exert the force on the taxi which will then - moves.
- I: Okay. Um, you say that the taxi slips on the wet ground. What makes it slip on - but before that can you tell me what you mean by slips on?
- S: Um, by slip on I - basically I don't expect the wheels of the taxi to sort of roll, show movement, so I expect since it was stationary then it will just move without the wheels being rolling. And by slipping on, I meant that basically that the wheels won't be rolling, as such, but it will move.
- I: Okay. Tell me, what makes it slip on?
- S: It's the wet ground, like I've indicated on the map that it's ground which is wet.
- I: Okay. And, um, in physical terms what would this mean? The wet ground making it to slip on, in physical terms and what physical concepts would be involved in such a case?
- S: Er, I don't know if I understand what you actually want but, um, when the floor is wet obviously you will have, um - I don't know what to call it but, sort of a mud road, I don't know whether that is the right word to use, but a mud road which will cause it to slip or - and as a result it, um, it won't - the wheels will be able to roll and to slip.
- I: Um, what prevents the wheels from rolling? That's my question?
- S: Ja, I say the road is wet and it is muddy, then the force on the ground won't be enough to grip those wheels to be able to roll, hence they will have to slip.
- I: Okay. Which force are you talking about?
- S: The ground force actually, that very - that which is expected to sort of return. Like I've mentioned, there's a relationship that I've shown between the ground and the force, the retarding force. And those that I've said, the ground exerts the force, that force. You see, the one won't be enough to allow or to make the wheels to roll.
- I: Thank you. Okay, you also say a force [which you call the dragging force] couples minibus plus taxi. What do you mean by that?
- S: Um, it is that force that those men exerted which caused the minibus and taxi to collide and as, um, since the minibus will exert the force on the taxi, so basically I meant that coupling that occurs during the - during the collision of the two, caused by the force which is exerted by the men on that - on that minibus.
- I: Okay. You also mention that minibus and taxi transfer kinetic energy. How do they transfer it and where do they transfer it to?
- S: Ja, um, during collision there is obviously a transfer of energy between the two objects that collide - that collide with each other, so by minibus and taxi transfer

- energy literally means that there will be a transfer of energy from the minibus to a taxi and hence I said the minibus will, as a result, lose that energy whilst the taxi will gain it.
- I: Okay. How does the taxi gain the kinetic energy?
- S: By men moving it, it means it's gaining the energy from the minibus.
- I: And how does the minibus, um, lose kinetic energy and why does it lose it?
- S: Um, minibus will lose kinetic energy, er, since its speed will be reduced when it collides with the taxi, as a result the kinetic energy will be lost. The speed will be reduced.
- I: Okay, thank you. You might have mentioned this one earlier, but I'll ask it again. Um, you say wet ground exerts retarding force. How does it do that, what happens when it exerts this force?
- S: Basically, it sort of opposed the movement by [indistinct] to be made by the minibus.
- I: Okay, thank you. Now, can you tell me what the differences are between this particular map, the wet road one, with the one that you had previously, and what is the impact of these differences on your concept map?
- S: Well, with the first one, as I remember, I think it was clearly mentioned that after collision - after collision, the taxi and the minibus moves, and in this one there was no mention of whether that thing moves or not, after a collision, so I had to deduce considering the fact that the floor was wet and the collision was made after the minibus has moved when pushed by men, that the taxi will actually slip and then move.
- I: Okay, and since in your map you haven't mentioned any collision in this particular map of wet road, what is it that you have deduced about the collision? What type of collision would it be and why would you think it should be that type of collision?
- S: I'm sorry, I can't remember what I had there, but whatever I've mentioned previously in terms of collision still applies in this case, because I didn't show them as [indistinct].
- I: Okay. Now you're saying this map, the second one, and the first one are the same when it comes to collision so there are no differences in terms of collision?
- S: Yes.
- I: Are there any other differences?
- S: No.
- I: Are you sure?
- S: Er, I mean, besides those that I've mentioned, then there are no differences.
- I: Okay. You have mentioned that in the previous one it was stated clearly that, um, when the minibus collides with the taxi, it drags the taxi along with it and they stop a few metres away. But in this second one that wasn't mentioned. Is that the only, um, difference that you see in the two problems?
- S: Um, the obvious one is that one of the different surface that we have, which had an effect on the taxi - on the couplings, and as to how - whether the taxis would move or not, depending on the surface that we had.
- I: Okay. Are you saying with the wet road, when they collide, the taxi's not going to move, it's going to slide or something?
- S: Yes.
- I: Okay. Is there anything that you'd like to add to this interview which you haven't mentioned in your map or which you haven't mentioned in the interview already which you think I need to know?
- S: Is it something concerning the concept map or anything?
- I: Yes, concerning the concept map.
- S: No.
- I: Okay. Thank you. Let's get ready for the second interview. Thank you.

END OF RECORDING ON CASSETTE S4 SIDE A

CASSETTE S4 SIDE B

- I: Okay. Are you ready now?
- S: I am.
- I: Okay. Again, I guess I have to use the assumption that the concepts left out are the same as the previous - the earlier map that we had. Er, can you tell me which concepts in particular are the same as the second map that you have here?
- S: Um, this one is somewhat different from the other two, especially the one coming to the collision that we had and energy, so there are some changes that we'd expect in terms of those concepts.

- I: Would you like to elaborate these differences?
- S: Ja, like I've said, this is the same as the one with the wet road because there was no mention as to whether both the taxi and the minibus moves after the collision or not. And then given this scenario, I decided to say then there's no collision - like there's a coupling, but there's no movement, this too. Basically what happens is the minibus will lose its energy, kinetic energy, [indistinct] and then the taxi will proceed to stop, seeing as we have, er, a snowy road which I regard as a great obstacle to the movement of both a minibus and a taxi.
- I: Okay. Thank you. Again I'll ask you about the links you have in this particular one. What do you mean by men exerts force? You call it dragging force.
- S: I don't know if I have to repeat this, but I've made mention of this already in the previous one.
- I: If, in any case, there is something that is - you feel that is similar, has the same explanation as the one previously, you can just say so. But I'll continue to ask the - ask you about the links that you have, to make sure that I understand clearly what you mean, okay.
- Again, you mentioned that dragging force couples bus and taxi. How does it couple them?
- S: I've mentioned this previously, so if you take the previous explanation as the same as this one.
- I: Okay. Again you say men push bus. Is it the same explanation as before, or not?
- S: Yes, it is the same.
- I: And then you mention that there is a retarding force which decelerates the bus. What is this retarding force?
- S: This is the force that I spoke about in a previous one, that is exerted by the ground.
- I: Okay. Now, how does this retarding force decelerate the bus?
- S: Er, it's obviously going to reduce the minibus' speed.
- I: Okay. How does it reduce the minibus' speed?
- S: It - I think I've explained this actually, but what I mean is that it - it - it - it - it opposes the movement of the minibus.
- I: Okay. And how does this retarding force stop the bus and the taxi?
- S: Now, since - since - since the taxi was already stopped, was already not in motion, and when the minibus collides with it, and knowing the ground was snowy, the force which is - the forces you bear by the ground will definitely be greater than the one that, er, is - should be - than the one that should be exerted by the minibus and taxi to overcome - to actually have them moving. So, given the scenario that I was given, er, I think there's no way that - the taxi will actually stop the minibus in this - due to that retarding force that was exerted by the ground.
- I: Okay. Are you saying because the road is snowy, the retarding force, which you explain as the force caused by the ground, is going to be greater? Is that what you mean?
- S: Yes, greater than the previous one.
- I: Are you saying the retarding force will be greater than the retarding force in the wet road?
- S: [No audible reply]
- I: Okay, thank you. Okay, I might be repeating myself here, but I'll ask this question again. You say snowy ground exerts retarding force. How does it do that, what do you mean by that?
- S: Er, what I mean is, it opposed the movements of both - of a minibus, or both a minibus and a taxi, in this case after coupling.
- I: Okay. You say men slip on the snowy ground. Is it the same meaning as what you had in Part A or does it mean something different now?
- S: It means the same thing, it's just at this time it's on men.
- I: Okay. Again, to get this clearer, do you think there are any differences between the wet road and the snowy road, and if there are any differences, what are the impact of these differences on your concept maps?
- S: Yes, there are differences. Well, the snowy road it should be - should be having - should be having more of the grasp than the wet road if we want something to move from one point to another.
- I: What obstacles are you talking about?
- S: In this case, the major obstacle which, to me, should be the retarding force that is exerted by the ground. The different surfaces do by - I mean the forces do - they both differ by different surfaces which will basically not be the same.
- I: Okay. Now, comparing the three maps, can you tell me, this retarding force, where is it greater?

- S: Er, I think it should be greater in the snowy one, because knowing, or considering how snow should be, and I expect this to be because usually, you know, snow is something above the ground and you find that usually it's not easy to move on the snowy road than to move on the ground road, hence [indistinct].
- I: Okay. Can you compare the wet road and the earlier map. The retarding force, which one will be greater?
- S: It should be greater in the other one, the first one, not the wet one, water should have a lower force, retarding force.
- I: Okay. So you are saying with a snowy road will have the greatest retarding force, followed by the earlier map, and then lastly the wet road?
- S: Yes, I agree.
- I: Okay. Is there anything that you'd like to add, any assumptions that you have made that you feel I need to know about?
- S: No.
- I: Thank you.

END OF RECORDING ON CASSETTE S4 SIDE B

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CASSETTE S5 SIDE B

- I: You mention that the other concepts are illustrated in the first map. What about the relationships that you have omitted here, should I take them from the previous maps as well?
- S: Exactly.
- I: Okay. Now, what do you mean by rain water opposes motion?
- S: I mean because the surface is not clear, there's water, then motion will be opposed by the rain.
- I: How is the motion opposed by the surface?
- S: Because of the water that's on the surface, that's - whatever, on the car, whatever.
- I: Jabu ...
- S: It's what I'm trying to say, correct, because there is water on the surface. It's not like when there's nothing on the surface and it's only cars just moving, so there is water. Maybe the water it might be in an opposite - it might be flowing in an opposite direction to the motion of the car. So, the motion won't be the same as - I mean, when there wasn't rain on the surface.
- I: Okay. What do you mean by the rain water increases friction? How does it increase friction?
- S: By the fact - by the mere fact that the motion will be opposed. That means there'll be greater, I mean, friction on the surface. Not on the surface exactly, but - there'll be much force opposing motion which I call, I mean, friction, I mean.
- I: Okay. Are you saying the water on the surface will be flowing on the opposite direction of the motion, that's why there will be friction increase?
- S: Even if it's - when it's not, I mean, flowing in an opposite direction, but I'm just assuming that it's flowing in - but even if it's not, er, - I mean I don't know how to say this, whatever.
- I: Okay. You're saying, even if as long as there's water in the surface, the friction will be high?
- S: Exactly.
- I: Okay. Now, what do you mean by watery road means more friction?
- S: Exactly, that's what I was saying, there's more friction because the surface is not free, I mean, it's - whatever.
- I: Okay. Is it the same answer as the previous one?
- S: Yes.
- I: Okay. Now, if you look at your previous map, the one below, and you look at our new map, you don't have any relationship between friction and motion in the new map. Does it mean that I have to take the relationship is ...
- S: Exactly. Yes, the same.
- I: Now tell me, if you compare the previous map with the current one, do you think there are any differences, and if there are, what differences are they?
- S: There are differences. I mean, like I said, like because the - because of the friction that's more than, I mean, on the first map, whatever, and the surface has changed from the previous surface, so that's the only differences that I would say are in this problem, whatever.
- I: Okay. Will I be right to say that, um, the surface have an impact on how much friction we have?
- S: Yes, it does. Yes, exactly.
- I: In the previous map, do we have more friction than the current one or do we have less?
- S: Er, I can say it's more, it's more because of the water, like I said.
- I: Okay, so there is more when there is - there is more friction when there is water on the surface than when there isn't any?
- S: Yebo.
- I: Okay. Is there anything that you need to clarify, that I need to know from the new map that you have?
- S: No.
- I: Okay thank you, and get ready for the second map.

INTERVIEW 2

- I: Okay. What do you mean by snow on the surface decreases friction. How does it decrease friction?
- S: Because the road is slippery, it means less friction, whatever.
- I: So, when we have snow the road is slippery and we have less friction?
- S: Yes.
- I: Okay. Now, what do you mean by snow on the surface increases motion. How does it increase motion?

- S: Because there's less friction so motion won't be opposed, so it may - whatever.
- I: Okay. I'll ask this one again. If - what do you mean by slippery road means less friction?
- S: Because the motion won't be opposed. That means there's less friction, I mean, than the previous - I mean, problem.
- I: Okay. Now you have another link that says motion because of slippery road. What does that mean?
- S: Motion because of slippery road? I can't remember why I had that. I see. I think I wanted to illustrate the fact that there'd be more, er, motion because of the slippery road. Er, which is the same as, er, because of the less - less friction, er, which is caused by the slippery road then there'll be greater motion, or something of that nature.
- I: So, what you mean is, because of snow we have slippery road and hence less friction and therefore greater motion?
- S: Ja, if I may say speed, whether it will increase, or the velocity of the thing will increase.
- I: So is motion and velocity the same thing?
- S: No. Motion and velocity are not the same thing. But they are related, whatever, as I illustrated in the first thing.
- I: Okay. So I'll look in the first map for that. Okay. Again, are there any differences between Part A of our second map and Part B, when we have wet road and when we have snowy road, and if there are any differences, can you tell me what the differences are?
- S: The difference is on the surface where motion occurs. The two surfaces are the same. On the first surface, like I said, there's more friction and the second one there's less friction, which will, er, impact on the motion of the car, whatever.
- I: Okay. Now, if you compare the snowy surface with our previous map, the original one, are there any differences, and what are they?
- S: Snowy surface and the surface where there's - I'm trying to think here. Yes, there are. There are differences, and the difference is the friction again, because of the different surfaces where the thing - the mass of, or whatever, the motion occurs - whatever.
- I: Okay, tell me, comparing the three of them, the three maps that you have, where do we have the greatest friction?
- S: I think the greatest friction would be on the water surface.
- I: And then, comparing the snowy surface and our first surface, which one has more friction?
- S: Er, I would say the first surface will have more friction.
- I: Okay. So you are saying when we have a snowy surface there is less friction and then when we have just our plain surface it's a little bit more than that, and then with a watery road, that's where you'll have your greatest friction?
- S: Exactly.
- I: Is there anything that you need to clarify about the interview?
- S: No.
- I: Thank you.

END OF RECORDING ON CASSETTE S5 SIDE B

APPENDIX D

STATISTICAL ANALYSIS

Chi-square calculations were done to find if there is any correlation between categories of description and study-provided contexts.

Chi-square χ^2 statistic is a measure of association between two variables that are viewed as responses generally in two-way tables.

$$\chi^2 = \sum \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}}, \text{ the sum is over all } r \times c \text{ cells in the table}$$

with degrees of freedom $(r-1)(c-1)$

where r = number of rows and

c = number of columns

O_{ij} is the observed cell count (see Table 5.3 on page 127)

E_{ij} is the expected cell count

The computed value of Chi-square is 11.2181, with 6 degrees of freedom. This value is significant at 0.1 level, so the hypothesis of independence is rejected, and we conclude that categories and contexts are related.

Chi-square can be used to determine the significance of the relationship between two categorical variables; it doesn't directly give a measure of the degree of the relationship. The measure proposed is p . The calculated p is 0.175, and it indicates that there is a statistically significant correlation between categories of description and contexts, even though it is not very strong.

The statistical analysis is discussed in Chapter 5, Section 5.4.1.2, page 129.

APPENDIX E

DETAILED MAPPINGS

These mappings are distributions of categories of description for each student in different context. I use these mappings to look for patterns that might emerge or trends.

Distribution of categories of description for each student in different contexts

Context 1: A familiar situation where friction is moderate (dry surface)					Context 2: A less familiar situation where friction is less (wet surface)				Context 3: An unfamiliar situation where friction is negligibly small (snowy surface)			
SK	A	B	C	D	A	B	C	D	A	B	C	D
AA	x	x	x		x	x	x		x	x	x	
SMP	x	x	x	x	x	x	x	x	x	x	x	x
SEM	x	x	x		x	x	x		x	x	x	
JB	x	x	x		x		x		x			
					x	x			x			

The summary of the distribution of the categories of description across the given contexts for each student is given in Chapter 6, Table 6.1, page 134.

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