The Context of Problem Tasks in School Physical Science

by

Paul Anthony Hobden

Submitted in fulfilment of the academic
requirements for the degree of
Doctor of Philosophy in the
School of Pure & Applied Physics
Faculty of Science
University of Natal
Durban

December 1999

ABSTRACT

The purpose of this study was to extend our current knowledge about what happens in physical science classrooms. The focus was the context of problem tasks. This involved the study of the situations, events and factors that relate to the solving of problem tasks at high school in order to understand their role and nature. The problem tasks that were central to this study were well defined, narrow in focus, and invariably involved the calculation of some quantity through the use of a formula and algebraic manipulation.

RQ

The main questions that guided the study were as follows: What is happening in physical science classrooms? What is the nature and role of problem solving within this context? What are some of the consequences of organising teaching and learning in this manner? How do external forces influence what happens? The study aimed at describing the activities that the teachers and students were involved in and understanding how they understood their own actions. An interpretive research approach was chosen for this purpose, having as its basis a detailed descriptive foundation using classroom observation.

Resea

Two high school science classrooms were studied in detail over a period of a year. The data gathered included fieldnotes from over a hundred classroom visits, extensive video and audio records, questionnaires, classroom documents and formal and informal interviews with teachers, students and examiners. Through a process of careful and systematic analysis of the data, six assertions emerged. These assertions are supported by both particular evidence in the form of analytic narrative vignettes, quotes and extracts, and general evidence consisting of frequency data and summary tables.

Findings

The analysis reveals that problem tasks occupied most of the teaching and learning time, and that the students found this experience of school science boring. Most of the problem tasks were routine in nature and of low conceptual demand. The majority of the students were unable to solve the more difficult tasks encountered in their tests and examinations. In addition, a significant number could not solve the routine problem tasks. This suggests that the predominant instructional strategies were ineffective. It was found that participants had an uncritical belief in the efficacy of teacher explanations and student practice on problem tasks. Further, the participants had different views of the role of problem tasks. A significant finding was that the examination exerted a powerful focusing influence on the classroom environment, the instructional activities and on the problem tasks used. It appeared that the ultimate goal of school physical science was to solve these types of problem task in preparation for the high stakes examination, rather than the learning of science.

The study has implications both for practice and for research on the teaching and learning of school physical science. These implications are discussed in terms of instructional strategies aimed at promoting a deeper understanding of physical science. In order to improve practice it is advocated that the role of problem tasks in learning science be made explicit while at the same time new types of instructional task need to be designed to achieve our goals for school science.

PREFACE

The work described in this thesis was carried out in the Department of Physics, University of Natal, from January 1993 to December 1999 under the supervision of Professor David Schuster (Supervisor) and Professor John Volmink (Co-supervisor).

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

Paul Hobden
December 1999

TABLE OF CONTENTS

CHAPTER 6 PROBLEM TASKS AND PROBLEM SOLVING

CHAPTER 7 WHY ARE THINGS AS THEY ARE?

CHAPTER 8 SUMMARY AND IMPLICATIONS FOR RESEARCH AND PRACTICE

APPENDICES

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

To Jack and Susan:
Two committed science teachers. Because of the need for privacy, I cannot cite your real names and those of your schools and students. You allowed me into your lives, gave generously of your time and opened yourselves and your teaching up to scrutiny. Without your co-operation, this study would not have been possible. To you my deepest appreciation.

To my supervisors:
Prof. David Schuster: Thank you for the time and advice that you gave in questioning my interpretations, focusing my ideas especially on the role of problem tasks in teaching physics and bringing clarity to my writing.
Prof. John Volmink: Thank you for your time, supportive comments and introducing me to the power of metaphors.

To special people:
Sally and our children Timothy, Frances and Christine: Thank you for the time, space and support you gave me during this study.
David Bateson: Thank you for helping me get started and your continued encouragement.
David Brookes: Thank you for your time and helpful advice that helped me bring this work to an end.

To Institutions:
Centre for Advancement of Science and Mathematics Education: For the sabbatical without which this study could not have started.
Foundation for Research Development: For having confidence in a new researcher and providing the financial support to start this study.

Dedication
This thesis is dedicated to Susan, Jack and their students.

Notes on stylistic conventions used in the text

This is an ethnographic research study. To gather data, the researcher established close and personal relationships with teachers and students. Steps have been taken to protect anonymity of those involved. Pseudonyms have been used throughout this study to protect the privacy of students and teachers. This involved changing some minor contextual information to protect identities. In all cases, it was judged that this information would have no influence on the interpretation of the data or findings of this study.

Transcription conventions

Dialogue: In transcripts, dialogue is shown as if the speakers alternate. In this sense, no overlapping is shown in spite of the fact that overlapping is common in classrooms.

Names: Students' names appear under pseudonyms. If students could not be identified then they were referred to as "Student" or "Students" in the case of multiple responses.

Symbols:
Square brackets [ ] enclose contextual comments and non-verbal information taken from fieldnotes
Brackets (??) with question marks indicate speech that is unresolved or unintelligible
Dots .... Indicate pauses in the speech. Where these are longer than a few seconds, the estimated time is enclosed in square brackets e.g. [5s]

Citation: The source of the transcript is provided, enclosed in brackets indicating the source, type of extract and date e.g. (Susan, lesson transcript, 02/05). Classroom transcripts were transcribed from audio tape with additional information extracted from fieldnotes. Unless otherwise indicated all quotes and transcripts are speakers' exact wording.

CHAPTER 1

INTRODUCTION

The purpose of this study is to extend our current knowledge about what happens in physical science classrooms. In particular, there is a focus on the role problem tasks and problem-solving play in this context. This introductory chapter provides some background to this study, a brief description of the nature of the problem, and the reasons for carrying out the study. In addition, a description of the research questions is given, together with a brief summary of the research methodology. Finally, the theoretical referents that guided my thinking are described.

1.1 BACKGROUND AND RATIONALE

In many years of experience with science teacher education, I have been struck by what seemed an over-emphasis by teachers on solving past examination questions. While the inservice courses I conducted provided many different activities from practical work to collaborative group work (Hobden, 1992), teachers' attention nevertheless kept returning to numerical problem tasks found in textbooks, worksheets and past examination papers. It was common to find a group of teachers, who had been assigned a practical task to work on, deep in discussion over a difficult question from a past examination paper. Moreover, when asked what teaching resources would be most useful, teachers would request booklets of past examination questions with model answers (e.g. CASME, 1990).

In response to this emphasis by teachers on problem tasks, I generated new instructional materials to promote conceptual understanding and at the same time to develop student problem-solving techniques (Hobden, 1992). The design of the materials was informed by findings emanating from research underpinned by the prevailing theoretical perspective to the understanding of problem-solving. This was the cognitive science perspective which assumes that the teaching and learning of problem solving could be improved by "understanding and modelling the information-processing nature of the human brain" (Lavoie, 1995a p.13). This perspective on problem-solving has been the basis for many studies in which students' performance was compared to that of expert problem-solvers, the so-called expert-novice research (Koballa, Crawley, & Shrigley, 1990; Mestre, 1991). Similarly, this perspective initiated studies focusing on the way students select and plan a solution strategy and the specific techniques or tools they use in their problem solving. Characteristics of this and similar research was that it concentrated on the individual, generally in a one-to-one relationship with the researcher. In addition it took place in laboratory settings or carefully controlled environments, rather than in naturally occurring classroom settings (Grouws, 1985).

However, in a review of science education research, Finley, Lawrenz and Heller, (1992) noted the apparent ineffectiveness of the instructional strategies that had been investigated in various studies dealing with problem solving. In addition, others (Brown, Collins, & Duguid, 1989; Lave, 1988; Nespor, 1990; Solomon, 1989) had also raised some concerns about the limitations of using only the cognitive based on general interpretive methods as described by Erickson (1986), Hewson (1995a) and Wolcott (1994).

1.3 THEORETICAL REFERENTS

I came to this study with a set of beliefs and assumptions (perspectives) about the nature of science education, teaching and learning, and problem solving. These perspectives developed through many years of teaching school science, working as a teacher educator, and developing materials. Theoretical perspectives developed by following the debates in the constructivist literature (Bodner, 1986; Cobern, 1993a; Driver, Asoko, Leach, Mortimer, & Scott, 1994; O'Loughlin, 1992; Tobin, 1993), through participation at an international seminar on learning in science (Driver, 1989) and at conferences.

According to Cobern (1993b) these fundamental beliefs and assumptions direct our actions and provide meanings for them. Similarly, Tobin, Tippens and Gallard (1994) speak of referents which “act as organisers of knowledge in the form of beliefs and images” (p.55). For example, in this study, social constructivism acted as a referent in the choice of the focus questions and in the interpretation of data. My personal referents filtered and organised what I chose to study, and how I perceived it. These referents played an important role in this study, and should be made explicit. Consequently, the referents which guided my thinking are given in the following sections.

1.3.1 Learning

Social constructivism, as a set of beliefs about knowing and knowledge (Tobin & Tippins, 1993), was used as a referent for understanding learning. The essence of the constructivist position is that all learning involves construction of meaning, irrespective of whether the information is discovered or received by direct transmission. It follows that knowledge or understanding cannot simply be transmitted directly from teacher to learner, but has to be actively built up by the learner. Accordingly, we cannot assume that one can simply transmit information to learners and expect that understanding will result (Confrey, 1990). Because learners must construct their own meaning, teachers cannot assume that all students have the same set of understandings, or that their ways of coming to an understanding are shared by their students.

From the social constructivist perspective, learning is regarded as “a meaning-making activity with emphasis on the collective generation of meaning by a community, as shaped by conventions of language and other social processes” (Schwandt, 1994 499, p. 127). Learning is characterised as a social activity in which learners are engaged in constructing meaning through discussions and negotiations among themselves and teachers (Edwards & Mercer, 1987). Consequently, in studying learning environments such as classrooms, the focus is not centred on cognition of individual students, so much as on the shared constructions of meaning by the participants in that setting. As the purpose of the research was understanding teaching and learning in classrooms, I believed that social constructivism would be a powerful lens that I could use to elucidate this.

1.3.2 Problems and problem solving

Problems are central to this study. Unfortunately, within both the research literature and the classroom, the label 'problem' can have multiple meanings making it an ambiguous term. For example, common terms used to describe problems in the literature include standard, drill, routine, complex, ill-structured and real. In this study, I have used the term "problem task". The task refers to a piece of work assigned by the teacher which is formulated with a situation and an associated question. The following example, taken from an examination paper (Department of Education and Culture 1992) illustrates what I refer to as a problem task:

$$2\,NO_2\,(g) \quad \rightarrow \quad N_2O_4\,(g)$$

> The equilibrium constant for the above reaction is 7,5 at 25°C. Two moles of NO_2 are placed in a 2 dm^3 tube and then sealed. The contents of the tube are then allowed to attain equilibrium at the same constant temperature. Calculate the concentration of the NO_2 at equilibrium.

In this example, the situation involves gas being placed in a tube and the question asks for the concentration to be calculated. It represents the type of problem tasks I encountered as a student and as a school physical science teacher. These problem tasks were well defined, narrow in focus, and invariably involved the calculation of some quantity through the use of a formula and algebraic manipulation. The conceptual difficulty of the task is not an inherent characteristic of the task. Depending on the student's familiarity with the tasks, they could be problematic or routine (Bodner, 1990). Such tasks are the focus of this study. Consequently, I will not be using the term problem task to refer to ill-structured or complex tasks. In my experience, they are not part of the South African school curriculum.

Given the wide-spread use of such problem tasks in the teaching of physical science, one asks whether this represents the assumption that some of the goals of science education can be achieved through such problem tasks. There are many perspectives from which this practice of giving students problem tasks to solve can be understood. A common perspective, identified by Gabel (1989), is that of viewing problem solving as a means to promote student understanding of science. From my perspective, it is a teaching strategy that has the potential to help students to appreciate and understand scientific knowledge. It is one way of making sense of this knowledge through manipulating ideas, principles and laws. It can reveal the power of fundamental scientific processes to explain phenomena and make predictions in terms of applying basic underlying principles.

However, this potential is dependent on the problem formulation and problem-solving approach used in the classroom. The situations provided can be interesting if related to student's life experience or they can be stripped of the detail that makes links difficult to see, but revealing the essence of the phenomena under study. Also the questions can encourage a direct route to an answer or a broader approach in which the principles associated with a situation are more fully investigated.

Solving of problem tasks can be taught in different ways. In a principled approach the focus of the instruction is on making sense of the problem situation using the appropriate principles (Wildy & Wallace, 1995 507). A range of situations is investigated to show that they have similar features, which can be understood using the same broad basic principles. On the other hand, in a purely procedural approach, the focus is on obtaining the answer to the question. The solving is reduced to a set of operations or procedures, which can bypass the underlying principles. After practice on similar tasks, the problem solving becomes familiar and routine.

The social and physical circumstances in which the cognitive actions of problem solving are situated, play an important role in interpreting these actions. From this perspective of situated cognition (Brown et al., 1989; Lave, 1988), problem solving is not simply a process internal to an individual mind but one also grounded in context and social practice. What is learned is inseparable from how it is learned and used (Hennessey, 1993). Therefore, understanding the context of the school classroom is central to understanding school problem solving. I see "doing problems" as a task that has a particular meaning within a classroom community (Lemke, 1990). If we hope to understand the role of problem tasks, it will be necessary to uncover the meanings participants attach to them.

1.3.3 Science education curriculum

There are many different perspectives that can be used to view the school science curriculum. For example, Shulman (1986), when referring to the realities of classrooms, implies that two curricula exist; the manifest curriculum involving the academic task, and the hidden curriculum involving the organisational and management aspects of classroom life (p.8). However, I have found it useful to describe the school science curriculum from three perspectives.

- Firstly, the published curriculum, which gives the perspective of the curriculum planners and is represented in the official curriculum and syllabus documents.
- Secondly, the implemented curriculum which is represented by the teachers' description of actual activities carried out and events that take place both inside and outside the classroom such as the external examinations.
- Thirdly, the experienced curriculum that represents the students' perspective on their school science experiences.

Consequently, when attempting to understand school science curriculum, we must be sensitive to which perspective is being described.

It is also recognised that the science curriculum does not begin and end in the classroom. It is embedded in a multiplicity of cultures such as the culture of the discipline. The culture of science involves making sense of the world through construction of meanings. The concepts of science are constructs that have been developed and imposed on phenomena in attempts to interpret and explain them (Driver et al., 1994 476). It has a set of norms and conventions for evidence and for what counts as a valid source of knowledge. However, it is recognised that science is only one of several ways of understanding the world and cannot claim privilege as the best or right way. In addition, many of the elements of methods of science e.g. careful observation and reasoning, are characteristics of logical thought in general (Doran, Helgeson, & Kumar, 1995 p.133). Learning science enables citizens to interpret their world in terms of science (Tobin et al., 1994). It involves being initiated into the ideas, norms and practices of the scientific community and entering into a different way of thinking about and explaining the natural world (Cobb, 1995). According to Lemke (1993a) it is these norms and practices that students need to learn about, and connect with what they do in classrooms.

In their efforts to implement the published curriculum, teachers are subject to many forces in their decision-making (Tobin, 1987). These constraining forces are found in and out of the classroom and educational system. It is also evident from the literature that what teachers do will be influenced by what they believe. Their beliefs about their students, the subject matter they teach, and their roles as teachers, are important influences on the ways in which they implement the curriculum. For example, the emphasis they place on particular classroom practices is determined by their perceptions of science and learning (Eisenhart & Borko, 1993). Therefore, we can infer that both the forces constraining teachers and their beliefs shape the implemented science curriculum. Accordingly, disclosing and understanding these beliefs and constraining forces, is an important part of this study.

1.4 STRUCTURE OF DISSERTATION

The dissertation divides naturally into three related sections. The first section includes the background to the study and the conceptual framework. The framework has three components. These are: the theoretical referents described in this introductory chapter; the locating of the study in the literature of problem solving in the classroom in Chapter Two; and a detailed description of the interpretive research approach in Chapter Three.

Section two has as its focus the description of Jack and Susan's classrooms which were the sites at which the majority of the data for the study was collected. Detailed descriptions of the learning environment, the activities and the participants' perspectives on the teaching and learning of physical science are given in Chapters Four and Five.

The final section presents the main analysis and interpretation of the data. This is done by making a number of assertions, which are the answers to the research questions. Assertions, which characterise the use of problem tasks, are made in Chapter Six. Assertions with a focusing on reasons why teaching and learning are organised in the way they are. Follow in Chapter Seven. Finally, the main findings of the study are summarised and the implications for action are discussed in Chapter Eight.

CHAPTER 2

PROBLEM TASKS: A CONTEXTUALISING FRAMEWORK

2.1 INTRODUCTION

The main focus of this chapter is to explore the academic task of problem solving within secondary school physical science. However, it is not my purpose to provide an encyclopaedic review of all the studies on problem solving in science. A number of reviews have recently been carried out which provide a detailed picture of the field of problem-solving research in science education. One of the most extensive appeared in a recent handbook (Gabel, 1994) which devoted nine chapters to problem solving in various disciplines. Of relevance to this study are chapters focusing on chemistry education by Gabel and Bunce (1994) and physics education by Maloney (1994). Earlier reviews of problem solving include those by Frederiksen, (1984), Garret (1986), and Champagne and Klopfer (1977).

These reviews show that the field is extensive. Each review has taken a different perspective, selecting particular aspects of problem solving and analysing the field accordingly. For example Maloney (1994) concentrates on individual problem solving with the associated knowledge structures and student study procedures, followed by methods to improve problem-solving skills. On the other hand, Garret (1986) analyses research studies according to investigative methods, purposes of investigation, problem tasks and subject variables.

I have approached the task of locating my study within the literature by analysing it from the perspective of an educator in a country with strong central control of syllabi coupled with a high-stakes examination system. I was guided in analysing the literature by the following questions, arising from my research focus: In what contexts do teachers use problem tasks? Why do they use them as a teaching strategy? What curricular goals do they feel they are achieving? How effective is the use of problem tasks as an instructional strategy?

I have represented my analysis through a detailed concept map in Appendix A. The map provides a background framework against which particular topics in problem solving are highlighted. The map represents the four main areas into which I see the field being divided, mainly the problem solving process, the types of problem encountered, the contexts in which they are used, and the role of problem tasks in instruction. These main areas of the map are represented in Figure 2.1. below.

By far the largest amount of research has been devoted to the problem-solving process itself. This is evidenced by the many studies on attempts to improve students' problem-solving skills. These studies fall into two main categories: those that focus on the problem-solving strategies and those that focus on factors that affect the process. The map shows firstly, that there are studies dealing with the different strategies used by experts and novices, as well as work on developing particular strategies through apprenticeship. Other work has concentrated on identifying the many factors that influence problem solving, such as language, schema development and prior knowledge.

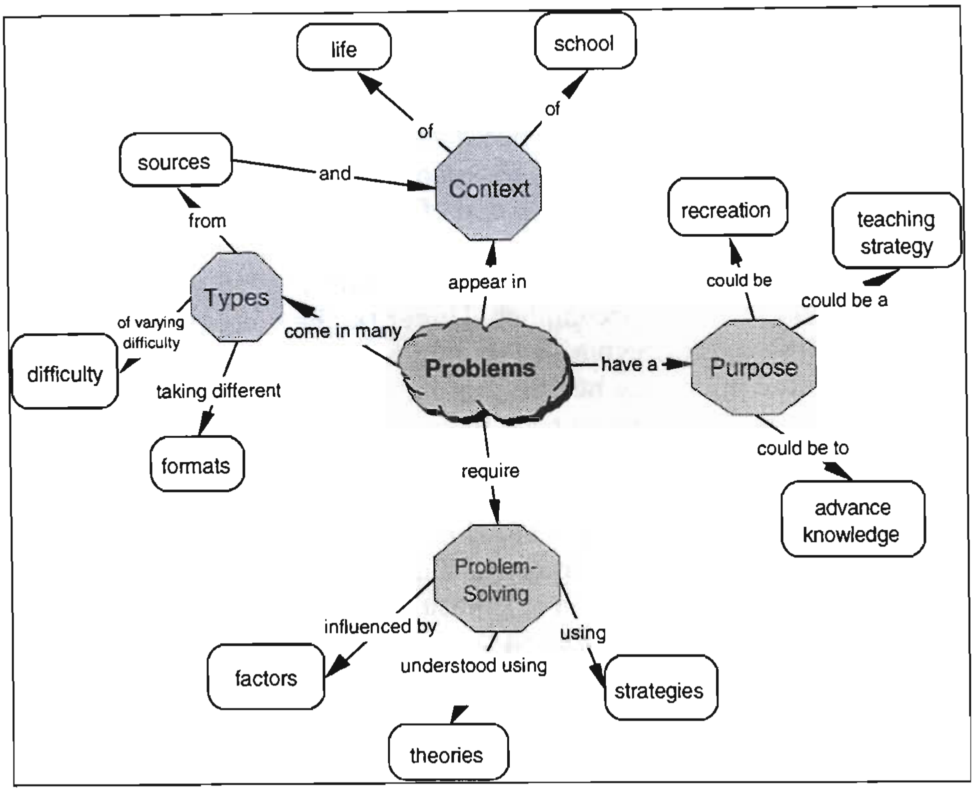


Figure 2-1 **Map of the main areas into which problem solving research is divided.**

The second focus is on the types of problem tasks which learners are asked to solve. Here, one emphasis has been on the labelling of problem tasks according to the perceived conceptual demand. Another has been examining the response required such as gathering experimental data or mathematical manipulation. A third focus is the context within which problem tasks are used. This is an area that has not received much attention although it has gained in importance over the last ten years. Recently, more research attention has been given to the solving of authentic or real-life problem tasks.

The fourth focus concerns the role and purpose of using problem tasks in instruction. It is my contention that work in this area is not as strong as in the other areas especially with reference to the use of routine problem tasks. Garret (1986) reported only three studies concerned with the enhancement of learning through the use of problem solving. While recent work reported in Lavoie (1995b) shows more studies in this area, they concern a much broader interpretation of problem solving, including investigative and open-ended problem tasks which are not currently found in South African schools.

2.2 THE CONTEXT WITHIN WHICH PROBLEM TASKS ARE USED

2.2.1 Local context

In order to understand the role of problem tasks, they have to be situated in their local context. As a first step the published curriculum (Erickson & Shultz, 1992 p.469) should provide some description of where problem tasks are intended to be encountered in the teaching and learning situation. In South Africa, the physical science curriculum for standard nine and ten (grades eleven and twelve) is described in an official education department document circulated to all schools and referred to as the syllabus. This document (Appendix B1) outlines the main aims of the school course and the requirements for the senior certificate examination which takes place at the end of standard ten.

It also provides details for each physical science topic, setting out what teachers and learners are expected to accomplish. Under the heading of content, a list of the main concepts, laws and principles associated with the topic are given. Then the objectives are stated under the headings of knowledge, understanding and higher abilities. A guide to the amount of time to be allocated to teaching is also provided. An extract from the local departmental syllabus which was in use at the time of the study, is provided for the topic of "Bodies in motion" (Appendix B2). Teachers are given considerable detail as to what should be taught and what skills should be developed. This includes the requirement under the heading "Understanding" that students should be able to "perform calculations using the equations above". (This refers to the thirteen formulae listed in the previous section.) Consequently, the solving of problem tasks is an explicit part of the published curriculum.

2.2.2 Description of the Classroom Tasks

There is evidence from the literature and personal teaching experiences that science classroom practices are very similar in senior secondary schools in many parts of the world. Similarly, the classroom routine within which students encounter problem tasks is fairly standard (see for e.g. Contreras, 1993; Gallagher, 1989). The following could be a typical sequence of events in a senior secondary physical science classroom. The teacher provides a context or 'scene setting' for what is to follow, normally a description of a phenomenon or a scientific principle. The problem task is then introduced. It is topic specific and the problem situation has been stripped of detail. The question requires the calculation of a physical quantity. The teacher introduces the associated formula and with limited student participation, illustrates the solution technique. The students are then assigned a number of similar problem tasks from worksheets or textbooks for practice. Some of these are worked in class and others are assigned for homework. When the tasks have been completed, some, if not all, are 'gone over' in class, or at least the answers are provided. The teacher acts as both expert and judge, by displaying expert use of the solution strategy and by pronouncing on what is acceptable and what is not. Students study for tests by examining the worked examples, working harder examples or practising on new problem tasks. A test is then given where students have to show they have mastered this particular problem type. Later, the solutions to the test problems are provided or demonstrated by the teacher.

2.
pproach

The implicit purpose of the sequence is for students to be able to solve different types of problem tasks (Hammer, 1989) as opposed to developing conceptual understanding. The students will be constantly motivated to participate in this classroom sequence by the teacher referring to tests and examinations (Tobin et al., 1994). They are led to believe that success at solving problem tasks will indicate competence in school science. The basic pedagogical assumption underlying this series of activities would appear to be that, having worked these sets of problem tasks, the students will have a new technique (e.g., the technique of solving 'rates of chemical reaction' problem tasks) to add to the other solution techniques already mastered. The solution strategies are demonstrated and then practised under the assumption that learners absorb them in this way. Looking at the process, it can be seen to be the development and practice of procedures or algorithms for solving particular types of routine problem task. In some unspecified way, this represents an addition to students' physical science knowledge and understanding. From the teacher's point of view, the sequence is normal instructional practice and appears effective in that students pass the examinations. Teachers have met their responsibilities to the students, school and society.

2.2.3 Didactical Contract

What are the participants' expectations, and why are things as they are in the classroom? The following analysis, borrowing from the work of Balacheff (1984), attempts to understand the relationship between participants and problem tasks from a particular perspective. It is an attempt to situate the problem tasks in classroom life and to understand the meaning attached to problem tasks.

Teachers use problem tasks to serve different functions e.g. for evaluation of learning. For each different function, a different social interaction is required. The interaction is governed by a "didactical contract", a set of rules often unspoken, but understood by those in the community of classroom life. These classroom norms or conventions which constitute the didactical contract, include the expectations of how the teacher will teach, how students are expected to work together, acceptable ways of talking and questioning, how teachers are expected to help those with learning difficulties etc. This contract determines the role of the teacher and students and sets the tone of the teaching-learning relationship.

Students will encounter problem tasks in the classroom in a situation organised by the teacher. They will learn what they are assigned to learn by the teacher (Noddings, 1988). For example, when confronted with a number of similar problem tasks to solve, the task will have meaning if the student knows that similar problem tasks are to appear on the test. Consequently, the drill of solving similar problem tasks becomes meaningful. Alternatively, if the teacher indicates that a problem is a difficult problem, the student has an expectation that makes him respond in a different way (Maloney, 1994). The didactical contract determines the place of the problem task in the teaching-learning situation. Depending on whether the task is for homework, or classwork, a test or examination, the student will respond in different ways. The meaning of the task is not fixed by the problem text itself.

One of the consequences of the contract is that students, for most of the time, are making sense of the classroom situation rather than the science. They give solutions acceptable to the context or implicit didactical contract. They are not necessarily making sense of the problem tasks, constructing knowledge for themselves or developing conceptual understanding. The students, according to Balacheff (1984), act in a practical way that make sense to them.

Because students are different and have different experiences, what on the surface appears to be the 'same' classroom task may be very different experientially for different students. Different students within the same class might approach a problem task from different perspectives, applying different effort and ascribing differing importance to the task, based on their understanding of the didactical contract. This highlights the importance of understanding the didactical contract from the learners' perspective, something that has not received the attention it deserves and certainly has not been done in South African classrooms.

2.3 WHY ARE PROBLEM TASKS USED IN TEACHING?

2.3.1 Different purposes

What are the different purposes for which teachers use problem tasks in their practices? What are the underlying beliefs of teachers as to the value of engaging students in problem-solving activities? There are a number of different approaches to understanding teachers' purposes. I have based my analysis on that provided by Stannic and Kilpatrick (1988) who characterise the role of problem solving in mathematics in terms of three themes i.e. as context, as skill and as art. Drawing on this and other literature, modified by personal observations and experiences, I suggest that one would find that teachers have one or more of the following beliefs or assumptions underlying their use of problem tasks as a teaching strategy:

(a.) *Learning science at school is about solving problems.* Looking back at past classroom activities, teachers see that doing science at school or college has always involved solving problem tasks. Therefore, teachers believe that it is their duty to teach students how to solve these problem tasks.

(b.) *Students will need to know how to solve basic problem tasks as preparation for further study.* Many tertiary courses of study in science assume that students can solve these problem tasks and build on that base. They make success at school physical science one of the requirements for entry to their degree programmes. Teachers see the use of problem tasks as a necessary preparation for later studies in science.

(c.) *Problems are a means to developing an understanding of the subject matter.* Solving problem tasks is seen as a vehicle through which a new concept or skill might be learned (Stanic & Kilpatrick, 1988). Teachers believe that they can introduce students to new subject matter and develop conceptual understanding through a sequence of problem tasks. Osborne (1990) comments that it appears as if nearly all physical science education, and especially the physics component, is based on this assumption.

(d.) *Solving problem tasks gives an indication of understanding.* Teachers believe that if you understand the concepts and principles, you can work the problem tasks. (This is even implied in the syllabus extract given previously.) Although learning to solve particular types of problem tasks is not a stated goal in the syllabi, success at solving particular types of problem tasks is taken to be the primary indicator of understanding (Dufresne, Leonard, & Gerace, 1992).

(e.) *Practice at solving problem tasks prepares students for examinations and other forms of assessment.* Teachers are under pressure to prioritise preparation for examinations so they provide practice in the problem tasks they expect to appear in the examinations.

(f.) *Problem tasks must be assigned for practice to develop general problem-solving skills.* Problem solving is seen as one of a number of skills to be taught in the school curriculum. Therefore, problem tasks must be assigned so that the skills can be mastered through imitation and practice (Schoenfeld, 1988).

In most of the themes identified, problem tasks are employed as vehicles in the service of other curricular goals. They are used as a means to one or more ends. They are not a goal in themselves, or seen as a valuable curriculum end. This has important implications. If the use of problem tasks does not achieve teachers' goals, they could discard these tasks or transform them to meet their goals. The question arises as to whether teachers are reflecting on their use of problem tasks or whether they are using them uncritically as an instructional strategy as suggested earlier.

2.3.2 Conception of teaching science

Examining physical science textbooks from early in this century will show that sets of problem tasks have long occupied a central place in the school science curriculum. The reasons for basing instruction on the use of problem tasks are not clear. However, we do know that teacher beliefs about teaching and learning would have some influence on this decision. In an effort to understand these beliefs, many different metaphors have been used to gain insight into, and promote reflection on, teachers' conceptions of their task (see for example Fox, 1983; Sfard, 1998).

One analysis, suggested by Erickson and Schultz (1992) provides an interesting way of linking teacher beliefs to their use of problem tasks. They suggest that teachers have a conception of curriculum and pedagogy as a meal. To explain this conception held by teachers, they use the metaphor of a school lunch where the food (curriculum) is divided into daily portions for students (the lesson content), thawed in a microwave (instruction) and often chopped into smaller bits to aid digestion (lowering the difficulty). The route to learning science consists of delineating the desired subject matter content as clearly as possible, carving it into bite sized pieces (diSessa, 1988), and providing explicit instructions and practice on each of those pieces so that students master them (Schoenfeld, 1992). Routine problem tasks fit conveniently into this conception of curriculum and pedagogy. They are "bite" sized, can be presented and "digested" in a 35 minute class period and are easily assessed. If the student does not understand, further practice seems a very reasonable teaching strategy. Teachers obtain their beliefs about the role of problem tasks from working within this system and appear content with current practice. It is no wonder that practices have not changed, as there does not seem to be a reason for change.

2.3.3 Assessment.

According to Tobin and Gallagher, there are external influences that force teachers to teach in particular ways (1987). Despite the best intentions of teachers, they are often constrained by external factors in the activities they plan for students. As found by Dewalt and Pelto (as cited in Gallard Martinez, 1990), when teachers choose their practices within their classrooms, they are influenced by the social and cultural milieu in which they work This can explain the mismatch between curricular goals and actual practice (Garrett, 1986). One of the more obvious external influences on practice is the assessment system. The question arises as to what roles assessment practices play in shaping the implemented curriculum and indirectly determining the problem tasks used by teachers.

There is a considerable literature on the influence of examinations and testing on teaching and learning in general. I mention only two to illustrate the diverse opinions. Madaus (1988) provides a review with a focus on what he considers to be the detrimental aspects, such as teachers teaching to the test. Ebel (1976) on the other hand provides a convincing argument to support the idea that assessment is an essential tool of effective teaching and learning. Using either analysis, it is obvious that assessment practices within a school system will be a major factor in determining the implemented curriculum.

South African high schools, have a long history of working in a centralised high-stakes examinations system. In their last weeks at school, all Standard ten (Grade twelve) students write the senior certificate examination. This is an external examination organised by the Department of Education and commonly referred to as the "matric" examination. In physical science, the students write two examination papers of two hours each. The first paper is on Physics topics and the second on Chemistry topics. There is considerable public interest in the matric results, which are published in the local newspapers.

The matric examination serves a dual role, as a gatekeeper for the entry of students into Universities and other tertiary education institutions, and acting as the exit point for schooling (Jansen, 1995). The examination is competitive, in that it ranks students by performance, and allows the more successful students to proceed to tertiary study. It is the point at which students' success or failure in the educational processes they have experienced is revealed (Fensham, 1995). It is here that they are, for all intents and purposes, labelled as having succeeded or failed at school.

It is surprising that there has been little research in South Africa into the affect of matric examinations on the school curriculum. Most studies are limited to reports of the number of passes and failures within different educational departments, and trends over time. These statistics of examination results are unable to reveal the kinds and qualities of experience students had in their classrooms. It seems possible for this matric examination to subvert the published curriculum, in that what we test and how we test is the one way in which a de-facto curriculum is defined (Schuster, 1993). For example, teachers could sacrifice learning with understanding for the immediate goals of drilling the students in problem tasks if similar tasks appear in the examinations. There is evidence that similar practice occurs wherever centralised examinations are given significant importance (Contreras, 1993; Deacon, 1989; Helgeson, 1993).

2.3.4 Teacher knowledge

There has been extensive discussion in the literature of the status of our understanding of various aspects of teacher knowledge (see for e.g. Fenstermacher, 1993). Common sense and conventional wisdom would seem to imply that the better the qualification in a discipline (i.e. the more subject-matter knowledge studied), the better the teacher. However, this relationship remains a contested issue (Kennedy, 1998). There are conflicting opinions about the amount and quality of discipline specific knowledge required.

The discussion has not been helpful in identifying what happens when teachers only have a minimum basic knowledge of their discipline. However, we do know that teachers' knowledge of subject-matter interacts with their beliefs about teaching to shape the ways in which they teach (Ball, 1988). Consequently, the quantity and quality of the teachers' subject-matter knowledge must influence the manner in which they teach science. In South Africa, more than 50% of physical science teachers do not have the pre-requisite academic qualifications to teach science at the grade level they are teaching (Foundation for Research Development, 1993). In many cases, the teachers are not even qualified to teach science at all having done their initial training in other disciplines. They would find qualitative explanations and discussions of science phenomena difficult, if not impossible. During discussions, learners might raise many open-ended questions for which the under-qualified teacher has neither the answer nor the ability to guide the discussion. For these teachers, the option of maintaining control of the subject-matter presentation is attractive. This can be achieved by using problem situations which can be converted to mathematical representations and solved by use of algorithms which they have practised themselves. Instead of uncertainty generated by having to respond to non-routine matters, the situation becomes one of dealing with manipulating formulae for tasks that are "closed" in the sense that the algorithm to obtain the answer is available and the answer is available in the text book or teachers' guide. In this sense, what we teach, is limited by that which we can teach (Osborne, 1990). Consequently, the use of sets of problem tasks as an instructional tool makes a great deal of sense to such teachers.

2.4 PROBLEM TASKS

2.4.1 The Categorisation of Problem Tasks

Another aspect that has not gained the attention it deserves, is the type of problem around which instruction is planned. As noted earlier, many of the problem tasks used for this purpose are similar to those published in texts 50 years previously, and their status and suitability for instructional purposes needs to be examined. My purpose in analysing and categorising problem tasks is to draw attention to their varied roles in teaching. In the research literature, many different systems for categorising problem tasks are suggested, based on the different criteria and the context of the particular research studies. For example in studies involving students' ability to solve problems (for example Donald, 1993), the problem tasks might be categorised according to level of difficulty or the number of steps in the solution path. Where the focus is on information processing (for example Johnstone, 1984) the demands of the problem task on the short-term memory are used to categorise problem tasks.

For the purposes of this study, I have categorised problem tasks using two perspectives, conceptual difficulty and instructional purpose. Firstly, I have used a set of three categories to categorise problem tasks based on their perceived conceptual difficulty. These categories are similar to those proposed by Johsua and Dupin (1991) and Fredericksen (1984). This scheme was chosen as it appears to include other classification schemes and fits our local context. The problem type categories are as follows:

Type 1: Routine problem task: The problem task is well defined, narrow in focus and is normally solved through the use of an algorithm or procedure. It invariably involves the calculation of some quantity through the use of a formula and algebraic manipulation of a number of variables. It normally appears in instruction as one of a set of similar problem tasks. A solution procedure or algorithm for this type of problem would be provided by the instructor and practised. This type of task would be equivalent to what Garret (1986) calls a puzzle, Johsua and Dupin

(1991) call a standard exercise, or Fredericksen (1984) calls the well-structured problem. Problem tasks of this type are in common use in South African classrooms.

Type 2: Maverick problem task: The problem task is similar to those above, but requires the learner to do more than just recognise or recall the path from previous attempts or similar problem tasks. It requires some interpretation of the context and the problem solver must construct all or part of the solution procedure. Similar to routine problem tasks, the solver knows when they have reached the end of the task i.e. there is a clearly defined answer. Fredericksen (1984 p.367) refers to these problem tasks as “structured problems requiring productive thinking”. Those problem tasks called “implicitly difficult exercises” by Johsua and Dupin (1991) would be placed in this category. The task initially appears to be the same as standard exercises but proves to be unexpectedly difficult.

Type 3: Complex problem task: In these problem tasks, the complete problem situation is not provided in the statement of the problem. The solver has to add information or make assumptions about the problem situation. Often there are levels of uncertainty about the actual goal and it is not certain when or if the goal has been reached. Alternatively, it is a completely new situation to the solver to whom the solution path is not known or readily available. This category is similar to that proposed by Simon (as cited in Frederiksen, 1984). He calls these problem tasks “ ill-structured” because they lack a clear formulation, a procedure that will guarantee a solution and criteria for determining when a solution has been reached. The category “innovative exercises” suggested by Johsua and Dupin (1991) would fit here. Personal experience indicates that these problem tasks are not found in South African school science classrooms.

A sharp division between the categories is not suggested, nor is it suggested that all problem tasks will fit neatly into one or other of the categories. Some problem tasks might have elements of more than one of the above categories. Similarly, when determining the conceptual demand of a problem task, a common theme that runs through most studies is the acceptance that the local context makes a difference. The demands of the task cannot be determined by analysing the problem task alone. Problem tasks cannot be labelled easy or difficult, independent of context. Depending on students’ familiarity with the task, it could be either of high conceptual demand or a routine exercise. Consequently, to understand school problem-solving, whatever the system of categorisation or labelling, the problem tasks must be considered in the context of participants' previous experience and their understanding of the didactical contract.

My second way of categorising problem tasks is from an instructional perspective. This is derived from teachers' underlying beliefs of the role of problem tasks in the teaching-learning process and is linked to the list of purposes presented earlier. Problem tasks used for instructional purposes can be divided into a number of categories as follows:

(a.) Tasks considered as preparation for further discipline specific problem-solving tasks and study;

(b.) Tasks related to real world applications whose usefulness is immediate;

(c.) Tasks designed to develop understanding of science concepts;

(d.) Tasks which serve a sorting function or set standards, and differentiate between students in tests;

(e.) Tasks that have always been assigned and whose place in the curriculum is assumed without question;
(f.) Tasks provided to develop general problem-solving skills or as an intellectual challenge;
(g.) Tasks which have to be practised as they will appear in the high stakes examinations.

This form of categorisation, focusing on the instructional role of the problem tasks, provides a different perspective for this study where the role of problem tasks is a focus of the research questions. It complements the previous categorisation which focuses on the problem formulation and the conceptual difficulty.

2.4.2 Students' Expectations of Problem tasks

An alternative way of understanding the role of routine problem tasks could be to look at them from the students' perspective. In our effort to make problem tasks accessible to students, problem tasks presented to students have generally been simplified. This has involved reducing the amount of text, removing real-world complexity and simplifying the mathematics. This makes it easier for the student to focus on the essence of the problem task but could result in subverting the original purpose of the problem task. On the other hand, when efforts are made to create realistic problem settings and make the problem tasks more meaningful and related to students' lives, the students ignore the cover story as irrelevant (Schoenfeld, 1992). This occurs because, after extended practice with similar sets of problem tasks, students see that the cover story as just "window dressing" designed to make the problem tasks appear relevant but which in fact has no real role in the solution process for which they are rewarded.

Because of these and other classroom experiences, students have a number of expectations of the problem tasks they will be required to solve.
(a.) *Students expect tasks to be familiar.* Students' understanding of what a problem task entails is merely recognition that it is similar (isomorphic) or identical to a previously encountered problem task, and that the solution can be obtained if they apply the appropriate procedure (Schoenfeld, 1988).
(b.) *Students expect problem tasks to be well defined.* In most routine problems, the task is to determine a specific value for one quantity. Students expect that this will be explicitly asked for in the problem. The problem text will contain all the information required to solve the problem and will not contain extraneous information. All necessary quantities will have values provided.
(c.) *Students expect problem tasks to be specific to a topic.* They are taught to solve problem tasks within the context of a topic (e.g., momentum) and will use the context as a cue to which solution technique to use (Reif, 1981).
(d.) *Students expect problem tasks to be solvable within a relatively short time.* Students' experiences of watching the teacher solve problem tasks, and what is expected of them in the short time available in tests, tells them that solutions should be found relatively quickly.
(e.) *Students expect problem tasks to have one correct solution method.* While they accept that other solution paths will be given credit, they suspect that there is one path in the marking memorandum that is accepted as the 'most correct' path. Consequently, there is a tendency to search for this path as opposed to solving the problem in ways that make sense to them.

(f.) *Students expect problem tasks to have answers that are 'nice numbers'.* Students often consider whether the numerical values they are calculating come out to be nice numbers (e.g., 4.0 as opposed to 3.67) as a clue as to whether they are using the correct strategy or not (Reusser, 1988).

These expectations emphasise the narrow scope of the problem tasks encountered in courses as well as some of the unintended strategies students learn from doing such tasks. Students' perceptions of the role of problem tasks and their expectations about the nature of the problem tasks, play an important part in the didactical contract.

2.5 HOW EFFECTIVE ARE PROBLEM TASKS AS AN INSTRUCTIONAL TOOL?

2.5.1 Evidence of learning

An argument for using problem tasks would be that they aid development of conceptual understanding. Given that students spend time engaged in problem solving, we need to ask questions about its contribution to the development of understanding. This use of problem solving as an instructional strategy possibly reflects teachers' tacit belief that solving problem tasks is an effective way to learn physical science. However, there are relatively few studies of problem solving as an instructional strategy in the learning of physical science, to support their belief (Garrett, 1986).

What we do know is that if teachers' primary goal is merely for students to be familiar with a given body of knowledge and to apply that knowledge reliably to solve some classes of problem tasks, then the strategy of encouraging students to follow and practise teacher-provided procedures will probably succeed. The teachers need only provide the laws and procedures and students will become familiar with them through practice in solving sets of similar problem tasks (Hammer, 1989). What is not clear at first glance is the consequence of this practice.

Studies of high school classrooms (Tobin & Gallagher, 1987) assert that classroom instructional practice focused on algorithms and procedures reduces the cognitive demand of the work. This is supported by other studies such as Maloney and Siegler (1993). If students can obtain the right answers using procedures cued by recognisable features, they have the option of not seeking understanding at all but rather operating at a lower cognitive level and simply following the procedures whether they understand the underlying principles or not.

In addition, despite the instructional practice of providing sets of similar problem tasks for practice, many students fail to correctly solve problem tasks that are slightly different. Many of the students, while able to produce solutions to routine examples, will not necessarily have an understanding of the strategies, algorithms, or the science involved. The instructional process results in students memorising solution procedures which are recalled by recognition of example type or by surface features (Webb, 1984). They will solve familiar well-specified problem tasks but have acquired only a superficial proficiency. Strategies such as "when you see these features in a problem, use this solution procedure" allow students to produce manifestations of seemingly competent behaviour. However, unless grounded in an understanding of the principles underlying the procedure, the skills are limited, fragile, error-prone and easily forgotten. This becomes obvious when a minor deviation from a routine problem task confuses a student. The student is unable to recall the solving procedure or adapt it (Johsua & Dupin, 1991). Students are not learning physical science concepts and principles but rather algorithmic procedures.

2.5.2 Construction of a Knowledge Base

Solving problems of a non-routine type is a complex and involved process that requires a significant, well-organised knowledge base. Studies have shown that successful problem solvers or so-called experts, have much more knowledge in a specific domain which they can bring to bear on the problem task than do neophytes (Chi, Glaser, & Rees, 1981b; Frederiksen, 1984). This would be an expected conclusion. However, more significantly, it was also found that they had a well-developed structure for their knowledge. Beyond knowing the basic facts, concepts and principles, they also had constructed connections between them. The knowledge base was organised and interrelated to facilitate retrieval when solving problems.

There is now convincing evidence (Clement, 1981; Heller & Hollabaugh, 1992; Sawrey, 1990) that conventional problem-solving activity is an inappropriate vehicle for developing a well-organised knowledge base. Some take an even stronger line and argue that instruction based on solving-problem tasks can be counterproductive for learning (Sweller, 1989). The evidence indicates that traditional practices result in many students having unconnected and fragmented understanding of the subject matter despite gaining proficiency at certain kinds of procedures (diSessa, 1988; Pickering, 1990).

2.5.3 Development of General Problem-solving Skills

Another belief that promotes the use of routine problem tasks in teaching is that students thereby gain skills which result in them becoming competent scientific problem solvers (i.e. of complex or non-routine problems). However, there is little evidence to support this belief. Experience and research tells us that students have great difficulty transferring skills to new contexts (Lemke, 1993b). Even where teachers aim to use problem tasks to promote more general problem-solving skills, a number of factors mitigate against these general skills being developed. These are:

(a.) Knowledge and skills that are usable in many circumstances are required, but problem tasks tend to be context dependent, resulting in skills only accessible when clearly marked by context (Campione, Brown, & Connell, 1988);

(b.) The ability to construct solution paths is essential, but students are provided with sets of procedures, leading to a state of 'learned helplessness' when asked to attack new problems (Noddings, 1988);

(c.) Real-world scientific problems do not always have clear-cut answers and are not always solvable in a short time through standard procedures, but students' classroom experience is to the contrary (Webb, 1984);

(d.) The ability to identify ambiguity and redundancy can be important for real-world scientific problems, but students get almost no experience solving ill-defined problems (Reusser, 1988).

2.6 CONCLUDING REMARK

The focus of this chapter has been on providing a framework of problem-solving research within which the study can be conceptualised. Firstly, I have provided a larger framework of the field of problem solving. This provides an overview and context for the study. Secondly, I have narrowed the focus to the specific areas of context and purpose. The approach to the literature provides a different perspective on problem solving to that normally taken but is well suited to the purposes of this study. The studies suggest that the didactical contract is the core to understanding what is going on and the meaning participants attach to solving problem tasks. The present work thus involves an examination of the context in which problem tasks are used, the participants' perspectives, the nature of the actual problem tasks used and the external factors that affect the contract.

CHAPTER 3

RESEARCH ACTIVITIES

This case study utilised an interpretive research design involving ethnographic data collection techniques and qualitative procedures of data analysis. In this chapter, I indicate why this design was suited to answering the research questions, followed by a description of the tools used to obtain data and the data collection procedures. In addition, the steps followed in the analysis and the phases through which the study progressed are outlined. This is done in some detail to provide the connections between my questions, the methods of data collection and the analysis.

The purpose of this inquiry, as previously stated in Chapter One, was to extend our knowledge about what happens in physical science classrooms. In particular, it focused on what the participants did, what activities they were involved in, the structure of these activities, and the role problem tasks played in this context. It was a central concern to uncover the meanings the participants gave to their actions. An interpretive method (Erickson, 1986; Gallagher, 1991a), starting with a detailed descriptive foundation obtained through classroom observation was chosen as the most suitable strategy for describing and understanding what was going on.

3.1 FIT OF RESEARCH DESIGN TO INQUIRY QUESTIONS

Interpretive research is the name given to a family of approaches that includes ethnographic, qualitative, participant observer, and case study research. It is an approach that views the classroom more from an anthropological perspective in which the classroom culture and social organisation are important than from a psychological perspective which focuses on the individual. However, it is also a scientific approach as it involves rigorous and systematic empirical enquiry that is data-based (Bogdan & Biklen, 1992 p.43).

As science educators have become increasingly interested in investigating what actually happens in classrooms there has been a growing acceptance among researchers that interpretive approaches are well suited to this. These approaches are suitable in helping answer questions dealing with classroom contexts and the differing intentions that may lie behind the observable behaviour of teachers and students. According to Gallagher (1991a) “Science educators who engage in interpretive research are in the business of making sense of, and giving meaning to, the ways in which science teachers and students make sense of, and give meaning to, their work in teaching and learning science” (p.7).

Many of the characteristics of interpretive research are different to those of much traditional research in science education, which has usually followed a hypothetico-deductive paradigm. This traditional research has involved intervention experiments, or the administration of predetermined questionnaires, or the filling in of observation schedules. These activities use research instruments based on existing models or theories and the researcher is trying to obtain evidence for an existing hypothesis. By contrast, a fundamental characteristic of interpretive research is that it develops theoretical positions based on the data. In this study, I wanted to find out how teachers see their own actions rather than for example, labelling their actions using a predetermined list. Furthermore, I did not want to influence their teaching through the manipulation, or control of any classroom or teacher "variables". Instead, I was interested in understanding the meaning behind the teachers' and students' actions as they were. While other research approaches often focus only on behaviours (e.g. number of teacher questions) or outputs (e.g. examination results), interpretive methods focus on reasons that underlie actions (e.g. why does the teacher use problem tasks in this class?).

While interpretive studies have the characteristic of being highly specific (Gallagher, 1991b) they also have to be located within the larger social context. Erickson (1982), outlining a theoretical perspective to help guide data collection, advises that to obtain an adequate description requires examination of three interrelated levels: a) the general socio-cultural system outside the school, b) the immediate learning environment in the school and c) individual functioning at school. He argues that teaching and learning in school cannot be understood only by reference to what goes on in the classroom itself. This study depended firstly on a detailed descriptive foundation with a narrow focus on just two classrooms, describing the specific context in which students were learning science. It depended secondly on the study of the broader context outside the classroom, as there was a need to understand the relationship between the specific science classrooms under study and the education system of which they were a part.

Another characteristic of interpretive research is that the researcher tends to enter into extended relationships with teachers i.e. months rather than days, for the purpose of learning in detail about the teaching-learning environment. This involves extensive fieldwork in the natural setting of the classroom itself. Such a study uses many of the tools of ethnography such as participant observation and interviewing. As a relationship between the observer and teacher or students develops, it permits ongoing discussions with them about their activities, uncovering how they think about them, and what factors influence their actions. It thus becomes possible to turn the focus from description to "meaning-perspectives i.e. the knowledge, beliefs and values that underlie their work" (Gallagher, 1991b, p.11). In this study, the development of these relationships helped elucidate the meanings underlying the use of problem tasks in the teaching and learning of physical science.

From the characteristics given above, it should be obvious that interpretive research, especially that involving fieldwork, allows us to answer questions which are very different from those that can be answered through more traditional methods (Gallagher, 1991b). Erickson (1986) lists a number of questions that he feels fieldwork can answer best. Using these questions as a guide, the following general questions were used to focus my study. Each question is associated with a number of sub-questions, which were useful in moving my focus from the general to the particular:

1. *What is happening in physical science classrooms?*
   What do the teachers do? What instructional strategies do they use? What do the students do? What tasks do they engage in? How do they engage? What problem tasks do they do?
2. *What is the nature and role of problem solving within this context?*
   What role do problem tasks play in teaching and learning? What beliefs do the teachers hold about teaching problem-solving? What do the students believe? What is the meaning of these actions to those involved?

3. *What are some of the consequences of organising teaching and learning in this manner?*
   What attitude do the students have to school science? Are the students able to solve problems? What sense do the participants (e.g. teacher, students and science educators) make of their experience?
4. *How is what is happening in this classroom influenced by external forces?*
   In what way does the external assessment affect life in classrooms? What other significant influences exist, e.g. curriculum documents? How are these influences related to each other?

These questions determined the initial data collection strategies that were to be carried out.

3.2 DATA COLLECTION PROCEDURES

When starting the data collection phase of the inquiry, I did not have a rigid plan of what data I would collect, or the instruments I would use, or a detailed time line for data collection. However, since I was using an interpretive research approach for the first time, I constructed a reasonably detailed data collection plan at the start, which is not always the case for qualitative researchers. These initial plans were informed by ethnographic data collection traditions (Bogdan & Biklen, 1992 p.58). For example, I knew that I needed to collect descriptive data using well-established procedures such as observation, unstructured interviewing and document collection. I also conducted a pilot study of close to a month in another classroom, to familiarise myself with these procedures and the difficulties in implementation.

While I initially entered the classrooms with a deliberate line of inquiry and a set of guiding questions because of the prior planning, these were flexible and I expected them to be modified as the inquiry proceeded. My data collection responded to the distinctive character of each classroom and to my growing understanding of classroom events. As I began collecting data and reflecting on it, a number of emerging themes guided subsequent data collection, such as who to interview and what to explore in depth. As I learnt more about the reality of classrooms, I made specific decisions to focus on classroom activities I considered to be the most salient. Thus both the questions and the data collection procedures evolved as I became more immersed in the classrooms.

3.2.1 Selecting the cases

As noted earlier, the nature of the research questions indicated an interpretive case study design with the unit of analysis (Merriam, 1988) being the classroom. I limited myself to two physical science classrooms for a number of reasons. Firstly, because interpretive case studies depend on a detailed descriptive foundation, they use small samples (Gallagher, 1991b). Secondly, this type of research takes a lot of time and is labour intensive. After the pilot study involving one school, it became apparent that there was only enough time to manage two school visits each day. Thirdly, I chose a study that seemed reasonable in size and complexity so that it could be completed in reasonable time with the resources available. Nevertheless, I felt that the two sites would provide me with sufficient data to deal with my research questions meaningfully.

Some might challenge the small sample size. They might argue that a goal of the study should be the degree to which the findings are representative of, or could be generalised to, a larger population of science classrooms. This argument is based, among others, on seeking of equivalency between the sample and the population it represents. It is argued that small samples may fail to provide findings relevant to the population at large (Delamont & Hamilton, 1989). However, my research questions did not lead me to search for the general characteristics of all classrooms, nor to identify a "typical" classroom. Nor did they lead me to use a research design where the case should represent the population so that the findings could be generalised to the population. I am not implying that all science classrooms are similar to those I selected. However, this does not exclude looking for the "generic in the specific" (Wolcott, 1988 p.203), which upon further investigation might be found to be relevant to a wider variety of science classrooms.

The sites of the study were determined using a set of criteria and therefore may be referred to as a "criterion-based sample" (Goetz & LeCompte, 1984 p.77). The criteria were pragmatic in that I wanted sites from which I could learn the most to address the research questions (Merriam, 1988). The following were important in the selection process:

(a.) The teacher had to be experienced and considered competent by the teaching community. This criterion was used to eliminate classrooms where the teacher was inexperienced in teaching the subject-matter or in dealing with students. I did not want the added complexity of an inexperienced or incompetent teacher to confound the issues.

(b.) The teacher should not be a personal friend or colleague. I recognised that "becoming a researcher involves changing the way you see others" (Bogdan & Biklen, 1992 p.61). If I had any close personal association with any of the participants, moving from normal situations to the research situations would create tensions and ambiguity.

(c.) The classroom had to be within reasonable travelling distance. I did not want to limit my time at the schools due to excessive time on travel. While this might be interpreted as introducing an element of convenience to my sample, I felt this was justified from a practical point of view.

(d.) The school must have a reasonable support structure. This included physical resources such as a science laboratory and a stable administrative environment. I did not want a classroom in which the provision of resources could potentially prevent some aspects of the published curriculum from being implemented.

Over and above the criteria already mentioned, the primary criterion guiding the selection of the second site was that it should complement the first. With the move toward the integration of schools in South Africa, I wanted a classroom reflective of this move. I chose a co-educational school with a diversity of learners including many who had limited English proficiency. While I accepted that this would limit my interaction with some of the students, I felt that the site as a whole would yield valuable information. Finally, although I was not looking for a "representative" case, I made sure not to select an exception or "oddball" case (Bogdan & Biklen, 1992).

As I collected and reflected on data, I had to make decisions about which students to interview and on whom to focus my observation. It was not possible to interview all students, but I endeavoured to sample widely enough, that a diversity of students' views was obtained. The choice of students was guided by the themes emerging from the initial data. I looked for some students who I identified as "target students" i.e. students who dominated verbal interactions in the classroom (Tobin, 1990, October). I selected some students who seemed to have isolated themselves from the general classroom interactions. I chose a number of students from each class rather than one or two individuals. I did not want the class to see me focus too much attention on only one or two key informants. I also chose from what I considered the more "typical" students, as I was aware of the danger of data being rejected because it was gathered from special cases. On some occasions, I was frustrated in my choices as students were not available or co-operative and so had to choose other students. The approach to selection of students is best described as purposive ongoing sample selection, a process similar to what Goetz and LeCompte refer to as "sequential criterion-based sampling" (cited in Merriam, 1988 p.51).

At both sites I used an overt approach to "negotiate entry" (Spradley, 1980 pg. 59), making it very clear what my interests were and seeking participants' co-operation for the research. This involved a few steps. After identifying four teachers who fulfilled the criteria, I approached them with tentative requests to allow me to carry out research in their classrooms. In one case, the teacher was going to be absent for a few months and in another case, the teacher asked not to be involved. After agreement was reached with the other two teachers, I approached their headteachers explaining the purpose of the research and reassuring them of confidentiality with respect to their schools. I also provided them with a letter outlining the research. In both cases, they were amenable on condition that the teacher involved was prepared to participate. At this stage I formalised the agreements by giving each teacher a copy of the "contract" which outlined the responsibilities of both the teacher and myself.

While both teachers were co-operative and made me welcome in their classrooms, I did not always feel at liberty to do whatever I wanted. In one case this meant that I did not have as much access to the teacher as I planned, but I was loath to pressurise her into providing more access than she was willing to give. I was always aware that they were the "gatekeepers" (Bogdan & Biklen, 1992, p.81) and I was there because they had granted me permission. This awareness came from the pilot study (detailed below) where the teacher was not willing to continue because he felt uncomfortable with my presence. However, I felt ethically secure in the knowledge that I had been open about the purposes of the study and did not have a hidden agenda.

3.2.2 Data gathering

The collection of data took place over a school year. The fieldwork at each of the classrooms started with the first lessons of the year in January and ended just before the students departed for their examinations in October. This duration was chosen for two main reasons. Firstly, I was interested in finding out what occurred during a complete year and whether classroom practices were consistent across topics and whether they changed as examinations approached. Secondly, in most schools teaching follows a set syllabus, that changes emphasis from physics to chemistry in about June. I was interested to see if the problem task usage changed as teaching moved from physics to chemistry topics.

For the first two months of the school year, I observed most of the science lessons in both classrooms. I knew that I had to be present in the classroom for a number of months in order to immerse myself fully in the classroom culture. I attended 25 of the 35 lessons in one school and 27 of the 36 in the other. I did not attend when students were writing tests. I then missed two weeks while away at a conference. Returning, I stayed until August by which time a complete section of chemistry with the solving of numerical problem tasks had been completed in the one class and the other class had completed two sections. As the days passed, I was learning a decreasing amount. I felt that "data saturation" (Bogdan & Biklen, 1992 p.68) was being reached and further classroom observation was providing redundant data. However, I maintained contact with the classrooms returning less frequently to observe lessons and to obtain copies of documents, until lessons stopped for the year. In this way I withdrew from the settings in a gradual manner. In all, I made over 60 visits to each school.

In this study, the classroom was to be viewed and described from more than one perspective. Eisenhart and Borko (1993 p.49) recognise two basic perspectives. Emic, which is that of the classroom insider e.g. the teacher or a student, who understands the classroom language and ways of working that have meaning to the participants, and etic which is that of the outsider e.g. a researcher, who wants to understand what is happening. The outsider is likely to notice things or perhaps gain access to understandings that participants caught up in daily routine would not be consciously aware of and thus could not articulate readily. The insider can reveal the motives that could probably not be inferred by an outsider from observation alone. Each of these perspectives used together help to build up our understanding of the classroom context. Thus fieldwork in the form of classroom observation provided the most appropriate way of gathering emic data with interviews and questionnaires giving insiders an opportunity to present their perspective.

The observer

The decision to become an observer to gain emic information was a carefully considered one. What was required was to enter the context with limited a-priori questions and in time discover what was important and focus on that. According to Guba and Lincoln (1989) the only instrument capable of achieving this flexibility is the human observer who is adaptable, and can draw on tacit knowledge and expertise to decide on what should be examined and on what to focus.

Such observation requires specific skills such as observation, recording, focusing, reflecting, interviewing and communicating with a non-judgmental attitude (Spradley, 1979). In order to develop them, I initiated a pilot study involving a month of observation of about 20 lessons. During this time, I tested my skills and methods, finding out their limitations and strengths. As a direct consequence of these early experiences, I decided to use video recording as part of the data gathering recognising the difficulty of dealing with the complexity of multiple interactions occurring simultaneously in a classroom.

Because my participation in the classroom was definitely secondary to my role of information gatherer, my position in the class could be classified as " observer as participant"' (Merriam, 1988). I had some opportunities to be more fully involved, as the teachers in both classrooms were absent for short periods, during which I became the teacher and as such an "insider". This was as close as I could come to feeling what it was really like to teach these students in these classrooms. During occasions such as these I was a complete participant, while on most other occasions I was complete observer taking no part in the activities. The extent of participation depended on the teaching style and the activities planned. For example, when students worked in groups on problem tasks or were involved in practical work, I was able to work with them as a teacher-helper. However, when direct teaching was taking place, I took the role of complete observer.

I did not want participation to occupy too much time nor to change the way the students reacted to me. The group knew my observer activities and I was happy to be defined as an outsider or neutral figure from the beginning as I felt this would minimise the effect I had on the classroom. However, I recognised and accepted that my presence affected both classrooms, and that as a result of the interactions and feedback all participants, including myself, would change in some ways (Merriam, 1988, p. 95). However, awareness of the possible changes and the extended duration of my presence in the classroom would help to minimise the overall effects on my interpretations.

Over 120 observations of complete lessons were made. Given the nature of the research questions, the focus was on participants' activities, especially the discourse between teachers and students. This was seen as more central to the study than other areas such as social structures and peer interaction, which were not ignored but mostly kept in the background. All classroom activities were recorded in as much detail as possible. This made it possible to identify both recurrent and atypical events.

Written fieldnotes focused on student and teacher actions such as time spent on various tasks, teacher movements, student behaviour, board and overhead work, students' interactions with the teacher or one other, and responses to questions. I collected information of a varied kind, noting whatever seemed significant. For periods, I would concentrate on patterns of questioning while on other occasions I would focus on individual student involvement in the class activity. To aid reflection once I had left the site, I made maps of the classroom showing student positions relative to each other. In the fieldnotes, I also included interpretive comments concerning student interest and the general classroom environment. At the end of each day, the fieldnotes were examined and further recollections were added together with interpretive comments on the day's activity.

In addition to the classroom observations, I attended two meetings associated with the senior certificate examinations. In both meetings I took fieldnotes and transcribed the full audio record. The first examination meeting took place early in the year at a local high school. Physical science teachers were invited to a review of the previous year's examination paper. The main input was from the teacher who set the examination papers (examiner) and the education department physical science advisor (advisor) who had acted as an internal moderator of the papers. They went through the physics and chemistry papers highlighting questions where students had difficulties. The teachers then asked questions of clarification and generally discussed the questions.

The second meeting, at a local college of education, took place at year-end after the senior certificate examination had been written. The chief examiner and a selected group of teachers (markers) had gathered to mark the senior certificate examination papers. The chief examiner presented his "model" answer and mark allocation for each question. The markers then discussed these, in some cases providing alternative solutions or requesting different ways of allocating part-marks for questions.

Audio and Video taping

All lessons except for the first few lessons were audiotaped using a directional microphone, usually situated at the back of the class. This enabled me to concentrate on activities in my fieldnotes with the knowledge that verbal interactions were available to be revisited once I had left the classroom. Subsequently, I brought a video camera into the classrooms after a few months of observation and recorded about 25 complete lessons in each classroom. The camera was placed at the rear on a bench overlooking the class. In this way, I was able to record details of general classroom interaction while focusing my own attention on particular students. For most of the time it was set to a wide-angle view of the class but could be zoomed in when I felt this would provide additional information.

The technique of supplementing observational data with video recordings is advocated by Erickson (1986), amongst others. Its use can reduce the bias toward recurrent events at the expense of rare events. It also provides the researcher the opportunity to revisit events later through playback. Such recordings subjected to systematic analysis can provide a valuable additional data source. Recording frees the researcher from the constraint of observing events only in real time sequence.

Interviewing

As questions of meaning were central to this study, interviews with the teachers and some students were essential. One cannot observe intentions directly so this had to be found out from them. As Patton (1980) describes it "We cannot observe how people have organised the world and the meanings they attach to what goes on in the world- we have to ask people questions about these things. The purpose of interviewing, then, is to allow us to enter into the other person's perspective" (p. 196).

In most cases my interviewing was open-ended and guided by relatively few focusing questions. Interviews were thus semi-structured as opposed to highly structured where the questions and their order are predetermined (Merriam, 1988). I did not use structured interviews, as I did not want to suggest to interviewees ways of understanding their actions based on my possible preconceived ideas. However, from semi-structured interviews, I was able to obtain some comparable data across subjects, as some questions I included were common to all interviews. I was guided by a list of questions focused mostly around aspects of problem solving. In addition, I was flexible and allowed the subject the opportunity to tell their own story through pursuing further topics or issues they raised.

All interviews were recorded, but the respondents were assured of the confidentiality and anonymity of the data i.e. no private information would be revealed, and names would be removed from transcripts. The student interviews took place at school, in rooms requested for this purpose. Thirteen interviews were recorded with each session taking about 30 minutes. For the two teachers, most interviews took place in their own classrooms after the students had departed. Five formal interviews were carried out, most lasting over an hour.

A number of unstructured interviews or spontaneous conversations after a lesson were also recorded with the teachers. These took place throughout the time I was an observer. For one teacher there were many opportunities for short informative sessions while the other teacher had too busy a schedule, with another class often arriving even before I had a chance to remove my equipment and preventing discussion. Consequently, I recorded fifteen informal interviews for one but only four for the other teacher. These were mostly between fifteen and thirty minutes long.

In addition, I carried out interviews with a local science advisor, a teacher involved with the setting of the matric examination and an examination moderator. Each of these interviews took about an hour. The purpose of these interviews was to obtain data concerning the influence of external factors on the teaching and learning of problem solving. In all cases, these were semi-structured interviews with the primary focus on the role of problem tasks and the role of the examination in teaching and learning. All three were very experienced in their jobs and were held in high esteem and respected by the local physical science teachers. The role of the science advisor was to support the teaching of science. This involved school visits, running workshops and meetings and producing information circulars. The moderator had the role of checking that the examination papers complied with the national examination criteria and that the standards of papers were consistent across education departments.

Questionnaires
During the course of fieldwork, there arose occasions where I felt the need for background information and exploratory responses to a specific event from the whole class. I wanted to use this exploratory data to provide focus questions to direct interviews with the teachers and students. As I was unable to interview all students, I decided to administer open-ended questionnaires to the students to obtain this type of data. I used questionnaires with single open-ended questions on two occasions in each setting.

In one questionnaire, I asked the students to describe their experience of school science. In one class I also showed them three short video recordings of themselves (receiving marked tests, talking before the teacher had arrived at class and listening to their teacher review a problem) and asked for comments on what was happening. In the other class, I did not have an opportunity to show a video but instead asked for their responses about an examination they had just written. This gave students opportunities to provide me with information about their feelings that I was unable to obtain through observation. Even though the teachers were not present when I administered the questionnaires, students were repeatedly assured of the anonymity of their responses and were told that they were not obliged to write anything. Responses were varied from being very open about their feelings to not responding in the case of two students. This data supplemented the data gathered from other data sources and was valuable in directing my focus during observations and in preparation for interviews. I was able to probe feelings that had been mentioned. The comments on the open-ended questionnaires were an unexpectedly rich source of data.

During the last week of school, after all observations had stopped, I administered a formal structured questionnaire to both classes. The questionnaire consisted of 32 statements about problem solving and students were asked to respond using a Likert scale. A copy of the questionnaire can be found in Appendix C. In both cases, the teacher was not present and students were not obliged to fill in the questionnaire. I decided to use this form of data collection at this point because I had completed my observations and had virtually withdrawn from the sites. I knew that administering the questionnaire to the students at that stage would not influence the ethnographic data collected so it would not compromise my study.

3.2.3 Data corpus

Over and above the data mentioned above, all documents used during the normal course of teaching were collected. These included over 1000 pages of teacher handouts such as notes, worksheets, and laboratory activities and student work such as homework assignments, student notebooks, and marked tests and examination scripts.

Table 3-1 Relationship between research questions and type of data collected.

	Question 1 What is going on?	Question 2 What does this mean to those involved?	Question 3 What role do problems play?	Question 4 What effect do external factors play?
Fieldnotes & observation	120 lessons	120 lessons	120 lessons	Exam meeting (3hrs) Exam marking. (4hrs)
Audio tape	120 lessons	120 lessons	120 lessons	Exam meeting (3hrs) Exam marking. (4hrs)
Video tape	20 lessons (16 hours)	20 lessons	20 lessons	
Interviews Student		13 student interviews	13 student interviews	
Interviews Teacher		5 interviews (10 hrs)	5 interviews (10 hrs)	5 interviews (10 hrs)
Interviews Other				Examiner (2 hrs) Advisor (2 hr) Moderator (1hr)
Unstructured questionnaire	1. Doing science	2. What's going on here.	1. Doing science	Role of problems
Structured questionnaire	Role of problems	Role of problems	Role of problems	Role of problems
Documents	Notebooks Worksheets Student test & exercise books Textbooks Syllabi			Examination papers. Model answers. Examination reports. Syllabi.

I also took some photographs of the two sites showing the students working in class. Because I was conscious of the need to consider the classroom in relation to its broader context, I also collected information from sources outside the classroom where I felt there was a chance that they had an effect on practice. This included past matric examination papers, examiner reports, syllabi, curriculum documents, and circulars to teachers.

The table above (Table 3-1), shows the relationship between the research questions and the source of the data collected. It should not be induced from the table that there were strict divisions between the data and the question they addressed. The table is presented to give an idea of the data corpus and how it comprised multiple data sources.

3.3 DATA TRANSFORMATION

This section describes the process of transforming data from transcripts and fieldnotes to descriptions and assertions. There was no single identifiable process but rather an ongoing transformation of the data, from the first fieldwork until the completion of the study. However, two overlapping phases can be identified. The first started during fieldwork and may be considered informal. It involved reading, reflecting on the data, writing memos, organising the data, searching for patterns, and deciding what seemed important. During the second phase in the latter stages of the study, the data was systematically analysed. This involved the same strategies but now included more systematic techniques such as computer analysis and production of data matrixes such as those recommended by Miles and Huberman (1994). What follows is a retrospective summary of the complete process; it should not be seen as chronological or linear but rather as an iterative process.

Data management

Data management is a term used by Huberman & Miles (1994) to describe the operations needed for a systematic, coherent process of data collection, storage and retrieval ensuring accessible data and the documentation of analysis. All documents collected from the sites such as tests, notes and worksheets, were given unique codes and summary sheets were produced to help in their management. Summary sheets of all lesson observations were constructed and fieldnotes and audio-tapes were labelled for reference. All interviews both formal and informal were transcribed verbatim, as were a number of complete lessons and extracts from lessons, from both sites. I decided not to transcribe all lessons but rather to select a number which could act as exemplars of practice. Near the end of the study, I also transcribed further extracts, selected to provide additional corroborative evidence. These provided contextual information and represented the participants' perspectives in their own words. While Bogdan and Biklen (1992) consider this a shortcut, they feel that the risks associated with using extracts are worth the gains, especially as the researcher has a more informed idea of what should be selected from the transcripts and what is superfluous as the study progresses.

Another strategy used was the production of what Miles and Huberman (1994) refer to as "data displays". They encourage the use of displays to "transform the data from being dispersed to compact, sequential to simultaneous, from poor order and bulky to focused and ordered all in one page, allowing the researcher to absorb large amounts of information" (p. 91). I used a number of displays including summary tables, a Gowin-Vee diagram, network diagrams and matrices. For example, the problem tasks that were used during the year were coded by topic and type, and entered into a summary display. As another example, the themes that arose were arranged into a matrix showing multiple sources of data, aiding the triangulation process. In this case, descriptive extracts and quotes appeared in the matrix. These proved very helpful when looking at the data holistically and trying to work out how events were connected.

Systematic analysis
The analysis process was derived from accepted interpretive methods of analysis (e.g. Erickson, 1986; Wolcott, 1994). The complete process proceeded through a number of stages that are represented schematically in Figure 3-1 below. This schematic, adapted from Hewson, Kerby, and Cook (1995 p.508), shows the iterative nature of the cycle of analysis. I use the term analysis here in the narrow sense used by Wolcott who limits it to "systematic procedures followed in order to identify essential features and relationships" (p. 24). He associates words like methodical, carefully documented and scientific with analysis.

The process of analysis could be said to have started from the first time I entered the classroom. However, the more systematic process of analysis began with the transforming of the data set, to more manageable proportions and attempting to make meaning from the complete data set. This process, involving condensing,

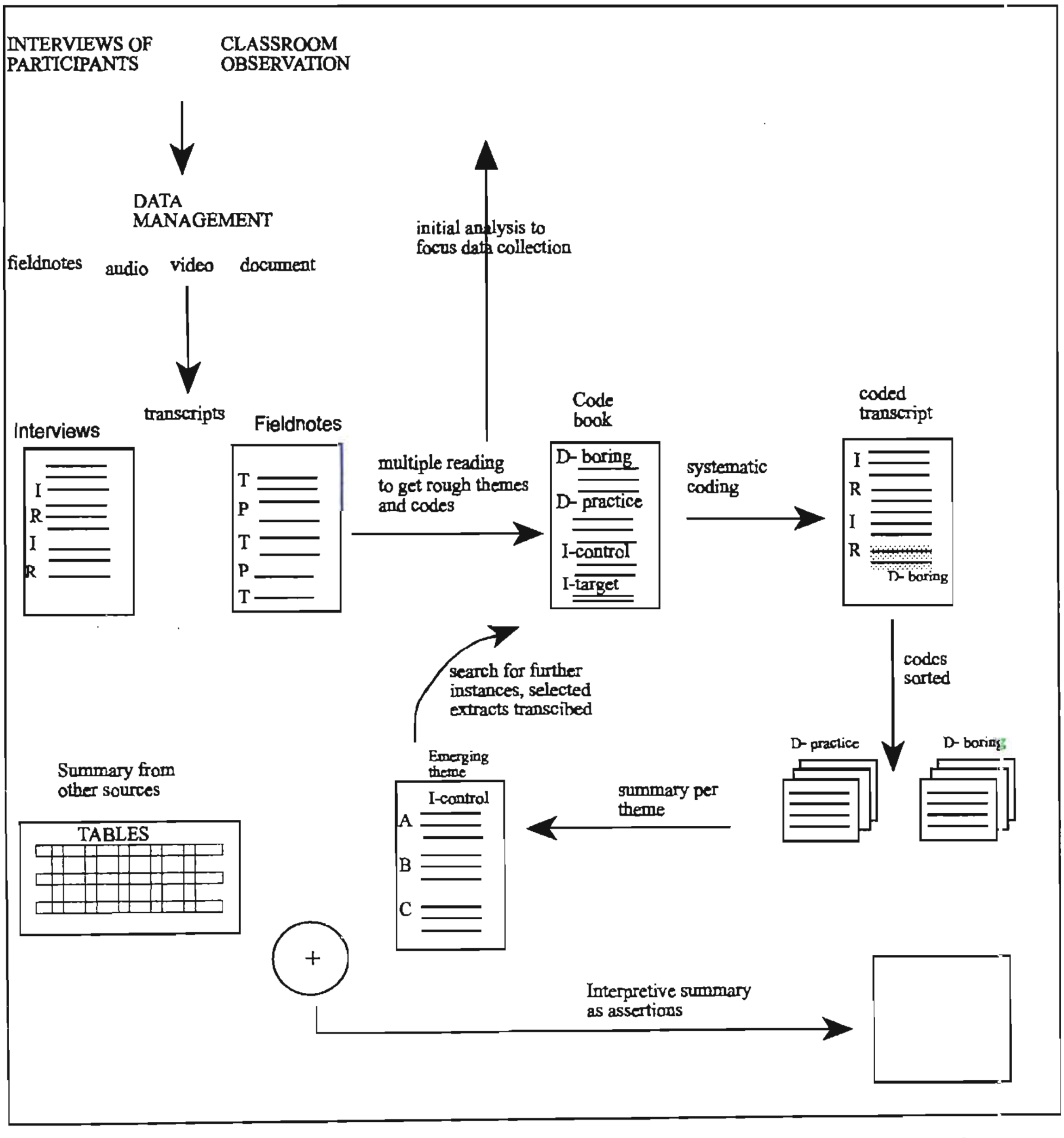


Figure 3-1 **Schematic diagram representing the construction of interpretive summary.**

clustering, sorting, and linking of data was achieved through two main strategies, that of producing data displays (described above) and of coding.

Coding involved attaching labels to chunks of text representing actions, events, and instances. These codes were initially used to order the data but later were used, during the systematic analysis stage, to pull together data and to retrieve similar chunks. A comprehensive set of codes was generated guided by the coding strategies described by Bogdan and Biklen (1992) , 1992) and Miles and Huberman(1994). They were applied to the data using the computer programme HyperResearch (Dupuis, 1993). The development of the code list was done inductively by repeatedly examining the lessons and interview transcripts supported by accompanying fieldnotes. A comprehensive list of codes emerged from this empirical process, together with some tentative themes. Despite the systematic nature of the analysis, I made choices about what data to code, what codes to allocate and which codes to group into themes. These particular choices were a consequence of viewing the data through my personal conceptual framework, which determined the significance of some events and not others.

Throughout the process, I looked for linkages among various coded items of data. Groups of similar codes or themes emerged. The flexibility of the software programme encouraged ongoing analysis and coding on which qualitative analysis depends (Miles & Huberman, 1994). It allowed me to delete codes, reapply codes, apply multiple codes and revise the names of codes. From this and the summary data displays a number of assertions were inductively generated. The assertions were essentially statements that represented patterns or regularities within the data. They connected up many items of data as evidence of analogous instances of the same phenomenon.

In order to maximise the probability that the assertions were consistent with the data, they were then tested deductively. I searched through the data corpus to provide evidentiary warrant supporting them. The data was repeatedly and systematically reviewed to test the validity of the assertions. The fieldnotes were scrutinised for comments and references to events. Other recordings that had not initially been coded, were scrutinised for disconfirming and confirming evidence. These extracts were transcribed and added to the coded data. Alternative sources of data, such as questionnaires and student work books were also examined. The structured questionnaire was analysed providing some descriptive statistics to supplement the data corpus. In this way, a few initial assertions were rejected as the discrepant cases outnumbered those that fitted the assertion, and therefore the assertion could not be warranted. In this interpretive stage, I continually asked "What else might explain this?" (Miles & Huberman, 1994 p.246). This iterative process of framing and re-framing the data provided multiple opportunities to reinforce or refute assertions. At the end I considered the strongest assertions to be those that had the most links to the widest sources of data.

3.4 PHASES OF RESEARCH

By nature an interpretive research study passes through a number of phases. While there are significant overlaps and blurred boundaries between phases, the process can be recognised as beginning with broad issues and initial experiences in the field. It proceeding through a funnelling process consisting of collecting data, making interpretations, looking for confirming and disconfirming evidence, and moving finally toward withdrawal and closure. The recognisable phases through which this study passed are outlined below:

Orientation and Pilot: During this initial phase I became acquainted with the literature and attempted to define the limits of my questions. I then started a pilot study in a local school. The initial visits were treated as exploratory opportunities to assess what was feasible and to determine the constraints and limits of an ethnographic study. During this time, my focus questions were finalised. Thereafter, the formal study was designed, especially in regard to obtaining a fit between the data collection procedures and the questions.

Starting Fieldwork: Phase two began on entering the first site and starting to observe lessons. For the first month or two, I struggled with the wealth of data and how to make sense of it. I reflected, obtained advice from other researchers, attended conference workshops and visited sites with experienced observers. This time away from the classroom was useful in improving skills as an observer and ability to analyse data from the field.

Becoming focused: During the observations and data gathering, I reflected on the data and made decisions on what to collect. As the data was analysed, issues which emerged guided the inquiry further. As a result, I started to concentrate on specific areas, following up with detailed interviews with all participants. I looked for in-depth information about those issues I considered significant. After four or five months, I started the process of withdrawal from the sites.

Systematic analysis: The next two years were spent in detailed data analysis and reflection. I presented two papers at overseas conferences on the emerging themes enabling me to obtain feedback from supervisors, colleagues and conference participants. This enabled me to revisit the data, finalise the analysis and complete the report on the study.

CHAPTER 4

WHAT HAPPENS IN JACK'S SCIENCE CLASSROOM?

This chapter provides a description of Jack's classroom, based on data collected over a year involving over 70 visits to the classroom. It provides a rich description of the classroom context in which problem tasks were used. However, it does not only focus on the problem tasks but rather gives a complete picture of what was happening in the classroom. Consequently, I have provided a detailed description of the physical classrooms, the participants, the classroom activities and participants' responses to these activities. Where appropriate, I have emphasised the participants' own words, allowing the teachers and students to speak for themselves. Because it was impossible to describe everything that happened during the school year, I have selected some key quotes and examples. I have also supported the descriptive account with summary tables and other data developed from the analysis.

The resulting description forms part of the answer to the first research question which asks, "What is happening in the science classroom?" This description, together with that of Susan presented in Chapter Five, serves as the foundation on which I have based my analysis and interpretation of the role of problem tasks which appears in Chapters Six and Seven.

4.1 CONTEXTUAL INFORMATION

Oakwood is a government school for boys from standard six to ten. It is situated in an upper - middle class suburb with a range of housing including both affluent houses with swimming pools and low cost housing complexes. The school draws on this area for its students who come from a variety of home backgrounds. Many of the students have one or other parent as a practising professional, but at the same time, many would be blue-collar workers. It is the only high school in this historically white residential area and has about a thousand students with a small percentage of black students. The school is well resourced and has many teaching facilities, an administration block, school hall, sports fields and swimming pool. It has a number of laboratories, modern library, computer room, specialist rooms etc. typical of all the large ex-Natal Education Department schools. Within the community, the school has a good reputation, administratively, academically and on the sports fields.

Jack has been teaching senior physical science for more than twenty years in a number of schools. His students consistently obtained good results in the senior certificate examinations. Amongst his science teaching colleagues he is recognised as being very knowledgeable and is well respected. He was often consulted by local science advisors and took an active role in departmental activities such as examination marking and inservice activities. He was known for his firm views and was considered an exemplary teacher by some. Jack occupied a senior position on the staff of Oakwood during the year of this study. Consequently, he had a relatively light teaching load with more periods set aside for administrative duties than teaching.

Jack's standard ten class of 32 students was the top set for Physical science. All the 150 plus students in the standard were ranked on their previous years results and then divided into "sets" for each subject. As this was done for a number of subjects, the same group of students did not stay together for all lessons, but divided as they moved from classroom to classroom for different subjects. They came together to a home class for registration each day. Jack's class comprised 24 students from the "A" class with about seven from the "B" class and one from the C. Most were taking 6 subjects with a typical package being English, Afrikaans, Mathematics, Physical Science, Geography and Art. Many took a "double science" i.e. doing both biology and physical science. The class only had a few students whose home language was not English, but these students were completely proficient in English.

The school timetable was divided up into about 35 periods per week. Typically, a subject would be allocated six periods a week. However, some like mathematics and physical science had seven. This was in the timetable as two double periods and three singles, so the class met for five lessons of physical science per week -- in fact, once a day with a double on Monday and Thursday. As this was the top science group, all the students had entered for the senior certificate examination on the higher grade. The students were on average about 17 to18 years old and most had been at the school since standard six (Year 8). Nearly all had Jack as their science teacher the previous year in standard nine.

The academic year for the students was broken up into four terms, each of about ten weeks. The fourth term was much shorter, due to the senior certificate examinations, which occupied about five weeks. During this time students stayed at home except when actually writing examination papers. Overall, the students had about 110 hours of science with Jack during the year. Without comparative figures from other studies, I would assume from my own experiences that this was on a par with other well-administered schools.

For a variety of reasons science teaching did not occur during 16 periods i.e. the students visited the local university on one occasion, Jack attended a rugby coaching course and was also off sick for a week. However, this did not imply that the students were not involved in some science learning activity. If he knew he would be away, Jack would give them a worksheet of problem tasks or schedule tests for that period. If off sick, he would phone in and assign work which would be given to the students by the Head of Department for science. When he was away for two weeks, I taught the class.

Being a higher grade class, all students followed the same syllabus. Jack did not leave any of the non-examinable sections out. However, reference to Table 4-1 below, shows that the school science department did change the order of the syllabus, starting standard nine with all the non-examinable topics such as "Waves" and " Bonding". While this was an internal science department decision, Jack felt that this order made sense as it linked all the mechanics sections i.e. "Vectors" to "Newton's laws" rather than have inorganic chemistry in the middle as was suggested by the official syllabus.

Table 4-1 **Jack's class: Order in which the syllabus topics were taught.**

Term	**Standard 9 Year 11**	**Standard 10 Year 12**
1st	Waves, Particle wave duality of light. Periodic Table	Newton's laws Gravitation Work, energy & power
2nd	General chemistry, Bonding	Electrostatics Electricity,
3rd	States of matter Inorganic (Sulphur, Nitrogen)	Rates & Equilibria Acids & Bases
4th	Vectors Graphs & equations of motion	Electrochemistry Organic

All teaching was carried out in the physical science laboratory. It was a large room with fixed cupboards down both sides. These were about 1,2 m high, with a continuous heavy wooden top. On the top were electrical trunking with plugs for both AC and DC, gas taps, and sinks with fold down swan water taps. These were closed with a cover unless practical work was taking place. There were louvre windows down one side facing onto the passage and opening windows down the other, giving plenty of light. At the back, instead of a wooden top on the cupboards, there was a thick concrete slab. This was designed for chemical balances but none were in evidence. On the back wall were display boards stretching from one side to the next. Pinned up were one or two marking-memoranda for past examination papers and a colourful chart advertising Arbour day. These did not change throughout the year.

At the front was a teacher's plain wooden desk, a double sliding green board which could be pulled up or down, a fume cupboard with a black blind pulled down and a door to a preparation room. This room was shared with the next laboratory and was used for storage of apparatus and notes. There was no overhead projector, which was unusual, as most laboratories and classrooms in the school had them. A small A4 periodic table was attached to the display board behind the teacher's desk. Outside the class in the corridor, there was an empty display cabinet on the wall.

The wooden student tables accommodated two students. I have provided a schematic diagram showing where each of the students sat in Figure 4-1 below. The students sat on high stools with backs. They were arranged in rows of three benches, side by side in the middle of the classroom, with no space between desks. There were five rows, with just enough space to walk between the rows. The rows tended to be bunched toward the front of the classroom, against the teacher's desk leaving a narrow passage at the front and a broad area at the back. As observer, I sat at the back on the concrete shelf. Except for one or two students, they did not change their positions during the year. Other than the basic furnishings, there was very little in the room to distinguish it as a physical science room.

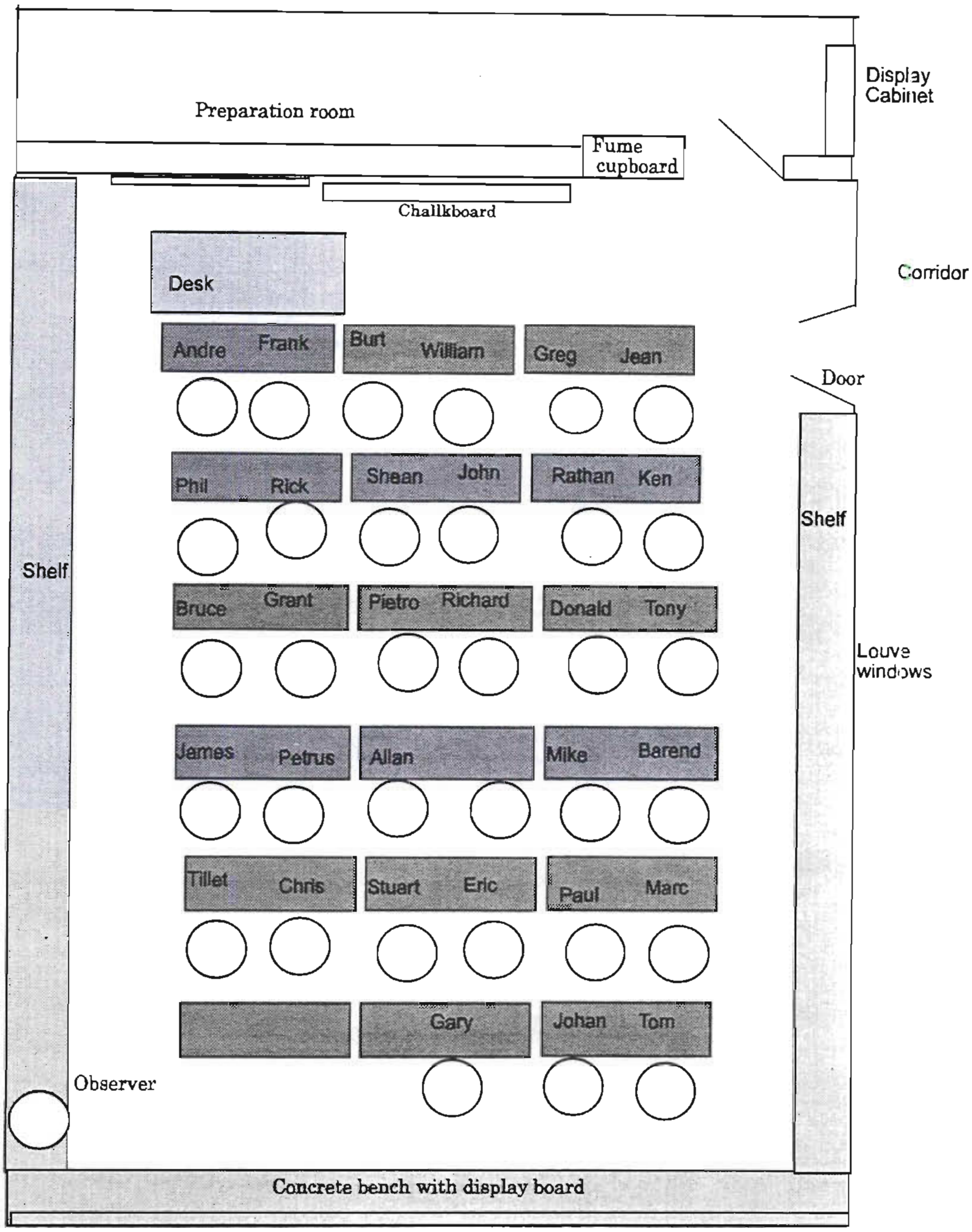


Figure 4-1 Diagram of Jack's classroom

4.2 UTILISATION OF TEACHING TIME

Each topic of the syllabus was dealt with as a separate series of lessons, which could be identified by characteristic stages. These were very similar across topics. Except for practical work and tests, virtually all the class activities involved Jack working with the class as a whole, interspersing his presentation with a series of question and answers. Tobin (1987) refers to this type of activity structure as whole-class interactive. The first two or three lessons would involve an introduction to the topic. He would introduce the new phenomena or concepts to the students through presentation, questions and answers. This would lead into the solving of typical problem tasks, which would be written on the board and solved by Jack. A number of problem tasks would be assigned from a worksheet and would be "gone over" during the next few lessons. While going over the problem tasks, Jack would introduce further concepts or different types of problem task as the need arose. On occasion, he would do a practical demonstration especially during the chemistry sections. A test would then be taken by the students, and usually marked overnight by Jack. These test problem tasks would then be gone over. A further test would be scheduled for a week ahead but in the meantime, a new section was started. The second test would interrupt the teaching of the new topic as a period was required to write it and at least a double lesson was spent going over the problem tasks.

There were exceptions to this pattern. For example, Jack spent a much longer time than normal introducing the section on "rates and equilibrium" before students started solving problem tasks from worksheets. However, much of this introduction revolved around graphical equilibrium problem tasks which he constructed on the board and the class interactively solved with him. On rare occasions, he would make the class read a section of their notes for a few minutes or ask them to individually solve a problem task in class. Class activities were essentially limited to listening, watching, asking questions and answering questions as Jack introduced new phenomena and concepts, went over homework and test problems, and carried out demonstrations. The activity structure of whole class interactive was the norm. For example, there were no instances of group work, project work, producing posters, open-ended investigations, debates, quizzes or role play.

The students moved from classroom to classroom during the course of the day and had to come to Jack's laboratory during their science periods. Normally he was not present and the students would make their way into the laboratory in groups, followed by one or two late-comers. Jack would arrive a few minutes after the bell had rung. He would greet them with "Morning, gentlemen" to which they would chorus "Morning sir". On eight or nine occasions, he had entered the class earlier and written the instructions for a practical or the answers to a problem on the boards.

The start of the lessons followed a very predictable pattern of "straight to work". Jack would nearly always continue where he had left off the previous lesson. Sometimes he would either ask a student "Where were we ?" or normally would look at his list of problem tasks, or the test paper they were working with to find his place and continue. He would sometimes spend the first minute or two briefly recapping something from the previous lesson such as the general principles that had been used to solve a problem task. More often than not, he would just continue where he had left off. "Right, we completed number nine last time , number ten... An object of mass forty kilograms collides ...." (Fieldnotes, Feb. 23). This exemplified his work attitude. It was immediately to the business of the day, with little time for distractions or pleasantries. He often worked without distraction or diversion for the full 35 minutes, or if it was a double for the 70 minutes, until the bell, often stopping 5 minutes after the bell had rung for the next period.

He expected the same concentrated work from the class. If he detected that students were not paying attention, he would always bring them back, " Right enough of that. Let's move on. Number fourteen. When two moles of hydrogen chloride react ....". or focusing on an individual by name " Guys! Too much chattering there" This pattern of straight to work, would only be broken after a test or examination when he would make comments to the class in general about their performance or hand out the test scripts or when he wanted to start a new section. It was very rare for the class to spend time on anything other than science topic.

In Table 4-2 below, I have given a more detailed breakdown of how time was utilised during the year on the main activities and teaching topics. The table indicates that Jack generally kept to the number of periods suggested in the syllabus guide for the physics and chemistry sections. (The physics section was

Table 4-2 Jack's class: Summary of how the periods were utilised.

Term	Topic	Syllabus guide	Actual	Tests & exams	Going over tests	Going over problems	Practical work	Direct teaching	Other
1	Newton's laws Gravitation	30	30	4	4	15	2	5	0
1&2	Momentum, & WEP	(included above)	20	4	3	9	0	4	0
2	Electrostatics & Electricity	42	42	4	6	19	2 *	7	4
	Physics Sub-total	72	92	12	13	43	4	16	4
2&3	Rates & Equilibrium	18	28	3	4	10	3	7	1
3	Acids, Bases & and solutions	18	14	2	2	3	2*	5	0
4	Elecrochem	15	17	3	3	3	1	7	0
4	Organic	21	15	2	2	4	3*	4	0
	Chemistry Sub-total	72	74	10	11	20	9	23	1
4	Exam revision		7			3			4
	Teaching TOTALS	144	173	22	24	66	13	39	9
1	March exams		11	7	4				
2	June Exams		21	7	12				2
3	Trial exams		13	7	6				
	Exam sub-total		45	21	22				2
Grand TOTALS			219	43	46	66	13	39	11

Note
* Indicates that students did a hands-on practical activity
The examinations are shown separately as they contained a combination of topics.
The periods allocated during the last sections of chemistry might have an error of two or three periods as I was not always present to confirm the activity.

more than normal due to his absence from the school.) However, he did not always place the emphasis suggested by the syllabus on individual topics. When the activities for physics and chemistry sections are compared, the table indicates that the time spent going over problem tasks decreased from 60% to 40% and direct teaching increased from 17% to nearly 30%, for the chemistry section.

4.3 CLASSROOM ACTIVITIES

During the year, three major activities predominated, taking up nearly 90% of all school time in Jack's class. I have called these direct teaching, writing tests and examinations and going over problem tasks. The percentage of time allocated by Jack to each of these activities is represented in Figure 4-2 and is discussed in the following sections.

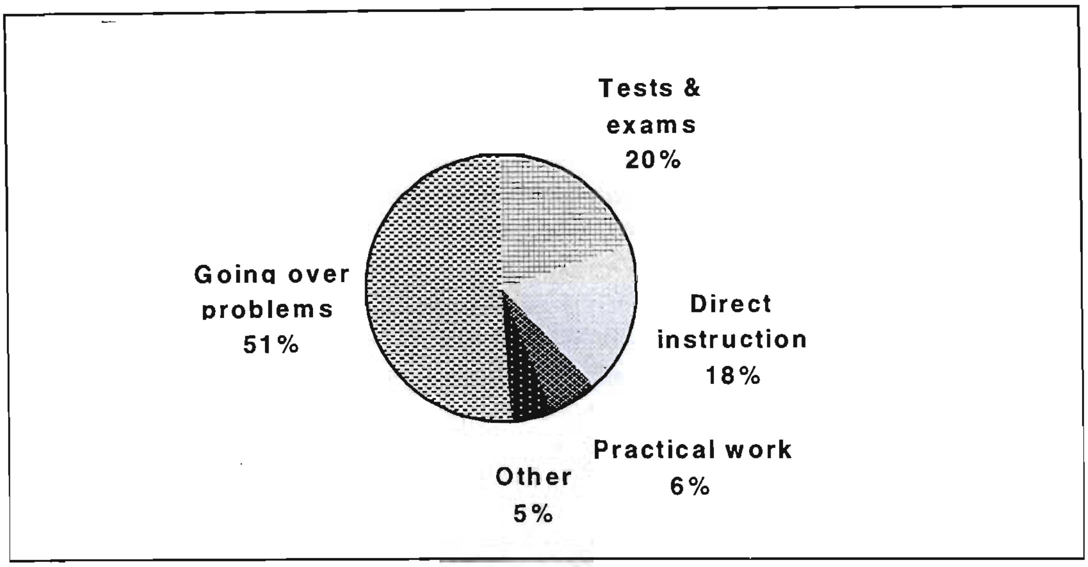


Figure 4-2 Jack's class: Percentage of time spent on each of the activities.

4.3.1 Direct teaching

The activity of presenting concepts and principles to the class for the first time was characterised as direct teaching. This form of teaching was encountered when a new topic e.g. reaction rates, was introduced or some specific science principle or law e.g. conservation of momentum, was presented by Jack. 18% of all classroom time was spent in this manner. The following is a typical example of what I have labelled direct teaching. The extract is taken from a lesson in which Jack is introducing the students to the section "Rates of reaction". He began by discussing a distribution curve dealing with the salaries of workers in South Africa. He then continued:

Mr. Jones:	Now we kick off onto our next section that we do, reaction rates. *[Writes reaction rates on board]* I have done this at the start of reaction rates because I am going to come back to distribution curves later and I don't want to go wasting time when I am half way through reaction rates on, once again revising what a distribution curve is. When I

deal with distribution curve in terms of reaction rates, then you will understand exactly what I am getting at. Close your books

[Some students have notebooks open at the new section. Jack cleans board and writes equation $H_2 + I_2 \longrightarrow 2HI$ *As he writes he talks.]*

H two plus I two goes to two H I This particular reaction can be seen in virtually every text on reaction rates and equilibria - which is the next section we will deal with. Now...hydrogen combines with iodine -hence the purple colour- to form hydrogen iodide. [??] iodine vapour is that purple colour.

[He refers to equation on board where I is drawn in purple chalk.]

Now...in order that hydrogen combines with iodine to form hydrogen iodide what has got to happen?....... This is done in the gaseous state. Right, we have hydrogen .... if we get iodine crystals and add them to hydrogen gas, the reaction is not going to proceed. We are going to have virtually no reaction - if any reaction at all. So what must happen first of all? ..... We are dealing with hydrogen and iodine in the gaseous state. What must first happen in order that hydrogen iodide is formed? Hands up. What has to first happen?......

[Two students put up hands immediately, James and Donald but Jack waits about 5 seconds.] .....

Hands down. Think about it guys ......What has got to first happen? .... and the answer I am looking for, is a very very obvious answer ... sometimes so obvious that it escapes you.

[Jack walks down side of classroom. He chooses Paul who sits at the back near where he is walking.]

Paul: They must first come into contact.

Mr. Jones: They have to come into contact with on another. Right,..... so in other words we have got hydrogen and iodine molecules, moving around in random space and they have to come into contact with one another. Right ..

[Returns to the board and draws molecules on board.]

Mr. Jones: How do they come into contact with one another?

[Points back to Paul.]

Paul: I don't know.

James Air.

Mr. Jones: I am asking you, how do they come into contact with one another?

Students: *[Some students shout out "heat".]*

Mr. Jones: No, merely come into contact with one another. How do they come into contact with one another?

Students: (???????) *[A number shout answers out.]*

Mr. Jones: Pardon? *[Points to student in back desk, Chris.]*

Chris: They just touch each other

Mr. Jones: But what causes them to touch each other? *[Point to William.]*

William: You just make them touch each other by applying heat or some force.

Mr. Jones: So are they not going to come into contact with on another unless they are heated?

Students: (??????) *[A number of students calling out.]*

Mr. Jones: What was your answer down here *[pointing to group near front]*
Somebody said something.

Student: Brownian motion

Mr. Jones: Brownian motion, diffusion...aahhh... can you be a little more specific?
[Points to Tom who has hand up]

Tom: One of the laws of gases is that the particles have random movement

Mr. Jones: OK, right.

Tom: When the gases come together, all the particles are moving around each other and obviously some will collide. When they collide they will touch.

Mr. Jones: Excellent ... In the gases....- one of the factors in terms of ideal gas behaviour, one of the features of ideal gas behaviour is that the gas particles are in random movement.
[He then explains what will happen and the lesson continues in the same manner]

Jack determined the pace and direction of the presentation and the students were expected to make sense of it. Where interaction took place, because the topic was new to them, the students were not always sure what was required and there seemed to be much guessing until one or other student mentioned the word or phrase Jack was looking for. This enabled him to move on to the next stage of the presentation. Jack would also do a fair amount of direct teaching while going over the solution of problem tasks. These instances were of much shorter duration and in a sense unplanned. He would spend a minute or too and remind them of important principles used to solve the problem task or where new types of problem were encountered e.g. problem tasks dealing with lifts were encountered as a homework problem before they had been introduced in class. In these cases, he introduced new concepts or principles, there and then. On three or four occasions after particularly involved sessions, where students were having difficulty solving particular types of problem tasks, he would recap or summarise.

When introducing a new topic, Jack did not allow the students to have their notebooks open. The notes, which were given to the whole standard and had been prepared by another teacher in the school, normally took a different approach to the topic. When he saw students writing, he would not forbid it, but would remark that he would rather they listen and understand, than copy anything down. He never dictated notes or constructed board summaries for them to copy later. The consequence of this was that important notes or principles would not always be recorded for later reference. However, students would often copy solutions to problem tasks from the chalk board.

During the time I observed, I never saw him use notes. He rarely brought anything with him to class, except for the current list of problem tasks, his mark book, handouts or work to be returned to students such as test scripts. In all lessons, he would use the chalk board to illustrate his descriptions or explanations. He had a very good understanding of the topics and made every attempt to explain carefully and clearly to the students.

I found Jack's direct teaching to be interesting and carefully constructed. He often expanded the topic, bringing in interesting and relevant facts in an attempt to relate it to student's lives or make the topic more relevant. For example, when talking about alternating current, he spoke about the historical reasons for the decision to choose it over direct current. A number of the students mentioned this when asked to comment on their science lessons. For example, Bruce had this to say: "Mr Jones makes it interesting. He tells a lot of stories, which you can relate to, so actually it does make the class interesting" (Bruce, Interview). However, this time spent on expansion was not always appreciated and some students felt he was digressing: "It's good that Mr. Jones adds some extra knowledge into the subject, to make it more enjoyable, but sometimes too much, and the syllabus is rushed at the end of the term" (Tony, Questionnaire).

4.3.2 Going over the problem tasks

By far the most frequent activity was going over problem tasks, particularly those assigned for homework and those encountered in their tests and examinations. This occupied about 50% of all available time.

The students were given sets of worksheets containing the problem tasks, with their notes at the beginning of the year. Near the end of each lesson or after the bell had rung, Jack would refer to his worksheet of problem tasks and tell the students to complete the next four or five problem tasks. He appeared to choose an arbitrary number of problem tasks. From comments made by students in the questionnaires, the tasks would take them about 30 to 60 minutes to complete. He rarely collected in their exercise books to check if homework had been done. However, he quickly found out when homework had not been done. He had the style of walking around the class while teaching and would ask students for their answers. If they were unable to provide one, he would then probe further to see if the homework had been completed. Besides making the student work through that problem task, he took no action.

Table 4-3 indicates the number of tasks per topic and the approximate number of periods that Jack spent going over them. While the table does not give an indication of the type or quality of problem tasks, it does give an idea of the number of worksheets the students had to complete during the year and the

Table 4-3 Number of problem tasks per topic and the time spent going over them.

Topic	Number of worksheets	No of problem tasks	Periods going over (approx.)
Newton's laws & Gravitation	1	29	15
Momentum, WEP	1	39	9
Electrostatics & Electricity	6	67	19
Rates & Equilibria	2	33	10
Acids, Bases	1	13	3
Elecrochem	1	17	3
Organic	1	13	4
Totals	13	211	63

differing emphasis from topic to topic. This table does not include the problem tasks from tests and examinations.

Whether he was introducing a new problem type or going over a problem task that had been attempted, the instruction would fall within a framework that could best be described as " watch carefully how I do it". This mode of careful explaining was the dominant activity in his class. Most of the time Jack did the talking. He made use of the board all the time and nearly every problem task was represented through a diagram of some description. He started by reading the problem task out and the students followed on their worksheets. He represented the information provided through a diagram and wrote in any values provided on the diagram. He then talked his way through the problem task providing the solution path. At this stage the interaction with the class increased as he asked them to fill in bits of information, often the results of calculations. At the end, he monitored how many had got the correct answer. Sometimes he ascertained who had difficulty with a problem beforehand or asked individual students how to solve the problem. He only came with prepared solutions after a test, in which case he had a one-page summary or model answer, to which he referred. Normally he just modelled how he wanted them to solve the problem. This pattern of going over problem tasks changed sometimes for multiple choice or drill questions where he would sometimes just call out answers.

A substantial extract from a lesson is provided in Appendix D which illustrates this activity of "going over problems'. In this case, a number of tasks had been assigned for homework and he was systematically going through the list of problem tasks showing the students how to solve them. The extract illustrates how Jack solved the problem tasks by providing the solution strategy. The student's role was limited to providing chorus answers, short individual answers to numerical calculations or confirming Jack's procedure and answers. During this process, Jack monitored the success of students and would immediately help any students who had a difficulty in understanding how to solve a problem.

4.3.3 Other activities

Practical work.

During the year, the students spent about seven hours doing practical work themselves. These were standard practicals, indicated as examinable in the syllabus and to be done by students. The practicals done by the students were: determination of gravitational acceleration; factors affecting rates of reaction; verification of Ohm's law and Joule's law; and titration of an unknown against a standard solution. These always took the form of working in groups of four or five and following a set of instructions provided by Jack. The first two took place during the appropriate topic while the others took place just before the scheduled practical examination at year-end. (Students wrote a pen and pencil practical examination which together with a similar examination taken at the end of standard nine contributed to their practical examination mark. This counted about 17% toward the assessed mark submitted by the school for each student.)

Practical work was not an integrated part of the instruction. It was not a matter of using practical work to illustrate a phenomenon or investigate a problem task which arose during instruction. It normally took place in a planned way, scheduled at Jack's convenience and not always at appropriate times within the teaching of a topic. When I queried the scheduling of a practical after the students had already finished the section on Newton's laws and were about to write a test on it, he replied:

> ....Yes, definitely a weakness in terms of how I have gone about it this year. It was bad planning on my part that I got to a stage where I should have had the prac, sorted it out and I had not planned for it. The ideal would be to have the prac early so they could see, as you load the suspended mass as opposed to the trolley mass, the acceleration increases...and if you have given me a wrap across the knuckles there, it is totally justified. I shouldn't have done it. I endeavour to do the prac before I do that but I just did not get around to it this time. (Jack, Informal interview, 17 /02)

On about five or six occasions, particularly during the chemistry topics, Jack carried out demonstrations. He would assemble (or ask the laboratory assistant to do so) all the apparatus and chemicals at the back of the classroom before the lesson. The students gathered around and he carried out the demonstrations in an interactive way, asking questions and getting students to participate. However, the majority would just stand and watch as Jack " explained carefully".

Tests and examinations

Tests and examinations occupied a significant portion of all teaching time available, i.e. approximately 20%. Jack attempted to give two tests for each of the sections. The only section which did not have two tests was "acids and bases". The students wrote 13 tests mostly during Monday double periods. The three examinations were written near the end of each term and consisted of two 2 hour papers (one physics the other chemistry). The students were told at least three or four days ahead of time that a test had been scheduled. On the day, Jack would make sure that the students were as spread out as possible, so they could not copy. No talking was allowed and students were given a page with the questions on. They worked in their test books. This allowed students to refer back to previous tests and corrections they had made. I saw students quietly turn back pages when Jack was not looking. From comments made in interviews, it was common knowledge that a few students did cheat during their tests and a student was caught assisting another during an examination.

4.4 CLASS ENVIRONMENT

4.4.1 Interactions

As mentioned in above, Jack would interact with a number of the students by asking them questions and getting them to raise their hands to indicate if they had a problem task correct or incorrect. Every now and then but certainly not every lesson, he would get a student to go to the board and either explain an answer or complete a diagram or graph that he was discussing with the class. Although he did much of the talking and explaining he encouraged all the students to ask questions :

> Generally Mr Jones does much of the talking, but he frequently asks for opinions and questions. There is usually not much written work taking place during the lessons, and generally not much homework. His lessons are

> enjoyable, since we are usually active during the lesson, and not merely expected to absorb like a sponge; it is also greatly emphasised that we must ask questions, his favourite saying being "Have I ever shouted at you for asking a question?" (Sean, questionnaire)

Not all had the same positive view of the classroom interactions. For example, Eric had this to say in response to a question about what they do in science class:

> You sit at the desk and, you just get taught and taught and taught, and you're asked a few questions and that's about it. And you must go home and learn that again. (Eric, Interview)

Although Jack encouraged all students to ask questions, not all students wanted to get involved. They would avoid answering questions or drawing attention to themselves resulting in a minimum of verbal interaction with Jack. One student, who for the most part was successful in avoiding Jack's questioning, was Rathan:

Int.:	Do you have occasions where you have questions that, "I don't understand what's going on there," and -
Rathan	I do, but then I - I don't feel that - okay, he's not going to - he told us plenty of times - he's not going to penalise us for asking questions. But I don't feel at ease with him, asking him questions. I don't know.
Int.:	Do you ask Ken?
Rathan	Ken sits next to me.
Int.:	So, do you communicate with him?
Rathan	Yes.
Int.:	Would you prefer to ask him a question than out into the class or to Mr Jones.
Rathan	Definitely.
Int.:	If you could put yourself into Mr Jones's shoes, and you're standing in the front and he looks at you, what do you think he's thinking? What does he think of you as a student?
Rathan	Well, probably he thinks I'm dumb. I just sit there; I don't ask him anything. I don't know. I would think that... because I just sit there...I just listen to him.
Int.:	So what do you think he thinks?
Rathan	I think he thinks I'm stupid, ... because I ... can't communicate with him.

(Rathan interview)

There were eight students, falling into two groups, who appeared to dominate the student-teacher verbal interaction in Jack's classroom and who I refer to as the target students (Tobin, 1990, October). The one group was Tom, James, William, Sean and Donald. They were selected by Jack to answer questions because they were usually first with their hands up to answer or were the only hands up. In these cases, Jack would normally select one of them to answer. If Jack was asking a number of questions in rapid sequence concerning a problem task and students were not requested to raise their hands, they would usually be first to call out a response. They were invariably the ones who would ask questions of clarification or extension. Consequently, they dominated verbal interaction with Jack and were most involved in the observable class interaction.

However, he did not always follow this pattern of selecting these target students during questioning. He would sometimes pose a question and ask for hands up and then wait for the majority of hands before selecting. About half the time in those case he would choose a student who did not have their hand up. These were usually students who did not achieve on the tests and who did not volunteer to answer. These students formed the second target group being Tony, Chris and Ken.

Both Jack and the students recognised that they formed an identifiable group in class, characterised by their involvement. This is shown in the following two extracts, one from Tom and the other from Jack.

> You just have a couple who ask a few more questions and tend to be a bit more, a bit more involved than the rest. I know, I mean there are a few of us who are involved but most of the others, just sit back and you know, they listen and they don't really get involved (Tom, Interview).

> Jack: That the top set operate at that higher level and that it is in their interest to in fact concentrate, ask questions etc in order to achieve that level. Rathan, Tony , a couple of other chaps, ... don't ask questions, they just don't ask questions and their improvement is going to be limited until such time as they do ask questions.
>
> Int: Why do you think they don't ask questions?
>
> Jack: ...... I think that maybe they are just tend to be retiring kind of kids. Andre front left, very very quiet kid, you never hear a peep out of him. Got a 100% for this test. He'll walk an A at the end of the year. ....Then there's Sean - sitting in the middle row - he asks questions constantly, some of them stupid questions, that I actually think he's almost taking the mickey out of me, but he works, he really grovels, and I believe that Sean over achieves because of that- 71, ...79.[referring to his list of marks] (Jack interview, 10/02)

An analysis of two weeks of teaching during the topic of electrostatics confirmed much of the above. Reference to Table 4-4 below, shows that over the 14 periods, the majority of students had three or less interactions with Jack. These interaction were of different duration, some involved one word answer, while other were more detailed responses. However, the vast majority of interactions only involved short exchanges of a few words, as evidenced in the extracts from the lesson transcripts. During a single period lesson between 6 and 10 students were involved in some form of dialogue with Jack while in a double period lesson this rose to between 20 and 30. During a lesson with direct teaching, e.g. the introduction to electric fields, the number of interactions halved.

Table 4-4 Number of students involved in interactions over two week period.

Interactions	0 - 1	2-3	4-5	6-7	8-9	10 +
No of Students	11	9	6	2	2	2

The analysis also confirmed that the students who had higher frequencies of interaction were the target students e.g. 10 plus interactions refers to Ken and

William. I repeated the analysis for a section of chemistry and interactions were very similar although one of the target students, Ken virtually stopped asking and one or two others i.e. James and Tom increased their rates. This indicates that a detailed study of interactions for chemistry and physics might produce a similar quantity of interactions but the students involved could be different.

4.4.2 Discipline

Jack had a very strong presence within the class and had no problems with class management. In my time as observer, there were no serious disciplinary problems where the lesson was disrupted to deal with an individual. There were also no instances of a student being punished with dismissal from the class, detention or extra work. He could command attention when he wanted it. He very rarely commented on students' activities outside of the class such as exploits on the rugby field or their personal matters. However, Jack recognised that the class environment was important especially the students' relationship with him:

> A great deal of motivation and there's another point, you - me can obviously pick it up that some of the kids respond to me as a person, respond to my humour or attempts at humour whichever way you look at it, and they like me as a person. And that's a big thing. Parents will sometimes come in and ask, and I've asked them - is it me- if they've been having trouble with science. ....I've asked them, I've said , "right well, you get feedback from Johnny. It might be a difficult question but does Johnny like me?" Oh yes, he likes you very much. Well that's half the problem solved if there was a problem. But if a kid doesn't gel with me, well it's going to be difficult because he comes in " Oh it's that fool again", and that's not a basis from which to work. I like all of these kids, that doesn't mean to say that I like all of the kids that I've ever taught. But in terms of relationships between two people they're on the right side already because I like them. And if they like me, well that's half the battle won. The kid who doesn't like me, who sits here and quietly sneers behind his hand if I make a comment etc is not going to ask a question. When I crack a corny joke and they all moan, I'm happy. [laughs] When they stop moaning I know I've got a problem. (Jack, informal interview, 10/02)

As indicated in the extract, Jack would make some jokes which would raise some laughter from the class. These were often related to the work at hand or at the expense of an individual student. On a few occasions he advanced on a student in a threatening manner mostly for a "stupid answer" or inattention. It would provide amusement for the class but obvious discomfort for the student. From their body language and the class response of jeering or mock warnings that they were dead, I felt their discomfort was due to all the attention rather than because they were unsuccessful in answering. Student laughter was at Jack's actions or the possibility of actions not the wrong responses to the question. He appeared to have complete overt control.

4.4.3 Student perceptions

Not all the students appreciated his attempts at jokes or the strict class environment he created. For example, Rathan said he did not feel "at ease" with Mr. Jones. When asked how this could be changed he replied that:

> .... I think crack a few jokes now and again. With Mr Jones you daren't laugh. Very seldom does he crack a joke, say something funny. If he does say something funny, it's not that the whole class that catches; it's just a few guys will catch. So we should be more at ease. (Rathan, interview.)

Some other students felt they might do better under a different environment. For example, Richard said:

> I work hard at science when I'm at home, but I have not achieved successful results. I am not criticising the teacher, but I believe I could do a lot better under a different teaching environment. I received an "A" in the Std 8 exam because I went to extra lessons. I feel that a more relaxed and enjoyable working environment is better for me. (Richard, questionnaire)

However, this was not necessarily the general opinion of all the students. A number focused on what Jack did for them overall as typified by the following comment from Jean on a questionnaire. "Science in the class, however, is made more than just interesting by an enthusiastic teacher who is obviously genuinely concerned about our individual achievements". Other students particularly the target students, enjoyed their science class:

> I enjoy the Science class. It's a very enjoyable ... I've been in some boring Science classes, but Mr Jones's class is actually very enjoyable, because he's always ... you know, it's never stale; he's always got a thrust of humour, and you can actually put across different points of view, challenge him at certain times - not all the time [LAUGHS], certain times. He covers everything very comprehensively.

When asked if they thought he was a good teacher the response was always positive. From these and other comments, I came to the conclusion that the classroom environment was perceived differently by different students. This first became apparent to me when I showed them a video extract of themselves, made while Jack was going over some problem tasks. The response from the students was interesting, especially the difference between someone I identified as a target student, Bruce who wrote "This seems to be a normal class 'functioning'. We are listening, paying attention and responding to what Mr Jones is telling us. A pretty normal, rather indifferent science lesson." and the response from another student Phil, "To me this is normal behaviour. I suppose one does get a bit bored sometimes and this might explain everyone's talking and all the looking out the window." Given that they were viewing the same event, I was surprised, but subsequent observations supported the view that there were multiple perspectives on the classroom environment.

CHAPTER 5

WHAT HAPPENS IN SUSAN'S SCIENCE CLASSROOM

In this chapter, I have presented the second case study dealing with Susan's classroom. It is also based on over sixty visits to the school during the year and gives an alternative view of what happens in a science classroom. The format of the description is not the same as the one for Jack. This was done for two reasons. It was not the purpose of the study to compare the classrooms, so it was not necessary to have identical analyses. In addition, because the class environments were different, I have focused on those aspects which appeared relevant to the study and helped create a rich description of this particular classroom. Taken with the case of Jack, it provides the descriptive foundation on which the analysis and interpretations of this study are based.

5.1 CONTEXTUAL INFORMATION

M.C. High School is a public school for boys and girls from grades 8 to 12. It is situated in an area historically reserved for members of the white community and was considered a lower-middle class suburb with a range of housing including both affluent houses with swimming pools and low cost housing complexes. Because of a dwindling school intake, the school began to draw in students from other historically black residential areas even before residential restrictions had been lifted. This resulted in the school having about 800 students drawn from diverse home backgrounds with approximately 40% being black students all of whom had joined the school within the previous 3 years. The school was well resourced and had many teaching facilities, an administration block, school hall, sports fields and swimming pool. It had a number of laboratories, a library, and specialist rooms. It encouraged a number of extra-curricular activities such as school plays and community projects.

Mrs. Susan Smith was an experienced science teacher, having been teaching for over ten years. At the time of the study, she occupied a senior position on the school staff and had many responsibilities, other than her physical science class. Classes would regularly be disturbed, as other staff would need to speak to her about administrative matters. She also was involved in organising the school sports programme, the school timetable and was actively involved in professional teacher associations. At the start of the study, I had already met Susan a number of times at many science teacher association activities.

Each week Susan taught 33 periods of 35 minutes with twelve "free" periods during which she could prepare, mark, or deal with administrative matters. Susan was a very busy teacher with little free time. She was always very busy with a number of extra mural and administrative duties over and above her teaching. She was always about to leave for a meeting or to meet someone or had a pile of administrative work on her table that needed to be finished as soon as possible. Consequently, it was difficult to organise interviews with her. She often appeared tired and rushed and had to apologise to students for not finishing the marking of work or providing notes for sections that they were doing.

The students and classroom
Susan's standard ten (Year 12) class, that I observed, had 30 students for most of the time I was present. The number fluctuated as a student departed in February with another joining the class a few days later. At the end of the second term, two students left. The class was multicultural in composition, containing 13 students for whom English was not their home language. However, all were able to read, write and speak English. These students had joined the school at various times in the past three years. About four were very fluent and confident in English but many of the others had difficulty with the language, especially when it came to classroom discussion or questioning. Often, during class interactions, they would converse with each other in Zulu.

There were 11 females and 19 males. The overwhelming majority had been at the school for at least two or three years. Susan had taught some of the students in previous years, either in Grade 11 or 10. About half her students had registered for the senior certificate examination (matric) on the higher grade and the rest on standard grade. During the year, some changed grades and eventually 12 chose to write the physical science examinations at higher grade. When the students were divided into classes for science, Susan received the higher grade students and the best of the standard grade students, based on the standard nine examination results. Consequently, it was seen as the top set. The class can best be described as heterogeneous, containing students of both sexes, different cultural and language groups, and students attempting the examinations at different grades.

Except when the students were doing experiments, which was a rare occurrence, all teaching took place in a lecture room. A schematic diagram showing the layout and student seating plan is provided by Figure 5-1. The room had five rows of wooden benches with aisles up the middle and sides. Each bench could accommodate up to four students although in the case of this class, Susan made them sit three to a bench except for the one bench at the back that had four students. Consequently, they each had plenty of bench space on which to work. Down each side of the room were large windows, one side adjacent to the corridor and the other side looking onto a field. At the back were two notice boards virtually covering the back wall. They contained school notices, a few posters from government departments concerning water conservation and the year of the tree. These did not change during the year.

The room was relatively small with a demonstration desk at the front. Behind it was a large blackboard on which all teaching took place. In front of the desk, on a small table was an overhead projector which was rarely used. Susan usually sat behind the desk using it as a large table. It was always covered with piles of student books, notes and Susan's personal books and effects. On the one side near the door was a bookcase that held copies of the notes given to the various classes and piles of student test books and a few textbooks. On the other side of the bench were an unused fume cupboard and a door leading into a storeroom. This contained a desk for Susan and chemicals, glassware and apparatus arranged on open shelves. It was not well organised and showed evidence of stuff being hurriedly put away or simply left on the floor after a practical activity.

All students were quite close to each other so conversations could take place between Susan and a student or between any two students without much effort or shouting. During the year, some of the students did change their positions. In one case Susan moved a student for disciplinary reasons and sometimes students would fight with others in their row and the next day would have swapped or just joined another row. However, this was not the norm. For the most part the students kept the same seats for the whole year.

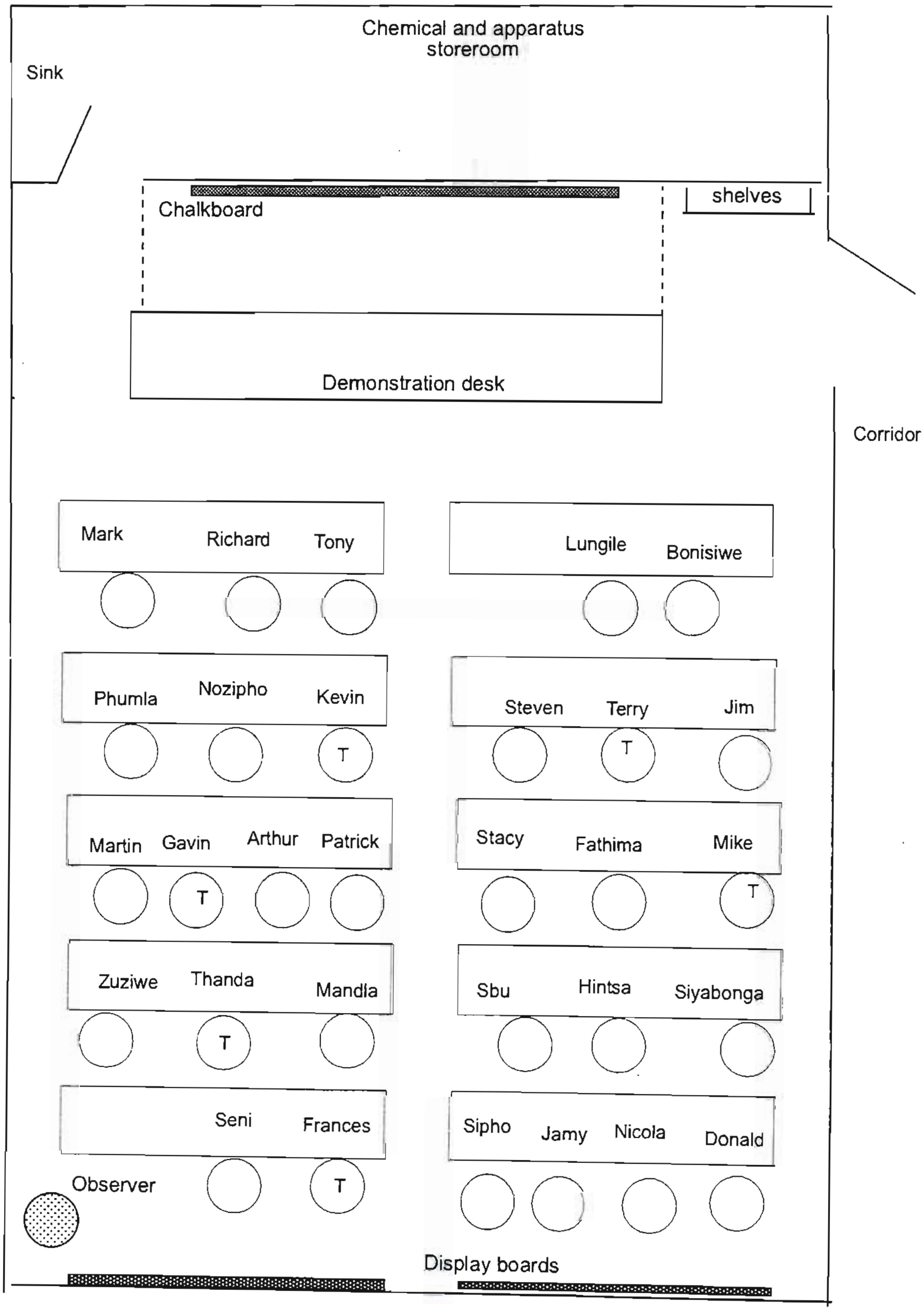


Figure 5-1 Diagram of Susan's classroom.

Use of time

Physical science was taught four times a week (three double periods and a single) giving a total of seven 35 minute periods a week. In all, the students attended 9 periods a day of 35 minutes each. Examination of Table 5-1 shows that they attended science class 122 times during the year for a total of about 116 hours with approximately 23 hours (44 periods) lost due to the scheduling of term examinations or other reasons such as Susan not being present at school.

Table 5-1 **Susan's class: Number of periods for teaching science in each term**

Std 10 year Term	Weeks	Scheduled periods of 35 min	Loss due to various reasons	Maximum available for teaching	Reserved for scheduled Exams	Teaching Periods (35 min)	Actual contact sessions
1st Jan-March	11	70	6	64	4	60	36
2nd April - June	12	80	8	72	11	61	34
3rd July- Sept	9	63	4	59	11	48	30
4th Oct- Nov	5	30	0	30	0	30	22
Totals	37	243	18	225	26	199	122

The syllabi for standard grade and higher grade contained the same sections or topics of work. Consequently, Susan was able to teach the sections at the same time. Table 5-2 provides the sequence in which the topics were taught for the two years.

Table 5-2 **Susan' class: Order in which the syllabus topics were taught.**

Term	**Standard 9 Year 11**	**Standard 10 Year 12**
1st	Basic concepts in chemistry Periodic Table	Graphs & Equations of motion Newton's laws &Gravitation Momentum & Work, energy & power
2nd	Bonding Kinetic model of matter	Electrostatics Electricity, Rates & Equilibria
3rd	Inorganic chemistry (Sulphur, Nitrogen etc)	Acids & Bases Electrochemistry Organic
4th	Vectors	Revision in preparation for examination

Where higher grade students were required to do different work, she would set work for the standard grade students and then work with the higher grade group. She often gave different worksheets and tests to the two groups and would go over the work independently. She would ask the one group to continue with their worksheet problem tasks, while she went over the other group's test or homework. This organisation of the teaching disadvantaged the standard grade students to some extent. Susan had to cover topics in more depth with the higher grade students. This took up time, which in a class of only standard grade students could have been spent working though relevant problem tasks at a slower pace. At the same time, the higher grade students were to some extent disadvantaged. When dealing with a task that was exclusive for higher grade more than half the class would not be listening, and there was a tendency for noise levels to rise as conversations started amongst the standard grade students. The flow of her explanations would be interrupted by students querying if this topic was also applicable for them, or by Susan checking to see that they were doing the work allocated or asking them to quieten down.

For example, during the teaching and learning of the topic chemical equilibrium Susan had to work with the higher grade students on the calculation of equilibrium concentrations which was not in the standard grade syllabus. In the following extract, Susan had just completed going over the previous day's homework involving a few problem tasks on Le Chatelier's principle:

Mrs S.: Today I want to do.......What I want to do today..."Let's look at a theoretical equation".

[She then explains the derivation of the equilibrium constant expression. She works on the board and some of the students are listening while others are not paying attention. She then ends her explanation.]

Mrs S.: ....divided by the product of all the reactants. Now that is a long mathematical explanation to get to this formula. That is the general formula for all equations.

Frances: Does standard grade need to know that formula?

Mrs S.: No.

Student: Standard grade doesn't need to do this?

Mrs S.: Standard grade does not need to know that.

[She laughs and some students make comments.]

Gavin: Here I was wondering how I was going to understand this.

Mrs.S.: But it is very easy to understand. You are not going to be examined on it as such, but I am going to give you a few examples to do, just......[Student interrupts her]

Frances: Is this a standard grade section?

Mrs S.: No it will be, ... Effects on the reaction rate is a standard grade section. Your............ Calculations are not a standard grade section.

Student: Theory?

Mrs S.: Theory is a standard grade section. So, I am going to let you go half way in the calculation process. All right. So how does that apply to a genuine equation. This is for HG. You must know the derivation of it.

Student: If there is more than one product.

Mrs S.: Goes on top of the line. I will show you what happens using hydrogen iodide example.

Gavin: Phew, I don't know how they expect us to know that.

Mrs S.: OK, let's take the example....

[writes on the board and explains how to get the Kc value.]

$$H_2 + I_2 \longrightarrow 2HI \qquad Kc = \frac{HI^2}{H_2I_2}$$

Mrs Smith: That's as far as I want to go.

Gavin	Is that the answer.
Mrs S.	That's the answer as far as standard grade are concerned.

This extract shows that the students were sometimes confused as to exactly what was to be left out. In most cases, Susan would simply announce that this section was not in the syllabus or not examinable. The students never questioned why it was to be left out but would rather concentrate on determining exactly what was to be left out.

5.2 OVERVIEW OF YEAR'S ACTIVITIES

During my time in the classroom, I paid careful attention to the different classroom topics and activities that took place in Susan's classroom. I felt that an important indicator of the role that various activities, such as problem solving and practical work, played in the teaching of school science, could be deduced from the relative amounts of time spent on them during the school year. In the following sections a general description of the time spent on each physical science topic and classroom academic activities is given. The focus is on how the time was used for teaching and learning. This is followed by a description of the recurring patterns of these activities, together with changes that occurred during the year from semester one to four and as the topics changed from physics to chemistry.

5.2.1 Use of available time

Each topic in the syllabus was treated as a separate unit of work with Susan announcing its beginning and end. It would have its own distinct set of notes, worksheets and tests. Table 5-3 below indicates the approximate number of periods that were spent on each of the sections during the year compared to the syllabus allocation.

At the beginning of the first term, Susan spent a few periods revising Vectors. She then dealt with the section “Graphs and equations of motion”. According to the syllabus, this should have been completed in Standard nine. Susan kept to the general guide provided by the syllabus. However, when it came to the third term and the final chemistry topics, much less time was spent than advised by the syllabus. On more than one occasion Susan stated that she could complete the topic of electrochemistry in a double period which is a significantly less than the 15 suggested. The fourth term was spent preparing for the matric examinations with students working through past examination papers.

What is not reflected in the table are the periods spent going over the term examinations in June and September and the periods spent doing general revising. These involved all the topics dealt with during the year and some of the examinable topics dealt with in standard nine e.g. inorganic chemistry and vectors.

Table 5-3 Time allocated in syllabus vs actual time spent per section.

Topics taught in Standard 10	Syllabus guide (35min periods)	Actual periods
Graphs & Equation of motion	(±15)	17
Newton's laws, momentum and WEP	30	30
Electrostatics and electricity	42	38
Total for Physics	72 (87)	85
Rates and Equilibrium	18	13
Acids and bases	18	15*
Electrochemistry	15	10*
Organic	21	15*
Total for Chemistry	72	53

( ) The topic "Graphs and Equations of motion" was supposed to be completed in Standard nine. The 15 refers to the allocation for standard nine.

* The distribution of periods for the chemistry topics is accurate to within two or three periods only as I was not always present.

5.2.2 Patterns of activities

Although the amount of time spent per topic was in most cases very different, the general pattern of lessons was very similar across topics. Susan often introduced a new topic by referring to the examination requirements for the section. For example, in the extract below she referred to the practicals that they needed to do as they were listed as examinable in the syllabus:

> Mrs. Smith:: Today, we're going to start the next section of work, which is acids and bases, and I've got the notes for you.
>
> *[Short time interval while students talk to each other and the notes are distributed by Susan]*
>
> Please make sure that you've all got those. Now, this is a very nice section of work, Standard 10. There are some pracs involved, which you will do yourselves. Um ... and they are examinable. Fairly soon - I'm not quite sure of the date, but sometime before trials - you'll be writing a prac exam ... on the examinable pracs so I will let you know which ones you're looking at.
>
> *[One minute discussion between Susan and a student who says he did not write any practical examinations in standard 9.]*
>
> Okay, Standard 10. Let's start off with two words that I want you to look at and explain the difference to me. We've discussed them before. The one word is "dissociate" and the other word "ionise". Spelt with s or a z. Right. Who can explain the difference to me between those two words. Give me the name of one substance which dissociates and one substance which ionises. ... Without reading the notes. ... I want you to use your memory, or the little bit that - hasn't been lost over the holidays. (Susan, fieldnotes, 28/07.)

Susan then spent a short time introducing the topic and explaining the main concepts. This did not generally exceed 20 minutes. During this time, some form of formula or set of principles would be introduced and a simple example demonstrated on the board where the formula or principles were used. A worksheet would then be handed out or problem tasks in their textbook would be allocated.

These problem tasks were assigned to be started in class but to be completed as homework. The following day she would work through the problem tasks. When that was complete, she would introduce a further topic or associated formula. The same pattern would be repeated with problem tasks allocated and gone over when completed by the class. When all the formulae or principles applicable to the section had been completed, then a longer period was spent with students doing further problem tasks. Susan acknowledged this regular pattern of dealing with the subject matter, as being typical of her teaching.

> Int.: I would like to reflect on that particular one, and the first question is how typical a lesson is that, in terms of the whole year? Obviously, no other lesson will be identical to that one.
>
> Susan: Yes. I think it's pretty typical. I try to do it so that I do the work at the beginning of the lesson, perhaps start off the lesson with marking homework, that type of thing, then I try and go through the ...if there's any content to be taught, to teach that content. I like to have questions related to that content answered immediately afterwards. And then an extension for homework and anything like that. I think it's pretty typical of what I'm trying to do.

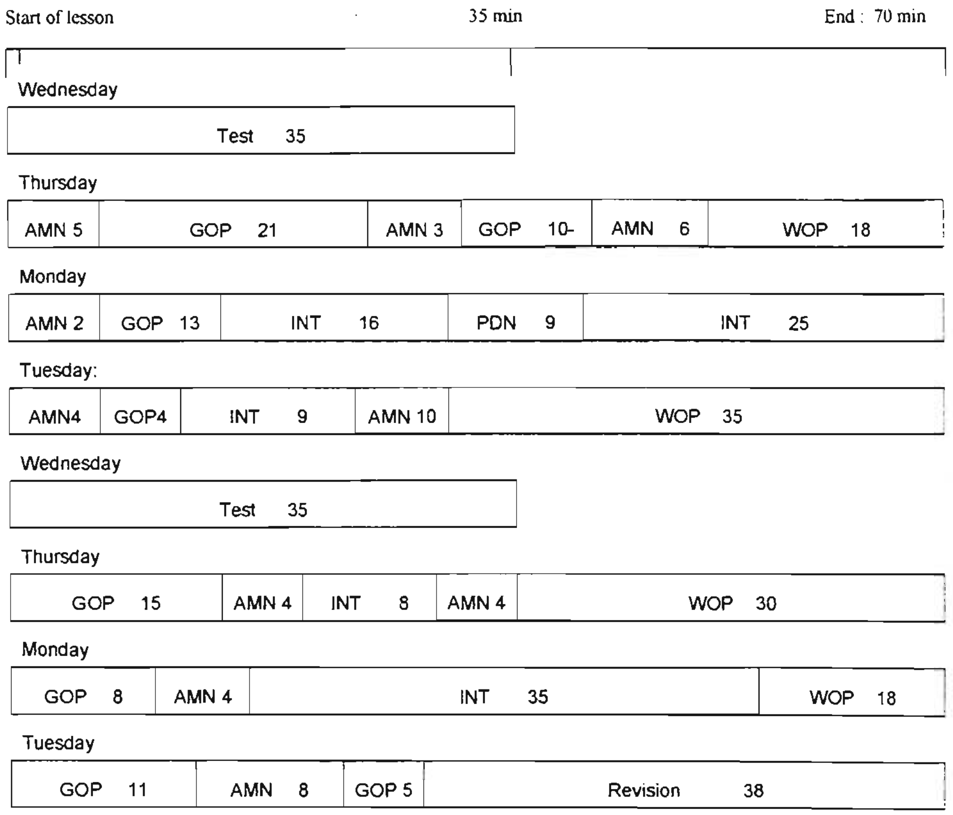
This pattern was also recognised as typical by the students:

> We learn about the certain chapter and we get notes and also worksheets on that chapter. If there's still some time before the end of period we start our worksheets and finish them for homework. Sometimes they are given simply as homework. (Bonisiwe, questionnaire)

This sequence would be interrupted by a test that was normally held on the Wednesday and some time on the Thursday or subsequent day, was used to hand back the books and go over the problem tasks. Very occasionally, they would spend time doing a practical activity. An example of this normal sequence of activities for two weeks, is presented in Figure 5-2 below.

Susan divided the section dealing with chemical equilibrium into four main topics. On the Monday, after completing the section on Rates of reactions, she introduced the topic of chemical equilibrium and concentrated on dealing with the general factors affecting equilibrium. Having given the class homework, she went over this on Tuesday. This was followed by an introduction to the expression for the equilibrium constant (Kc value). A worksheet of problem task was given and the students work on these in class. The homework was to study for the test that would take place the next day. On Thursday, Susan went over the problem tasks from the Tuesday and introduced problem tasks dealing with the calculation of the value of the equilibrium constant.

The pattern continued with the last part of the topic dealing with the calculation of equilibrium concentrations taking place on Monday. These time intervals of presenting new topics or problem types were followed by activities of working on problem tasks and going over problem tasks. This was a characteristic sequence of



Key to abbreviations

Numbers represent time in minutes. Example INT 8 represents 8 minutes spent on introducing a new topic.
The bars and divisions are not to scale

AMN	Administration.
GOP	Going over worksheet or test problems .
INT	Introducing a new topic or problem type.
WOP	Working on problems.
Test	Writing a test.
Revision	Working on problems from a previous section
PDN	Practical demonstration

Figure 5-2 Susan's class: Sequence of activities during two weeks.

activities for Susan's class interrupted only by work associated with tests and examinations or a rare practical activity.

5.2.3 Changes during the year

Although the sequence of activities were very similar across topics, the proportion of time spent on each of the activities changed as the year progressed. Table 5-4 indicates the time spent over a two week period at the start of a new section for both a physics section of work (equations of motion in February) and a chemistry section (chemical equilibrium in June).

Table 5-4 **Comparison between time spent on activities for a chemistry and a physics topic.**

Activity	Physics topic		Chemistry topic		Average	
	(min.)	% of total	(min)	% of total	(min.)	% of total
Administration	59	12%	85	17%	144	15%
Direct teaching	85	18%	106	22%	191	20%
Working on problems	224	46%	101	21%	325	33%
Writing a test	35	7%	70	14%	105	10%
Going over problems	87	18%	88	18%	175	18%
Revision			38	7%	38	4%
Minutes available in two weeks	490	100%	490	100%	980	100%

While the other activities showed little significant difference, the relative amount of time given to the students to work on problem tasks in class, decreased significantly from 46% for the physics topic to 21% for the chemistry topic which took place later in the year. It must also be remembered that while the time decreased by half, the total amount of time allocated to a topic also decreased for the chemistry topics (see Table 5-3). Consequently, the actual time allocated to working on physics problem tasks in class was significantly greater than that spent on chemistry problem tasks.

5.3 THE CLASSROOM ACTIVITIES

To provide some perspective on the years activities, the percentage of total available time allocated to the various activities is represented in Figure 5-3.

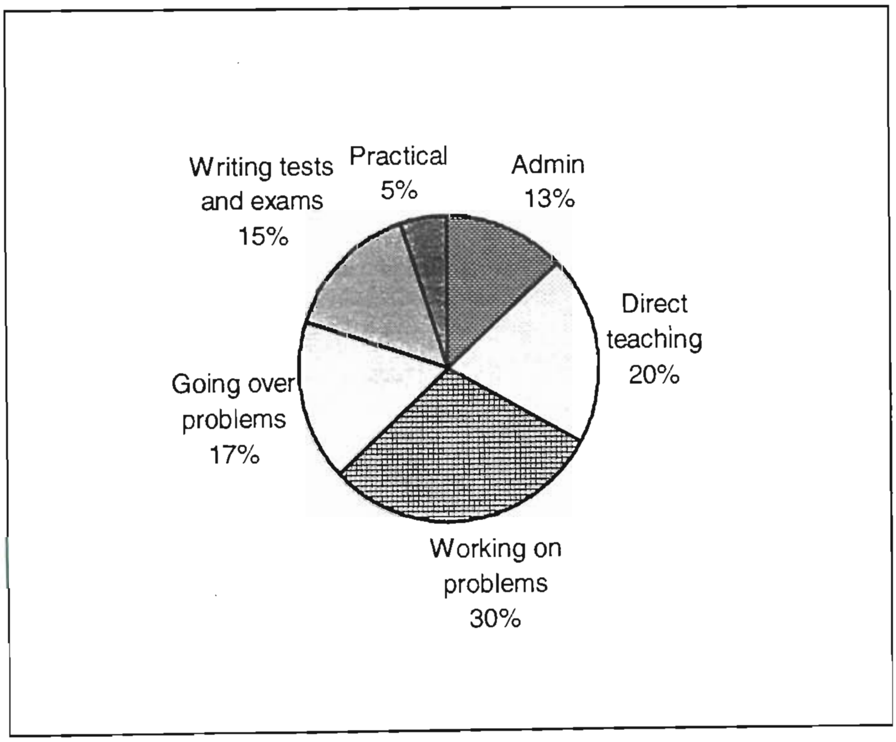


Figure 5-3 **Susan's class: Percentage of time spent on each activity.**

Because I was not present for every period that was allocated for science during the year, the figure represents an accurate approximation based on a detailed analysis of four weeks of teaching i.e. two weeks of physics and two weeks of chemistry. I extracted incidents of other activities such as tests, examinations and practical session from my fieldnotes. Combining this information produced the approximations presented. Each of these teaching activities is described in the following sections.

5.3.1 Direct teaching

When Susan wanted to introduce the class to a new section of work or show them how to solve a new type of problem task, she used a style referred to by Tobin (1987) as whole class interactive. She would talk to the class as a whole using the chalkboard to illustrate her explanations. While she was explaining she would interact with individual students by allowing them opportunities to respond to questions she posed or to ask questions. The rest of the class would listen while this took place. This type of class activity occupied about 20% of all time.

A typical example of the style of teaching used in presented in Appendix E. This extract was typical of Susan's style of teaching especially for the physics topics. Her direct teaching style fits the pattern of being “formula-driven” (Touger, Dufresne, Gerace, Harddiman, & Mestre, 1995). She would introduce the new law or concept through a question and answer session trying to link it with work they had previously done or with something, they could identify from their everyday lives. In this example, she is leading them through, appealing to personal experience and logic e.g. “If I had two identical objects, one made of iron and one made of plastic and I applied the same force to each of them. What is going to happen?”. Once the main concepts or nomenclature had been introduced, she would provide the appropriate formula to use. She would then demonstrate how to solve simple examples.

This pattern was normally used, except where a concept or principle did not involve a formula e.g. Newton's first law. During her direct teaching, many questions were asked by students mostly asking for clarification. They would constantly call out questions, while she explained. These questions were limited to five or six target students. There was also an emphasis on what was likely to be asked in the examinations. If Susan did not indicate exactly the range of problem tasks or requirements for the examination, one or other of the target students would ask e.g. in this extract Frances asks clarification “ Will we have to know the actual wording of the law?”.

I normally found Susan's explanations lacking in qualitative exploration of the concepts or principles. Rather the direct teaching would focus on the relevant formula and typical problem types associated with it. In general, it appeared that Susan would use direct teaching whenever she wanted to introduce students to new ideas or problem types, or to help them when they were stuck with getting to the solution to a problem task.

5.3.2 Going over problem tasks

Susan spent a considerable amount of time (17%) going over problem tasks, which the students had attempted in class, for homework or during tests. Although this activity was very similar in nature to direct teaching, I have placed it in a category of its own. It always had the same focus of providing answers and solution paths to the allocated problem tasks. Despite the large number of problem tasks only a relatively small amount of time was allocated to this activity. She was able to do this by using two methods detailed below.

If homework had been set, then Susan would wander around the class and sign their books while checking to see if they had done the work. She would then proceed to go over the problem tasks using two methods. The first method, which I refer to as the oral method, would be used with simpler problem tasks and would not involve board work. Susan would sit on a desk at the front of the class and read out the problem task from the worksheet, test or textbook. Sometimes she would just state the answer, and on other occasions a student would call out the answer. If there were no dissenting voices, she would ask if anyone had a question. If no student indicated a difficulty, she would move on to the next problem task. In this way, she could complete a number of the problem tasks in a short time interval.

The second method involved verbal explanation and board work. She would read the question out aloud and then lead the class through the solution steps with constant reference to diagrams, equations and calculations that she wrote on the board at appropriate stages. She would use this method when students indicated they did not understand how to do the problem task. She would also do this for particular problem tasks without requests coming from the class, as if she was aware of which problem tasks would be found difficult.

In the following extract, Susan was going over a test which was written the previous day. She had handed out the marked test books and proceeded to explain how to solve the problem tasks. Only about five or six students are paying careful attention to her explanations of how to do the problem tasks. Most are busy looking at their test answers:

Mrs. Smith: Question number four. Did the mass have anything to do with this question? ... Was the mass important to this question? ... No! . OK, right. A steel ball of mass 10kg is released from a tower 320 m high. It reaches the ground after 8s. Neglect air pressure and air resistance and calculate the value of g using this information. OK what have you got?...You have got the initial velocity was zero, the mass 10kg the tower was 320 m high and the time was 8s and you have to calculate g
[She writes the values on the board]
The mass in this situation had no bearing on the question. Right, so you can in fact ignore the mass.
[She crosses it out]
We are trying to find the acceleration with initial velocity, time and displacement ......Which formula are we going to use?

Student: *[Some start calling out s equal ut...]*

Mrs. Smith: $s = ut + \frac{1}{2}at^2$ and because u was nought we can ignore that part and we find that a is equal to s over $\frac{1}{2}t^2$.
[Writes this formula on the board]
So that will be equal to 320 over $\frac{1}{2}t^2$. 8 x 8 is 64. So 32 ..... so your answer is 32 ms^{-2}.
Very simple straight forward calculation. Are there any questions standard grade? Are you happy with that?....
[A few students make indecipherable comments about the length of the test and after a short discussion the lesson

> *proceeds with the next activity.]*
> (Susan, Lesson transcript, 18/02)

Although the majority of students responded positively to my questions about Susan's methods of going over problem tasks, there were some who had suggestions to improve the activity. Hintsa expressed a need for Susan to allow the students more opportunities to work on the board and demonstrate how to solve a problem task, something which she only allowed to happen on rare occasions. Mark complained, "But she doesn't go through many standard grade problems. She goes through them orally but not physically on the board." At the same time, he suggested that she not provide explanations where only a small number of students had difficulties but rather just "show them where they made their mistakes". One can understand this latter comment. Even if one student said they did not understand, she would do it all again "for their benefit ". In most cases, the explanation would be similar, using the same notations on the board. However, she would emphasise each step of the solution strategy and check with the student to see if they were following or had a question. While this occurred the other students waited patiently or not so patiently.

5.3.3 Working on problem tasks

Students had opportunities to work on problem tasks both at home and during normal class time. They were given a large percentage of the time available in class (30%) to work on the problem tasks. Susan allocated the problem tasks, taking them from worksheets or from their textbook. The precise number of problem tasks was allocated sometimes out of sequence (e.g. "Do numbers 1,2, 4, and 9"). She would indicate the formula or principle that they had to apply to solve the problem tasks and she would emphasise that the task would not take them very long.

When given these problem tasks, the students worked in a variety of patterns. The most common pattern was working as a pair, with the student sitting next to them. About nine pairs of students worked together in this way. They would work individually in their exercise books and keep up communication on the problem task with the person sitting next to them. If they were uncertain about the value to use or the formula that had to be used, they would simply confer. Often they would work together on a problem task i.e. writing on one piece of paper and both contributing ideas for the solution which would then be transferred, so both exercise books had the solution. The remaining students worked by themselves. Students were permitted to walk around in the class, and several of them took advantage of this to consult with other students. During this time, Susan did a lot of interacting with pairs or individual students. They would leave their places and go down to Susan at the front bench where she would help them with their task.

5.3.4 Writing tests and exams

Tests and examinations were a regular feature of the timetable. Susan allocated a single 35 minute period on Wednesdays for tests. During the first half of the year, they regularly wrote a test each Wednesday. In addition, school examinations took place in March, June and September in each case, a week or two before the school term ended. In all, they wrote twelve tests and three examinations occupying about 15% of time available. At the end of a section, Susan would announce when the test would take place. She would provide a few days for study and then schedule for the nearest Wednesday. This resulted in tests taking place a few days or weeks after the completion of the section. Although the students knew that regular tests were a part of the school programme in all subjects, they would always complain about tests that had to be written. When they approached a scheduled examination, time would be allocated in class for revision of some topics. Susan would allow them to choose a topic they were having difficulty with and she would answer any questions or provide a quick revision of the main concepts and problem types. Students would also prepare by doing past examination papers. Consequently, the writing of tests and preparation for them took a significant amount of the science lesson time.

5.3.5 Practical work

While the school had a number of laboratories for practical work and employed a laboratory assistant, only a small amount of time (5%) was spent doing practical work during the year. That which was done fell into two categories, demonstrations by Susan and group work by students. The demonstrations were of short duration and would illustrate some principle that they were dealing with in class. There were no more that four or five demonstrations during the year. There was only one demonstration during the physics' sections. Susan took the class onto a sports field and she threw various objects, such as a cricket ball and tennis ball, at them to catch. This was used as an introduction to the section on momentum.

When the students did group work, these practicals took place in the laboratory next door to the classroom. The students would be divided into groups of four or five and given an instruction sheet to follow. For example, when the students were doing a practical involving Ohm's law, the apparatus required was given to each group. Following the written instructions, they set up the circuit, had it checked by Susan and then took a series of readings which they recorded in their practical book. For homework, they had to analyse the data by drawing graphs and write up the practical. (The steps were provided in their instructions and again described in detail in their textbooks, including the analysis and conclusion.) Susan then marked this. Besides the Ohm's law practical, they did a titration for acids and bases and constructed an electrochemical cell.

These practicals did not necessarily take place at the time in the teaching sequence when the principles were being dealt with or immediately after the "theory" lesson. For example, the titration preparation took place on the 5th Aug while the practical itself was done on 24th August. A written practical examination was held later in the year. While this included questions on a number of practicals that they had not actually done themselves, they were able to learn for this test by referring to their textbooks which described all the relevant practicals in detail.

Neither the students nor Susan was satisfied with the situation involving practical work. Susan expressed a desire to do far more and blamed herself for being lazy. However, she did not appear convinced that the practicals would help the students significantly in their examinations. The following comment was made after a lesson on the force between parallel conductors. She had drawn the diagrams on the board, drawn attention to the sketches in their textbook and presented the formula to calculate the forces, but no demonstration was carried out despite the apparatus being available at the school. In the interview, I was asking questions about the usefulness of a demonstration:

Int.:	Would it have helped them in any way to solve problems?
Susan:	I don't think so.
Int.:	Would it have helped them to get better marks in the final exam?
Susan:	They might have got one extra mark remembering that it came together and went apart, but I don't think it's any ...perhaps...I mean I doubt whether it would have been anything that they couldn't learn, but it is better if they do see it, then they do......they do tend to remember it better. But I just find with practicals ......it actually takes up so much of lesson time, and preparation time. At the moment I just actually don't have it. ....I say it's probably laziness and I should have made more effort. But I don't think it's going to get them an extra mark in the exam. If they're that keen then they would have learnt it anyway. (Susan, Interview, 28/06)

The students enjoyed the practical work and were unanimous in a desire for more practical work. This is exemplified by the following comment from one of the students:

> Maybe we should do practicals more than theory, by then everybody will have a chance to do experiments. I promise you that's what every science student would enjoy the most. (Zuziwe, Questionnaire March)

5.3.6 Administration

A feature of Susan's class was the significant amount of time that was spent on what could be termed non-teaching activities. I categorised these activities under the heading of administrative matters. It included a number of activities such as the handing out of notes, students arriving late and delaying the start of class, obtaining test marks from students, chatting to students on matters unrelated to the syllabus topic etc.

It was extremely rare for all 35 minutes of the period to be used for teaching and learning activities. Often the start of the lesson would be delayed a few minutes as the students arrived late from a previous class. They would enter talking, fooling with friends, go to their place, and spend a minute removing their science books from their bags and settling in for the lesson. At the same time, Susan would also be putting notes and books aside from the previous lesson. It would have been impossible for Susan to start the lesson at this stage. There were often administrative matters that needed attention, especially at the start of lessons. Added to this, there were many disruptions to the lessons. For example, Susan would be called away from class to deal with a general school matter. As previously stated, she had a number of responsibilities and would be called to deal with them. These ranged from a quick consultation in the passage to leaving the class for up to 5 minutes while she went to some other part of the school. While Susan complained about the variety of responsibilities and the work involved she did not prevent staff from interrupting her lessons. Overall this administrative "activity" added up to a significant amount of time being approximately 13% of all available time and was accepted as a normal occurrence by all the participants.

5.4 CLASSROOM ENVIRONMENT

In describing the classroom environment, I have focused on four areas that I felt would help characterise Susan's classroom environment. These were the general classroom behaviour, the student-teacher interactions, the participants' views of each other and their views of school science. These are each described in the following sections. Together they should provide the reader with some insight into the environment that existed in Susan's classroom.

5.4.1 General classroom behaviour.

While time was set aside for the different activities, this did not necessarily mean that all the students spent their time concentrating on the task given to them. In fact, many of the students were busy with other tasks. While most students would pay attention at the beginning of her explanations, this was not the case, all the time. At every opportunity, students would get distracted and it was not unusual for her to talk with a background murmur from a few students holding conversations with the student sitting next to them. A couple of students would simply read their textbook or notes. They would look up every now and then and would keep pace with the lesson, but were obviously not listening to Susan's explanations.

Sometimes they would fall behind and would not know what stage had been reached, as evidenced by the following comment during a lesson. Susan was using direct teaching to explain the derivation of one of the equations of motion. Gavin had been talking to the student sitting next to him and on looking at the board, was obviously lost.

Mrs.S: Right. So we want to get A on its own. U is added to A, so it will be V - U = AT. We want A on its own, so A is going to be equal to (V - U)/T. If you can do that in one step, please go ahead..... Do you want to go wash your face. [Speaks to student who had her head on the desk]

Fatima: No, thanks.

Mrs.S: You're sure?

Gavin: Where is this place?

Mrs.S: It's not anywhere. I'm talking to you. I'm teaching.

This was not an isolated incident. On many occasions students would be "lost" and would ask those sitting next to them "where are we?"

I can only infer that Susan was aware that students were not attentive. The evidence was overwhelming, including the background noise of students talking, students reading books on their desks rather than watching her teaching, students cutting and pasting their notes, the many requests for guidance as to what section they were doing or where they were. Every now and then, she would appear upset at the lack of attention For example in the following extract she was going over the solution to some homework problem tasks and interrupted her explanation:

Mrs. Smith: Right for question c. Find the velocity of the car after 11 seconds. What information do you use now? ..... You only need to use the time...5 s because the first 6 seconds it was moving at.....constant.....

Students (?velocity?)

[A few indecipherable murmurs from one or two students. Many students are busy with other activities.]

Mrs Smith: Standard ten! I actually get the feeling that nobody is listening.

Students (?No, miss.?)

[Two students laugh. Others make comments denying this.]

Mrs. Smith: I do get the impression that nobody is paying any attention and that I am wasting my time. .... Are you listening?

Students Yes

[A few students loudly reply "Yes" while many other give a general murmur of agreement.]

Mrs. Smith: OK. Right .... Right the velocity after 11 seconds .... Right the first 6 seconds it was moving at constant ....

No disciplinary measures were taken to encourage attentiveness or concentration on the task at hand. When working on problem tasks there was a similar background noise from students talking to each other and requesting answers or confirmation of answers for Susan.

There were four or five students, who actively avoided doing any productive work for as long as they could. For example, they would take five or ten minutes to settle down and actually start working on a problem task. Even then, they would become distracted and on occasion disruptive. Moreover, the number who avoided working increased dramatically when there was only a short time e.g. 10 minutes, before the end of the period. They would start conversations with friends, read their science or other schoolbooks, read library novels, or generally avoid doing any productive work in class. Given that this working on problem tasks activity was usually the last activity of the period, the students would anticipate the bell and start packing up their books. On some days especially when this was the last lesson of the day, and the bell would signal the end of the school day, some students would stop working as much as 10 minutes before the end. They would start talking to friends and the noise level in the class would slowly rise. Susan would always request them to "quieten down" and on occasion threaten them with more homework but this threat was never implemented.

Some students were not happy with the noise and indicated that it disturbed them. Mark raised this issue without prompting and said "I do try and work and people are making a noise and it puts me off. I can't concentrate and I'm trying to work ... and they don't want to do their work and it puts me off."

5.4.2 Interactions

When Susan was teaching or going over problem tasks, she encouraged the students to ask questions. However, very few of the class actually participated in asking or answering questions, without being directly asked by Susan. This was in part due to the presence of five or six target students who dominated interactions to the exclusion of others. Contributing to the lack of interaction was Susan's style of questioning which gave students very little time to respond before Susan "filled in" the answer.

Two of the target students, Frances and Thanda were by far the most vocal. Thanda was one of the top students while Frances, who dropped to standard grade during the year, had a very outgoing and dominating personality and was on the student representative council. When Susan asked questions of the class, they would shout out answers before others. They would also ask questions while doing problem tasks, by shouting to Susan at the front desk. When I asked Frances about all her questions and the lack of questions from others her response was:

> Their bad luck. They must look after themselves. The point is I mean it's the matric year. You can't put any one else worries on top of yours. I mean your main goal in life is to get through matric. Everyone thinks it's such a breeze. It's not as breezy as everyone thinks.

The target students were not limited to those who did well. When asked who he thought were her favourites in class, Mark responded that they would be those who got the highest marks but "There are people who don't understand and will not be her favourites but they will still get her attention." Gavin was one of these. In his case, many of the interactions were discipline related as Susan attempted to get him to work or prevent him from disturbing others.

Two of the students, both English second language speakers, indicated that they did not ask questions in class because they "had no problems". They said they would ask if they did not understand. Other than Thanda, the English second language speakers rarely asked questions during whole class activities. Within the data record of general classroom discourse there was very little record of students, other than the target students, asking questions. However, when the students were working on problem tasks, many different students would approach Susan for help either individually or in pairs.

5.4.3 Views of participants

When asked her opinion of the class, Susan responded that she liked the class but they were of very mixed ability and she was not expecting wonderful results from them. Susan would often talk to the class on topics that were unrelated to science. She would engage with individuals or the whole class on diverse topics such as career choices to school sport to current affairs. From her comments, it was obvious that she knew in which extra mural activities they participated. From all the questionnaires and interviews that I carried out, only one student had what could be considered a negative comment to make about Susan. The comment came from one of the students who was not achieving very well:

Hintsa: I would like a teacher that checks the work every time. And a teacher that wouldn't leave anything when teaching. A teacher that will teach everything that is necessary.

Int.: Everything that's necessary for what?

Hintsa: For the syllabus. Like ... like a teacher that wouldn't leave some other things because she thinks they're easy. Or a person that will, a teacher that will do the work thoroughly. Until the ... students understands it.

Int.: And at the moment, do you think Mrs Smith does that.

Hintsa: Yes I think so.

Int:. So she does it thoroughly.

Hintsa: Ja, but sometimes she is ... fast. ... And she doesn't. Is she going to know about this.

Int.: No Nobody will know your identity except me.

Hintsa:	Ok She doesn't check to see whether all the pupils understand what she teaches.

The students were convinced that Susan judged them in terms of their success at school. A number of student responses, especially from the students who were not doing well academically, indicated this. Hintsa's comment was typical.

Int.:	What do you think the teacher is thinking about you.
Hintsa:	I think she is thinking about my low marks in the test.
Int.:	So do you think she's saying that you're not good at science or that you need to study more, or that you're not clever, or, what do you think the teacher is thinking. That you don't pay attention. What do you think the teacher is thinking about you.
Hintsa	I think she thinks that .. I'm not clever.

Overall, the students responded positively to the class environment. They felt the atmosphere was friendly and relaxed. Kevin, one of the target students saw it this way:

> Very friendly. If you have a problem speak out. There's always someone to help you. If it's not the teacher one of the pupils will give you a hand. Don't be afraid of making mistakes, everyone does.

When it came to commenting on the science they did, the comments were not all positive. The comments fell into three main categories. About 12 students made direct reference to the learning of science. Four stated that they enjoyed school science. About an equal number indicated that they either disliked a part e.g. physics, or when they did not understand, they disliked the science lesson. This view was most strongly expressed by Nozipho:

> Sometimes I enjoy science and sometime I hate it, like when I don't know something or keep on failing, I feel like I'm a stupid and this leads to a point where I hate the science period. (Nozipho, questionnaire)

A small number did not have positive attitudes. Unexpectedly for me, Frances, a target student who showed much enthusiasm for the learning of science, did not have much positive to say about the science lessons:

> Well I can't say it's the most interesting subject. But I mean it is a little bit more interesting than say History. I mean I used to do better in History, in standard seven, going into eight to choose my subject package than Science. But I mean History was just so boring to me that I took Science you know. It's a little bit more interesting than most subjects. But I mean I would say Art and even Maths is a little bit more interesting than Science.

However, most students expressed very positive attitudes toward Susan as their science teacher and their general attitude can be summed up by the following comment from Mark:

> Well she, she is a good teacher. She tries, she tries to help everybody individually. She tries to make you understand your work. And she's a good person. (Mark, interview)

CHAPTER 6

PROBLEM TASKS AND PROBLEM SOLVING

6.1 INTRODUCTION

The previous two chapters provided detailed descriptions of two contexts in which the teaching and learning of science took place. The case studies of Jack's and Susan's classrooms provide a rich description that enables a holistic picture to be developed, of what happened in those classrooms. These descriptions and pictures provide the contextual base for the knowledge claims made in this and the following chapter. These chapters provide an interpretive commentary, which is the point of the study where I have gone beyond the descriptive facts and tried to suggest what the meaning of all the data and analysis could be. This interpretive commentary consists of assertions, empirical evidence and commentary.

The empirical assertions are the answers to the original research questions. They represent knowledge claims about patterns and regularity found in the data. These assertions were obtained from the data through a process of careful and systematic analysis, described in detail in section 3.3. Each assertion was constructed from a cluster of related sub-assertions, each supported by its own evidence. Two types of evidence, particular and general, are given to support the assertions. Particular evidence consists of analytic narrative vignettes, quotes and extracts found in the data during analysis. They show that the actions described or referred to in the assertion did happen. Where appropriate, I have emphasised the participants' own words allowing the teachers and students to speak for themselves. Key or critical events in which "the essence, but not the detail, of the whole is revealed " (Wolcott, 1994 p.19) have also been selected. General evidence consists of frequency data and summary tables. They indicate that the occurrence was typical and occurred in different circumstances and that one can therefore generalise within the case. In the commentary those details which have contributed to understanding and interpretation of the context, are highlighted. It is here that the findings are linked to the theoretical framework by comparing and contrasting the findings with those of others in related literature.

The interpretive commentary is presented in two chapters, based on the nature of the assertions and the questions they answer. This chapter (Chapter Six) has as a focus the problem tasks and the first research question, "What is happening here?" Consequently, the assertions are essentially descriptive in nature. In Chapter Seven the focus turns to the other research questions i.e. What role do problem tasks play? Why are they used in the way they are? Consequently, the second set of assertions focuses on understanding why things are as they are.

6.2 THE PLACE OF PROBLEM TASKS IN INSTRUCTION

Assertion 1: ***The solving of problem tasks was the primary focus of the teaching and learning activities to the virtual exclusion of other activities. Students found the repetitive solving of problem tasks boring. They encountered hundreds of problem tasks, the majority of which were stripped of real-world complexity. Nevertheless many students found the situations interesting, relevant and linked to their lives.***

6.2.1 Introduction

Science teachers have a responsibility to provide a learning environment in which the students can develop the desired skills and understanding set out in the syllabi. To achieve this they plan educative experiences that provide students with opportunities to engage in appropriate learning activities. The role the activities play will depend on the types of activities, the order in which they are encountered and their focus.

Many different types of activities are possible within the school environment. These range from individual activities such as writing a test to whole class activities such as a teacher explaining how to set up apparatus. Depending on a number of factors such as school resources, students may encounter a limited set or a broad range of activities in their science lessons.

Secondly, teachers differ in how they present a topic. They organise events in different sequences and construct them differently (Contreras & Gallagher, 1989). This depends on the teacher's beliefs, interpretation of a topic and previous experience. One teacher might introduce a topic by elaborating conceptual issues while another teacher might start with a practical activity.

Thirdly, there are a number of alternative focuses for the individual activities. For example, in the case of a discussion activity, an explanation of a phenomenon or provocative statement could be the focus. Other examples of focuses are: a debate on a controversial issue; the gathering and interpretation of data in a practical activity; and a piece of scientific text.

Taking these three components together, it is clear that students could experience a variety of activities, in different combinations and with different foci. The assertion above stands in contrast to this possibility. The following sections provide evidence to support it.

6.2.2 A focus on boring problem tasks

Assertion 1a: *Activities with a focus on the solving of problem tasks occupied about three-quarters of all available time.*

The extract of Jack explaining how to solve a problem (Appendix D) is a typical example of the educational experiences provided by Jack. In particular, it illustrates how a problem task formed the central focus of the classroom activity. The students were assigned the task for homework the previous day and Jack was explaining how to obtain the answer. The focus of the activity was solving the problem task through an understanding of the problem situation and manipulation of appropriate formulae. At one stage, (line 65) Jack had the opportunity to use this problem situation as a vehicle for conceptual development i.e. change the focus of the activity from simply seeking a solution. When a student did not understand the problem, he expanded on the problem situation through providing analogies and short practical demonstrations. It is at this point that he could have changed the focus and allowed the students opportunities to discuss the situation. However, Jack did not allow this to happen. He cut short the start of the potentially fruitful discussion on friction and returned the focus to the next problem situation (line 118). It is clear that the purpose of his short demonstration was to provide a richer picture of the problem situation and through this to understand the solution strategy. However, the central focus of the activity remained the problem task.

This basic pattern occurred throughout the activities in both classes. A detailed examination of the use of teaching time in both cases gives convincing evidence that the problem tasks were the focus of teaching and learning for most of the available time. Table 6-1 below, presents the percentage of available instructional time spent on different activities for both classrooms. At least 70% of all time in Jack's class and over 60% of time in Susan's class involved students explicitly solving a problem task or being shown how to solve a task. The justification for deeming these activities to be solely focused on problem tasks was that questions that did not revolve around a problem task, such as those involving explanation of concepts or phenomena, were so rare or short, as to form an insignificant percentage of time spent. Such aspects did sometimes appear as a part of a problem task in a test, but in this case only a few marks would be allocated, implying only a short amount of time to be spent answering them.

Table 6-1 Percentage of time spent on different teaching activities for Jack and Susan.

	Activities with a problem task as the focus				Balance of activities			
	Writing tests & exams	Going over problems	Working on problems	Sub total	Direct teaching	Practical	Other	Sub total
Jack	20	51	0	71	18	6	5	29
Susan	15	17	30	62	20	5	13	38

The activities labelled as "practical" and "other" did not involve problem tasks. However, a case can be made for stating that problem tasks were also the focus of a significant proportion of the time spent on direct teaching i.e. when new topics were introduced with their accompanying new concepts and formulae. This was especially the case in Susan's teaching. This would raise the percentage of time spent with problem tasks as a focus to over 75% of all instructional time.

The following vignette, provides evidence that even when direct teaching took place at the beginning of a topic, the primary focus was often a problem task.

In this particular lesson, Susan is dealing with Newton's laws. She has handed out sets of notes that cover the topic and she explained Newton's third law to the whole class. This took no more than 5 minutes and she then introduced Newton's law of gravitation. A short discussion ensued between her and some target students about attraction between bodies and she introduced the symbols to represent the various physical quantities and the mathematical relationship between them. She then posed the question of finding the units of the universal gravitational constant. She explained how to determine this on the board through changing the subject of the formula. Once this was done, the formula was established and she introduced a problem of calculating the force between two students in the class. They discussed the size of the force in relation to the force of the earth on a student:

Mrs. Smith:	Now compare that force with the one which Patrick is exerting on the earth of 650 Newton's. The earth is exerting on Patrick 650 Newtons.
Students:	[*Indecipherable murmur*]
Mrs. Smith:	OK. Look now. Patrick and Arthur are exerting 9 times 10 to the minus 7 Newtons on each other. OK, the value of zero comma 1 2 3 4 5 6 7, *[Counting out the decimal places as she writes on the board]* Now that is the force that Patrick and Arthur are exerting on each other when they are sitting close together. Now the earth is exerting a force of 650 Newtons on Patrick and 780 Newtons on Arthur. All right, so can you see how much larger the force that the earth is exerting on you people, than the force that you are exerting on each other. OK that's a very, very tiny. Minute. All right, are you happy with that standard tens?
Student:	It's still there?
Mrs. Smith:	It's still there, yes it's still there. If you want to be 100 percent accurate, you actually have to work out all the forces, that the brick walls are exerting on you and the roof and everything else.
Student:	Is that your answer?
Mrs. Smith:	Probably 9, something. Around about that. When you're looking at 0,0000009 I think that's close enough. *[There is a 30 second break as Susan refers to two examples in the notes.]* And then there's some examples, or one example. The second one I want to do. Second type of question. The reason I won't go through this first question, it's pretty straightforward. OK it's just determining the force of two objects. 50 and 60 kg's separated by a distance of 2 metres. Very similar to the one I've written on the board, using Patrick and Arthur's mass. Now, the next question is especially for the Higher Grade. This type of question has recently also come up in the Standard Grade paper. Where you are given a force *F*, ... and you are asked what would happen to that force if you increase the mass. Now, as you can see from the way I set out the question here, there's no calculation involved. You're not given any values, you don't know what the mass was. So how are you going to work it out. You go to the formula. Can anybody give me any suggestions. Starting with the formula..........? (Susan, lesson transcript, 08/03)

Discussion continues with Susan giving examples such as "let's triple the distance", or "let's halve the distance". A lot of confusion is apparent and at the

> *end, Frances asks her for the answers to the examples given in the notes. She then tells them to read their notes on weight on their own. This is about half a page long and deals with the formula* $g = G M / s^2$ *and an associated example. She hands out a worksheet and they work these problem tasks for the rest of the lesson.*

Although I have classified this activity as direct teaching, it can be seen that a considerable proportion of the time was spent dealing with the formula for Newton's Law of gravitation and the solving of an example problem task. In the complete lesson, the theory introduction occupied a relatively significant portion of the lesson time, in total about 15 minutes of the lesson. However, it does represent one of the longest periods of concept discussion that took place in Susan's class during the year. In most cases, a very short time was spent on concept development before formulae were introduced and the focus turned to problem tasks even in the activities labelled as "direct teaching".

While Jack did spend the majority of time labelled as direct teaching focusing on conceptual understanding, there were some occasions when he used a problem task as a focus for introducing and developing the concepts. From the above examples and examination of the fieldnotes, I believe that it would be reasonable to infer that a significant percentage of the time classified as direct teaching, had as a focus the solving of a problem task. This would increase the actual time given in Table 6.1 to at least 75% for both classes. This allows me to make with confidence the assertion that about three quarters of all instructional time was spent with a focus on problem tasks.

Further evidence that problem tasks were the focus of nearly all activity came from student interviews in which they were asked to describe their science lessons to a visitor from another country. The following comment by one of Susan's students represents a typical response:

Mark:	Now well. ...... I would say science is just basically you've got a lot of formulas you have to know, you have to learn and you've got a lot a problems to work out, you know, to do with equations mechanical problems and then your chemistry problems. You've just got to know your equations.
Int.:	So what do you do everyday in this class?
Mark:	You work on problems. We spend time working different problems out.

It was obvious that for the students, doing science at school was identified with "doing problems". Problem tasks were the focus of instruction.

Assertion 1b: Students found the repetitive solving of these problem tasks boring.

There was overwhelming evidence that the majority of students found this instructional focus on hundreds of problem tasks to be boring. For example, in an open-ended questionnaire, given to students in which they were asked to describe what they did in science each day, more than half of the students expressed negative sentiments about the daily activities and the term "boring" or "bored" was frequently used somewhere in their description. The following comment represents one of many written responses:

> I believe school, as it has with all other subjects, has managed to destroy all the interest that is inherent in science - it is, after all, man's attempt at understanding the world around him. But this 'specialness' is lost in boring classroom routine, irrelevant trick questions and such like. (Marc)

On another occasion, when students were shown a video recording of a lesson in which Jack was explaining how to solve a problem and asked to comment on their actions, again a number of students gave negative written responses:

> Boredom - nothing interesting. Monotonous - nobody paying much attention. Too repetitive and boring to hold anyone's interest. Going over a simple question in too much detail. It almost puts me to sleep. (Burt)
>
> Science is not considered - by most normal students - as an exceptionally exciting or gripping subject. Our attention therefore does tend to be lost after some time. It is also extremely repetitive. As an artistic person I prefer more spontaneous subjects such as English and Art and therefore become bored by the monotony of science and maths for example. (Gary)

The evidence from classroom observation, the responses on the questionnaires, conversations and interviews were consistent with the assertion that the students found the science classroom activities, and in particular the solving of problem tasks, repetitive and boring.

6.2.3 Large numbers of problem tasks

Assertion 1b: *The students encountered a large number of problem tasks during the year.*

A common characteristic of both classrooms was the fact that the students encountered a large number of problem tasks, or as one student in Jack's class said " millions of problems", which they had to solve. In virtually all situations, the source of the problem tasks was the worksheets, the end of chapter textbook exercises, class tests or past and present examination papers. In Jack's class the students were given a booklet containing all the problem tasks and notes at the beginning of the year. In addition, when some sections were done, supplementary worksheets, which consisted of lists of problem tasks, were handed out. In some instances, these were tests from previous years. The students were given a few problem tasks to work on for homework and these would be "gone over" in class the following day. Where tests or examinations had been written, the problem tasks would also be gone over in class.

Table 6-2 provides an indication of the number of problem tasks encountered by the students in Jack's class during the year. Many of these problem tasks had multiple parts that each required answers. However, nearly all the part questions referred to the same situation or context e.g. a car stopping at a traffic light, and were counted as one problem task. If a problem task had two parts, each of which dealt with different problem situations, then this was counted as two problem tasks.

This table does not include the problem tasks from the notes, examinations, or textbooks or the extra problem tasks that students in both classes attempted as revision exercises. It was normal for students to purchase booklets containing examination papers from previous years senior certificate examination and to attempt these additional problem tasks on their own initiative. In addition,

Table 6-2 **Number of problem tasks encountered per topic in Jack's class.**

	Worksheets		Tests			Total
Syllabus Topic	Number of Worksheets	Problem tasks	Number of Tests	Problem tasks	Multiple choice questions	Total no. of tasks
Newton's laws & Gravitation	1	25	2	9	11	45
Momentum, Work, Energy, & Power	1	39	2	11	7	57
Electrostatics & Electricity	6	67	2	8	11	86
Rates & Equilibrium	2	33	2	9	9	51
Acids & Bases	3	26	1	4	8	38
Electrochemistry	1	17	2	6	8	31
Organic chemistry	1	13	2	8	12	33
Totals	15	220	13	55	66	341

examination of one student's revision exercise book in Susan's class revealed a number of extra worksheets from either another teacher or school or previous year. The evidence indicated that most students attempted some extra problem tasks. Unfortunately, I was not able to maintain an accurate record for these problem tasks and consequently they are not represented in the table. While the table does not give an indication of the type, quality or nature of problem tasks (all of which are discussed later), it does give an idea of the minimum number of problem tasks the students encountered during the year and the differing emphasis from topic to topic.

Jack assigned these problem tasks and systematically went through virtually all worksheets and tests in class. It is not possible to determine if the students conscientiously attempted all the assigned problem tasks for homework. However, the impression from class interactions and examination of exercise books was that the majority had attempted the problem tasks for homework before Jack went over them.

The situation was similar in the case of Susan. I have not provided detailed breakdown of the problem tasks because it was only possible to provide an approximate total. For example, she handed out separate worksheets for higher and standard grade students. However, she encouraged the higher grade students to also complete the standard grade problem tasks. Sometimes, she allocated only four or five problem tasks for homework. The students were then encouraged to attempt the rest on their own. While some students did not even complete the minimum, other students, especially from the higher grades did all the problem tasks. When it came to going over the problem tasks in class, Susan did not provide detailed solutions for all tasks, but concentrated on those which students asked her to do. Consequently, the exact number of problem tasks attempted by the students and gone over in class could not be accurately determined. In total, the higher grade students were given 35 worksheets containing from 3 to 23 individual problem tasks, giving a total of approximately 325 individual problem tasks. The standard grade students were given fewer worksheets and problem tasks and were not as diligent in seeking out extra problem tasks. However, over and above these must be added the examination and test problems, together with additional problem tasks allocated from their textbook which Susan assigned on a regular basis. Therefore, I can say with confidence that the students doing higher grade did as many and possibly more problem tasks than students in Jack's class.

Consequently, looking at both classes, the evidence suggests that during the year the students encountered a minimum of between three and four hundred problem tasks, many of which had multiple parts.

6.2.4 Stripped but relevant problem situations

Assertion 1c: *Most problem situations were stripped of real-world details. Nevertheless, many students were able to link the problem situations to their lives.*

When new topics were introduced, there was an attempt by both Jack and Susan to link their teaching to phenomena that students might encounter in their daily lives. This would evoke some questions from the class and on some occasions, a short discussion would ensue. However, when it came to the problem tasks, they used those appearing on the printed worksheets, tests and examination papers. It was exceptionally rare for either Jack or Susan to construct a new problem situation while teaching. Consequently, the situations provided in the problem tasks were fixed in print and were rarely expanded in any way to make them relevant to a current event or interest expressed by a student. The following list provides an idea of the types of problem situations that were used. They were chosen from tasks used in both Susan and Jack's class and are representative of the types of problem situation encountered by the students.

1. Two trolleys, A and B are moving under frictionless conditions in the same direction along a horizontal line. Trolley A has a mass of 4 kg and moves with a velocity of 5 ms^{-1}. Trolley B has a mass of 2 kg and moves with a velocity of 1 ms^{-1}.
2. A golf club exerts an average force of 3 kN on a ball of mass 0,06kg. The golf club is in contact with the ball for 5×10^{-4} s.
3. Ten identical light bulbs are used to illuminate a doll's house. The bulbs are marked 11V 5,5W and are connected in parallel.
4. Calculate the concentration of NO_2 in a container at 300K if the concentration of N_2O_4 is 10^{-2} $mol.dm^{-3}$
5. A 63,5g block of copper (one mole of copper) is suspended in a beaker containing 1 dm^3 of 1 $mol.dm^{-3}$ silver nitrate solution ($AgNO_3$) as shown in the diagram.
6. A domestic garden spray gun comprises in part a 0,45 dm^3 capacity pump (P) and a 5 dm^3 container (C) which is initially "empty". Each pumping cycle, pumps 0,45 dm^3 air (initially at atmospheric pressure) into the container.

Analysis of the problem tasks revealed two main types of situation. Firstly, many of the problem situations were similar to situations number one, four and five. They are what I call "skeletal situations". It appeared that they had been specifically designed to have no obvious link to recognisable real-world events or objects. The second type of situation is represented by numbers two, three and six. I refer to these as "stripped" situations. While there were direct links to everyday objects and events, they were uncomplicated situations, with no extraneous information and were stripped of all real world complexity and ambiguity.

The policy of using these situations was a deliberate one and from Jack's perspective had educational value. For Jack, there was a need to simplify the situation so that the students could visualise the essence of the situation and not be distracted by the complications. This assertion is encapsulated in the following excerpt from an interview with Jack:

> Full descriptions are so complex and, and....umm...., it means that you've, you've got a problem sitting in the middle of a shoal of red herrings and the kids ... I said earlier, that when you give them a problem, it thinks up here. When you give them a problem, they must sit back and look at it holistically ...., and try and visualise the situation, .. .whether it be literally, a mental picture or mathematical or whatever, to be able to see the problem holistically.. ...., ... If, in fact, there are too many complications, you going to have so many trees in front of the problem that you not actually going to see it. So .. as teachers,.. we take that away, so that the problem is in fact simplified. (Jack interview, 01/02)

Susan volunteered different reasons for avoiding complex real-world problem situations. For her, they posed two complications. Students expected "nice numbers" while real situations introduced messy fractions, and students were not necessarily interested in linking the problem situations to their lives. Her view is evidenced in the following excerpt:

> I don't use as many real-life questions or examples as one should, really, to sort of give them a rounded science education. But using real-life type problems you're going to get large numbers and perhaps fractions, sort of running on and on and once, ...you know,..... kids don't like fractions at the best of times, and you know, numbers, large numbers or realistic numbers tend to throw the kids. They like numbers that will divide easily and sort of give an answer which, sort of looks okay to them. They don't sort of think "Well, is this realistic?" I try and encourage them to think, well, you know, if you've got a television and you've got 25 amps going through the television, is that a reasonable situation? And I try to get them to think like that, but they don't think like that. They don't sort of, although you try and associate science with what's happening outside in everyday lives, its schoolwork to them. (Susan interview, 28/01)

Attempts were made by the examiners to introduce real-world situations into examinations albeit in a simplified format. The examiner spoke of creating problem tasks around situations he had personally experienced. In the excerpt below, he is referring to a problem from a previous examination paper which he had produced, based on his experience with putting up tents while camping:

> In my last year's physics paper,....... the tent problem involving a pole and two ropes holding it in...... it's a very, very down to earth problem..........., that they can sit back and visualise very easily. (Examiner interview)

The evidence from interviews strongly suggested that the teachers and examiner supported the use of problem tasks created around real-world situations from which the complexity had been stripped. They wanted the students to see the links to everyday life but not have to deal with the complexity.

On the whole, this strategy appeared to be moderately successful in that the majority of students saw links to their lives. In the analysis of the structured questionnaire (Appendix C2), students agreed that they found the problem tasks interesting (Q.20 - 63%), related to real-life situations (Q.8 - 57%), helpful in recognising how science concepts appear in real world situations (Q.18 - 59%) and that they made the subject more relevant (Q.3 - 78%). The assertion that many students made these links was further supported by a few comments made in interviews by students. Bruce, a target student in Jack's class, saw clear links between what he was doing in class to his life experiences. The following is an excerpt from his response to my question about the usefulness of the problem tasks:

> And science can teach you why it's happening so you can actually understand what's happening around you. ....For instance when Mister Jones was talking about the kettle. And, saying that, talking about the current and resistance and...... needed for the heating effect. And now I look at a kettle in a whole different light. It's not just something that heats up water. It's actually, ... you have to work everything out, it's highly detailed. (Bruce, interview)

Again, another student in the same class shared how he had viewed a motor accident in a different light as a result of the work they had done on energy and momentum. Similarly, I asked Sbu from Susan's class if he had ever had an opportunity to use what he had learnt in class in his own life:

Sbu:	Yes. when, I was walking. When, today I came off the train, when it was in motion I wanted to apply something. Because I used my science
Int.:	What did you use your science to do?
Sbu:	I get out. You know I ... , Mrs Smith says if it is moving forward and if you, if you want to go out of it without, without falling down, you should, you should try to push yourselves backwards in, when, when you step down as it's going ... before, you are pushing yourself backwards and it is going forward, and then you are going to remain straight.
Int.:	Ok?
Sbu:	That is what I did. I nearly fall down.

Together with the previous excerpt, this yields evidence that many students attempted to link the problem situations encountered in class with their everyday experiences.

However, reference to the questionnaire responses shows that there were a significant group of students who did not make these links. For example 43% (Q.8) disagreed that the problem tasks were related to real life and 37% (Q.13) disagreed that they were realistic. The following excerpt from a student's response is indicative of the existence of this minority opinion:

> I learn "off-by-heart" how to solve problems, as all we have to do is apply the methods and formulae. This is because I feel there is no reason to have to know about concentration/time graphs or how to work out the ending velocity

> after a collision. It has totally nothing to do with our daily lives. Why would I want to work out how much energy was left after a collision in a pendulum? But it is interesting how it works. I feel less emphasis should be placed on mathematical problems and more on understanding concepts, which affect us in our daily lives, so that we may be able to use these concepts to our advantage. (Tony, interview)

6.2.5 Commentary

Doing physical science at school involves a number of different activities that have as their focus the solving of problem tasks. A common pattern of instruction involves the teacher explaining the characteristics of a scientific phenomenon or concept e.g. gravitational attraction, and then attaching an individual formula to it. The formula shows the links between the different physical quantities associated with the phenomena e.g. force, mass, distance. Simple problem tasks are then constructed using the formula that has recently been presented and discussed. The problem tasks, in which students are asked to find one quantity, given numerical values for the remaining quantities, then become the focus of the classroom activities. This instructional process was typical of the two cases in the study and has also been reported by many other studies of classroom practices (see for example (Gabel, 1989); (Contreras, 1992)). Although Jack and Susan differed from each other in the patterns of activities used, they inevitably used problem tasks as a focus of the activities. In contrast to some other studies (see for example Tobin, 1987), where it was found that the classroom activities were strongly influenced by the text book, this was not the case in this study, where the influence was rather the worksheets of problem tasks. In fact, it was interesting to note that in both classes, the progression through the syllabus work was frequently referred to, by both teacher and students, by means of the number of the particular problem task or the title of the worksheet of problem tasks that was currently under discussion. It was not unusual to hear students or teachers asking, "Where are we?" The answer would invariably be the number of the problem tasks not the page of a textbook.

From this and other evidence, we can confidently imply that the solving of problem tasks was the main vehicle for what Jack and Susan considered to be "teaching and learning science". It would appear that even when the focus of an activity was the discussion of theory or phenomena, this was done in order to provide background ideas or understanding necessary for the solving of the associated problem tasks. It appears that both teachers used the direct teaching or theory introduction activities as no more than a preface to the solving of the problem tasks. Perhaps they reasoned that some theory was needed to solve the problem tasks encountered in the topic. Once it had been presented then the main work of the day could be continued. The ultimate goal was always to apply the concepts and principles to new types of problem task (Hammer, 1989). This could also be inferred from the short duration of time allocated to discussing the theoretical principles or concepts, compared to the long time allocated to explicit solving of example problem tasks. Also, once this theory stage had passed, there was virtually no more discussion of the theoretical principles until a new concept was introduced. It appeared as if the other activities were only a means to get to the focus, the manipulation of the formulae and solving of the problem tasks. The only exceptions to this focus occurred when the lessons were organised around a practical or demonstration or when the topic in the syllabus didn't contain quantities that could be related and expressed as a formula e.g. organic and inorganic chemistry, which are essentially descriptive in nature. Overall, the implicit purpose of school science was for the students to be able to solve the problem tasks.

If we assume that Jack and Susan did have as aims, the developing of problem solving skills and the necessary physical science knowledge base (see section 7.2 where this is discussed), the question arises as to whether this focus on problem tasks was an effective teaching strategy. Unfortunately, there does exist substantial evidence that this use of conventional problem tasks is not appropriate. For example, Sweller (1984) maintains that the mental effort involved in problem solving may compete with, rather than assist in the learning of new material. He suggests that once new concepts have been introduced, it would appear to be inadvisable to use problem-solving activities to practise and gain experience in them. Reif (1981) in his analysis of the solving of routine problem tasks states that there is particular knowledge needed to routinely solve a particular class of commonly occurring problem. This knowledge involves the interpretation of symbols, manipulation of quantities, knowing the conditions under which a principle applies etc. He suggests that we need to explicitly teach this knowledge, not just give problem tasks. Finally, McDermott (1991) reports that although it is necessary for students to solve problems in a physics course, important intellectual objectives are often ignored when instruction is geared to solving problem tasks.

The syllabus, in its aims (Appendix B), refers to the developing of skills, techniques and methods of science; to introduction to scientific explanation of phenomena; to use of scientific language; to introduction to applications in industry; and to developing a knowledge of the subject as science and as technology. Given these stated goals for the science curriculum, there appears to be both an imbalance and overemphasis on the use problem tasks to achieve these goals to the disadvantage of other aspects of science. There is also convincing evidence that it is an inappropriate instructional strategy. In addition, this heavy emphasis on problem tasks led to students finding the school subject of physical science boring. Given that the tasks teachers assign students determine how they will come to understand a curriculum domain, it would be no surprise if the students gained the erroneous impression that science was only about solving problem tasks.

While the majority saw links between the problem situations and the real world, there existed a significant minority of students who did not see these links. For them, the experience of science must have been “unreal”. Within the class there were definitely opportunities to make explicit links between some of the problem situations to students lives or experiences e.g. Sbu jumping off the moving train. These could have resulted in rich discussions. Unfortunately, the focus was too strongly tied to numerical problem tasks for teachers to take the opportunities offered or they did not see them as valuable.

It is obvious that the achievement of the published curriculum aims would require a focus on many other activities and areas of science than just numerical problem tasks. Examination of the literature in science education or appealing to our own experiences, reveals many different activities that students could be involved in which do not have problem tasks as a focus. If Jack and Susan took the curriculum aims seriously, we should expect students to be involved in activities involving theorising; explaining of phenomena through writing and discussion; examining and transforming data; discussing, gathering and interpreting evidence, looking for patterns and making predictions; to name a few. Unfortunately, this was simply not happening and some reasons for this are presented in Chapter Seven.

6.3 THE PROBLEM TASKS

Assertion 2: ***The majority of the problem tasks were routine. They were of low conceptual demand mostly requiring quantitative responses. However, some problem tasks appearing in tests and examinations were not routine and students found them difficult. These problem tasks could be identified by particular characteristics.***

6.3.1 Introduction

The previous sections showed that problem tasks were central to teaching and learning. In this section, I turn to the problem tasks themselves. In the first chapter I have provided an example of a typical problem task and described them as being well defined, narrow in focus and invariably involving the calculation of some quantity through use of a formula. The focus of this section is on these tasks. Given the time spent solving problem tasks, I felt that it was important to describe in more detail some of the characteristics of the actual problem tasks used by Jack and Susan. This will contribute to the picture being constructed of the use of problem tasks in the teaching of physical science. I will provide evidence to show that the problem tasks were very similar in nature and sometimes sets of virtually identical tasks were used. The majority involved simple formula based calculations. While these tasks could be considered problematic when initially introduced to the students, by the time they wrote their examinations at year-end, these tasks should have only required a low level of conceptual involvement and could be called routine problem tasks. On the other hand, there was an identifiable group of problem tasks with distinguishing characteristics which students found difficult to solve. They generally encountered these for the first time in their tests and examinations.

6.3.2 The problem tasks were routine.

Assertion 2a: *The majority of the problem tasks were ordinary, uninteresting and predictable i.e. routine in nature.*

The vast majority of the problem tasks were specific to a syllabus topic such as electricity or equilibrium. Within each syllabus topic, there were clearly identifiable sets of problem tasks that were similar to one another. They were identified by two main characteristics: they were formulated using similar problem situations and; they required the same set of principles and formulae to solve them. Figure 6-1 below, represents a typical problem task from a set referred to as “pulley problems”, by students and teachers alike. The problem situation normally involved connected objects and pulleys. In Appendix F, I have listed a complete set of these “pulley problems” solved by students in Jack's class during the teaching of Newton's laws. The problem tasks shown are in the sequence in which they were encountered during the year. I chose this particular problem set because virtually the same list of problem tasks was used in Susan’s class. The worksheet problems, together with the March and November examination problem task were all the same. Examination of the problem tasks shows that students were given worksheets containing a set of similar problem tasks with only superficial changes to the problem situation for each task. They were then given similar problem tasks in their tests, followed by similar problem tasks in the examinations.

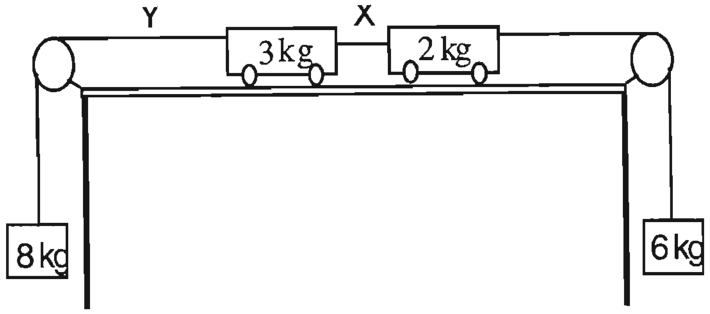


Figure 6-1 Problem task: A pulley problem

Examination of any of these sets revealed two characteristic types of problem task. The first type, which I refer to as the "drills", can be identified by the fact that they were virtually identical problem tasks except for the values of the quantities involved. They normally involved the manipulation of a formula with the main challenge being the ability to change the subject of the formula and substitute the values for the given variables. The second type, which are what I refer to as "variation on a theme", are similar but there are superficial changes to the problem situation. In the set of pulley problems given, the actual force that had to be determined varied, the number of objects involved varied and in some cases friction effects had to be taken into account. It must be obvious that these should have become no more than routine tasks as the year progressed. Although they might have found them difficult at first, they should have become ordinary, uninteresting and predictable by the end of the school year. I have indicated the source of the problem tasks and the number of similar problem tasks which students encountered as the year progressed for two physics topics and two chemistry topics. Table 6-3 below, indicates that particular problem sets were encountered at different times and from different sources during the year.

It should also be noted that as the year progressed, and new topics were "covered", the opportunity to have significant amounts of practice decreased, until topics, such as redox chemistry, were only encountered in the trial examination before the final examination. While all the problem tasks in the worksheets from the early topics were completed, this was not always the case especially in the third term where only a selection would be given due to the lack of time available. A problem task from the topic vectors, might be revised for the March, June and Trial examination, and "gone over" in class. However, some acids and base problem tasks might never be revised. This was noticed in Susan's class where there was a significant decrease in the number of problem tasks in the third term.

Given this lack of time to encounter Chemistry problem tasks, it might be said that they do not become routine as there were not as many opportunities to encounter them in examinations, to go over the solutions, to revise etc. However, I contend

Table 6-3 **Problem sets showing their source and frequency.**

WHERE FOUND PROBLEM SETS	**Examples in Notes**	**Worksheet Exercises**	**Class Tests**	**March Exam (common)**	**June Exam**	**September Exam**	**Nov Final Exam (common)**
JACK							
Pulley & Tension	-	17	8	1	2	-	1 M.C. 1
Simple DC-Circuits	1	23	10 M.C. 9	-	3	2 M.C. 1	1
Concentration & pH	3	55	8 M.C. 4	-	-	4	1
Electrochemical cells	-	17	16 M.C. 6	-	2 M.C. 1	3	1 M.C. 1
SUSAN							
Pulleys & Tension	-	17	1	1	1 M.C.	-	1 M.C. 1
Simple DC-Circuits	-	13 M.C 42.	4	-	1 M.C. 1	3 M.C. 1	1
Concentration & pH	5	6	-	-	-	1	1
Electrochemical Cells	2	3	-	-		1 M.C. 2	1 M.C. 1

Note: M.C. refers to multiple choice questions.

that the students had every opportunity to turn them into routine tasks even in Susan's class. One only has to look at the syllabus to see that a single topic in physics (e.g. kinematics) has five or six formulae or principles associated with it, while a topic in chemistry (e.g. electrochemistry) might only have one. Consequently, students did not have to concern themselves with a variety of situations, all requiring slightly different solving strategies.

In chemistry, the contexts were predictable and narrow resulting in a few clearly defined sets of problem tasks. Consequently, only a few problem tasks had to be attempted before they would have in all probability been routine. Consider the following example taken from Jack's class. While dealing with the topic of acids and bases, there were only three problem situations that students needed to consider. These were concentration of solutions, the pH of solutions and titration. Each of these situations had a simple formula associated with it e.g. Molarity = No. of moles (n) / Volume (dm^3). The students were given the following tasks:

1. Twenty-four drill calculations in which they had to complete a table with some given values and some missing values.
2. Eight titration calculations of the "variation on a theme" type.
3. Eight pH calculations of the "variation of a theme" type.
4. Two worksheets with six and seven problem tasks of the type "variations of a theme".
5. Thirteen problem tasks labelled as "past matric questions" involving part questions and requiring combinations of these three formulae.

Despite this section being completed in the third term and there being no opportunity to encounter the problem tasks in a number of examinations and revision sessions, there is no doubt that the problem tasks should have been routine tasks by the time the students were ready for the matric examination.

Both teachers made sure that the students were given sets of problem task for any type of problem that there was a chance of getting in the examination. Most of the problem types were well known to both teachers and students. When the examiners introduced new types, the teachers made sure examples were obtained and given to students. For example, in the previous year's examination, a new type of problem task was encountered dealing with the situation of reaction equilibrium and involving interpretation of graphs. This was a new, clearly defined type of problem task requiring a specific response and was not present in the textbook or worksheets. In Susan's class the normal worksheets were supplemented by a separate worksheet with eight of these problem tasks. The same set of problem tasks was also given to Jack's students for revision. It was obvious that this was recognised as a new problem type and worksheets were being circulated through the schools to prepare students for the expected new problem type in the examination. By the time they wrote the examination, even these problem tasks were ordinary, uninteresting and predictable. Further examples of problem tasks that became routine are provided in Appendix G.

6.3.3 Conceptual demand of routine problem tasks

Assertion 2b: *The majority of the routine problem tasks were quantitative in nature requiring the simple one or two step application of a formula or principle for solving. They were of low conceptual demand.*

In the previous section, I have provided evidence to show that the majority of the problem tasks encountered by the students were routine in nature. This indicates that by the time they encountered them in the matric examination, they should have been relatively easy problem tasks with low conceptual demands being made on the students. This claim is based on the assumption that as a student became more familiar with the tasks, the conceptual demand made on the student would decrease. Accepting that it is impossible to determine how difficult a problem task is solely based on the text of the problem task, I felt that it would be valuable to examine the tasks themselves in more detail and the participants' expectations of them, to determine their expected difficulty.

I viewed the problem tasks from two different perspectives in my attempts to reveal the explicit conceptual demands made on the students. Firstly, I considered how the task was presented to the student. I found four main presentation modes or formats for the tasks:

- *drills* (DS): in which the problem situation was limited to description of the variables and the task was to substitute into a formula and calculate different variables given new values each time;
- *multiple choice* (MC): in which a number of alternative answers were provided and the task was to choose the best response;
- *single answer* (SA): where the task was either to determine a single numerical answer or provide a non-numerical answer such as balance an equation or predict a reaction and;
- *multiple part* (MP): where the task was to answer a number of questions dealing with different aspects of the same problem situation. These are sometimes called structured questions.

Analysis of the tasks showed that the format was not related to the conceptual difficulty. For example, some of the multiple-part tasks appeared in my opinion to be very simple while some of the multiple choice tasks appeared difficult. Continuing, I then analysed the tasks from the perspective of the response required from the student. I identified six basic responses which were most frequently asked for. These were:

- *definitions* (defn.): definitions, principles or other information had to be recalled;
- *constructions* (const.): a graph or scale diagram had to be constructed;
- *calculations* (calc.): responses requiring the use of formulae to calculate an answer;
- *qualitative* (expl.): responses requiring the student to describe or explain some phenomenon or event;
- *interpretation* (intp.): responses involving the analysis of data, or interpretation of formulae or graphs;
- *prediction* (pred.): a principle or law had to be applied to predict or control an event.

This analysis, although similar, revealed more categories than the broad ones proposed by Chi (1989). Three categories of response were proposed being: declarative requiring recall (i.e. similar to defn.); quantitative requiring procedural skills (i.e. similar to const. and calcs.); and qualitative requiring reasoning and inferring skills (i.e. similar to expl., intp. and pred.). A hierarchy is implied, with responses requiring recall considered of low conceptual demand while prediction requires higher conceptual demand

In Table 6-4 below, I have analysed in more detail the problem tasks that Jack's students were given during the first term for the sections dealing with “Bodies in motion”. All of these were assigned as homework and then gone over in class. An analysis of problem tasks given in Susan's class uncovered a very similar pattern. Not all of the categories mentioned above, appear in the table. This is because problem tasks requiring that response or in that format were not used in that section. For example, prediction type responses were more evident in chemistry topics than in physics topics while multiple choice type questions were generally only encountered in tests and examinations. The analysis indicates that over 90% of all problem tasks required students to respond by manipulating formulae to calculate a numerical answer. The tasks were numerical in nature, requiring the simple one or two step application of a formula or principle for solving. Very few

Table 6-4 **Mechanics worksheet problem tasks analysed by format and response required.**

		Format				Response			
Topic	Number of problem tasks	**DS**	**SA**	**MP**		**Intp.**	**Expl.**	**Calc.**	Total questions
Newton's laws	20	3	8	9		0	0	50	50
Gravitation	9	1	5	3		3	1	17	21
Momentum	17	1	8	8		0	3	34	37
Work energy power	22	4	9	9		3	1	50	54
Total tasks	68	9	30	29		6	5	151	162

tasks required students to provide descriptions, explanations or interpretations of data.

The picture was very similar for some sections of chemistry. For example, the worksheets for the acids and bases topic mentioned earlier, required a total of 66 answers of which eight required a chemical equation to be balanced and the rest involved numerical calculations of concentrations and pH. However, in other sections of chemistry, such as organic and inorganic chemistry, there were no calculations required. In these topics, the majority of responses required the application of a rule or chemical principle e.g. Le Chatelier's principle, to a problem situation (pred.). As described earlier, these situations were stripped down of all complexity, in most cases being "skeletal" and were very similar. The rules and principles required to interpret the situation were presented in the notes and required what the students referred to as "learning". While labelled as "pred." they certainly should not have been difficult.

Further evidence that the tasks were overwhelmingly quantitative with higher order questions missing, was obtained when I examined the student exercise books to ascertain what their written responses were to the problem tasks. Their exercise books were filled, virtually exclusively, with page after page of formulae and calculations, being the answers to the worksheet problem tasks. In a careful analysis of one student's book (Pietro) only 30 lines of text were found in 50 pages of the student's answers. Two short paragraphs of 3 lines were found for topics in physics and four for chemistry. There were six or seven simple sentence responses spread throughout the book e.g. "The terminal velocity will increase" or "HX will be stronger than HY". There was a complete absence of qualitative descriptions of phenomena or situations, with only about 15 simple annotated diagrams and a few rough sketch graphs. The overwhelming majority of the problem tasks were marked as correct with only a small percentage showing evidence of having been corrected. Given the above analysis, it appears that the majority of the routine problem tasks that were given to the students were quantitative and of low cognitive demand.

This analysis is supported by comments made by students. For example, in the following excerpt from an interview with Bruce, I had asked him to account for the fact that he had found a pulley problem relatively easy to solve on the test:

> Well again, we've done so many examples, ...there's a whole worksheet full of them.. and when once you've done one, you remember the rest...... and just basically apply the same formula, you know, over and over again.
> (Bruce, interview)

While the task might look difficult at face value, it was a routine task to Bruce and made minimal conceptual demand on him when it appeared in the test. In an open-ended questionnaire, I asked the students to describe their feelings toward their homework tasks. A variety of responses was obtained with many negative comments about the numerous tasks that were similar. The following excerpt illustrates again that for some students the routine tasks were of low conceptual demand and required "no thought":

> I always put my share of work in. However, I become angry when there is something which I don't understand and will therefore sometimes spend time at home trying to work out science problems that are more difficult. I find it frustrating when homework includes a bunch of problems which are all the same and therefore require no thought and are simply a waste of time.
> (André, Questionnaire)

The structured questionnaire produced additional evidence that the tasks were quantitative and involved formulae manipulation. Students agreed that the tasks were numerical in nature (Q22 – 63%), required them to engage in equation manipulation (Q16 – 85%), and involved matching a formula to the situation (Q19 – 67%). However, only 59 % agreed that solving them involved matching a previously done problem solution with the current problem task (Q15). I expected a much higher agreement but this result could be explained by the fact that the students were referring to all problem tasks and not only the routine problem tasks. Also 52% disagreed that the problem tasks could be solved by straightforward application of single principle or formula (Q31). Again, this was not surprising as even the routine problem tasks often required more than one solution step to obtain the answer.

Furthermore, both examiners and teachers expected that the problem tasks would be "relatively simple". In the following comment, made by the matric examiner, he acknowledges that these simple problem tasks are to be expected:

> As the examiner, I'm part and parcel of this system, where it is expected........., in this section for kids to be able to answer relatively simple questions, ..., problems associated with the laws. It's written into the syllabus.
> (Examiner, interview)

Both Jack and Susan agreed that after dealing with the problem tasks a few times they became simple routine tasks. Jack referred to them as "exercises" as seen in the following comment about a test question, "Number ten is almost identical to questions we have done already, so that is not a problem as such, it is just an exercise." Susan would often refer to these simple routine tasks as "calculations:

Susan:	The first time round is a problem. Once they've done one its no longer a problem anymore, because now they have the mechanism to cope with it. It's now a calculation.
Int.:	Okay. And if you think about what they do, how much problem solving do they do?
Susan:	Not very much, its mostly sort of more rote type calculations. (Susan, interview, 23/03)

If students obtained incorrect answers to these problem tasks, then both Jack and Susan explained this by saying the student had made a careless arithmetic mistake, had not converted the units, or had not read the task correctly. At no stage with these routine problem tasks did they attribute the errors to a lack of understanding of the principles involved. This implies that they thought the problem tasks were of low cognitive demand and required little understanding.

Adding to this picture constructed above of students being asked to solve many easy routine problem tasks involving calculations, was the fact that these problem tasks were of short duration. This adds to the evidence that they were of low conceptual demand. In Susan's class, where problem tasks were attempted in class, reference to the fieldnotes shows that the time students took to obtain a solution varied from a few minutes to 15 minutes. However, the longer intervals were normally a result of students becoming distracted and not concentrating solely on the problem task at hand. They would also be asked to solve three to five problem tasks in their tests, which were normally one period of thirty-five minutes. Although some problem tasks were solved in a short space of time and others took up to 15 minutes, on average students spent between five to ten minutes per problem task.

In the case of Jack's students, the exact amount of time spent by individual students attempting to solve the tasks on their own is unknown. They were not given time during class to do problem tasks, except during tests and examinations. In these situations, they were expected to do about five or six multiple choice questions and between three and six other problem tasks in about 60 minutes. When Jack was going over problem tasks, he would do about three to four problem tasks in a 35 minute period. (Approximately 112 periods were spent going over about 300 problem tasks during the year.) The time spent on individual problem types did vary, depending on their difficulty and the different responses required. Examination of student exercise books showed that the students completed about three to five problem tasks per A4 page. Each part or calculation only occupied about four or five lines, again indicating a short time to solve. From the above analysis, we can infer that whether in examinations or worksheets, it was expected that the solution paths would be found within a relatively short space of time. They were not intended for prolonged reflection or extended involvement. This again adds weight to the assertion that the routine problem tasks were of low conceptual demand.

6.3.4 Test and examination problem tasks

Assertion 2c *Some examination problem tasks were of high conceptual demand and the students found these problem tasks difficult. These problem tasks could be identified by a particular set of characteristics that made them difficult.*

The above analysis was restricted to the sets of problem tasks encountered in normal classwork i.e. those taken from the notes and worksheets. A different picture emerged when the problem tasks encountered in tests and examinations were also considered. While most of the problem tasks in the tests and examinations could also be referred to as routine, within each test or examination there would be one or two problem tasks or parts of a task, that would be novel. These could be classified as "Type two: Maverick problem tasks" and were considered difficult by teachers and students alike. Jack differentiated them from the routine problem tasks, which he considered exercises, and referred to them as problems. He characterised these problem tasks as having a new context and requiring a new solution approach. He indicated that he liked to give these to students "particularly in tests":

> But they know in fact that in the final paper they'll have 3 questions at the end on the 3 different sections, and the intention is to have a swinish one in each one. So in other words, we'll have a test this long, there might be one, maybe 2 swinish questions. (Jack, interview, 10/02)

Consequently, the students expected to find these more difficult tasks in their tests and examinations. For example, when I questioned one of his students about his performance on a test, he replied, "I found the questions to be more challenging than those we do in class. The ones in class are pretty simple and then when we get a test they always seem harder."

The examiner confirmed this expectation of finding these harder problem tasks appearing in examinations and referred to these as "elegant" problems:

> You asked "What is a good question?" A good question is, as I see it, an original question. The word that comes out quite often in terms of questions are "they're elegant questions". I like to get a couple of those in. I've got to be very, very careful, in terms of the standards, that I don't put in too many smart questions, and nail the kids. When exams are set there are certain bread and butter questions that everybody should get right. There are other questions in fact that are going to eliminate some fellows and there are other questions designed specifically for those going for A's and B's.
> (Examiner, Interview)

The examiner also expected teachers to use these problem tasks from past examination papers in their teaching. In fact, he spoke about the struggle to produce good problem tasks and the fact that he attempted to create them, as this enhanced his professional status and made him feel good.:

> So, I suppose also that I'm setting questions for teachers. The teachers are the ones who are ultimately in fact going to go through these. OK, I set papers for the kids, ...and for the teachers as well. I don't want the teachers out there to say "This examiner, he sets hum-drum sorts of questions, papers, there's no thought in it. Particularly the good teachers, who are at the top academic schools, who're really pushing their kids. "That's no meat for my good kids" ......I actually get a large amount of pleasure out of setting an original question. (Examiner, interview)

While Jack appreciated and deliberately exposed his students to these "elegant" problem tasks, Susan did not have the same feeling toward them. The following was her response to one of the more difficult problem tasks that appeared in a common examination paper. She had not been able to do the problem task given on the common March examination (see p. 100) and had asked one of her colleagues for help. "That was a horrible question, in fact, because I couldn't do it, it was horrible. That was quite a tricky question for matrics anyway." Clearly, these tasks were a distinct set of problem tasks that even some teachers would find difficult.

In both classes, it was common to hear the students and sometimes Susan or Jack, refer to these difficult problem tasks, by a number of terms such as "tricky", "nasty", "sneaky" and "swinish". For example, when I asked Tom why he had made a mistake in a test he replied:

> Oh, that I got wrong because I took into account those resistances.... well the resistance of that.... I forgot about an ammeter not having any resistance at all, ... very little resistance. Well. Oh, that's just one of the trick questions I suppose. (Tom, interview)

Bruce, did not agree that these were trick problem tasks or set with the purpose of tricking students. When I asked him if the problem he had got incorrect in a test was a trick question, he replied:

> I don't think any question is really a trick question, because there has to be an answer to it. If you know your work, then it's not supposed to confuse you. I don't really think there's such a thing as a trick question............As I said, there's nothing unfair if you know your work. Maybe, they might have been a little unfair, because we never dealt with anything like that before, but it's just something that you have to live with. (Bruce , interview)

Other students agreed with Bruce that this practice of getting difficult problem tasks in the tests and examinations was not fair:

> I find that what we are tested on is not always what we learn in class, and we are expected to deal with new monstrously difficult aspects of science that we never even knew existed. It's just not fair. (Grant, questionnaire)

The above evidence yields a pictured of students receiving large numbers of routine problem tasks in class and for homework, but expecting to receive a few difficult ones in the tests and examinations. While Jack and the examiner encouraged the use of these difficult problem tasks with novel situations and approaches, referring to them as real problems and labelling them as "elegant", the majority of students referred to them as "tricky" and some even considered their use unfair.

6.3.5 What makes a problem tricky?

Assertion 2d: *The tricky problem tasks had specific features that made them difficult.*

In an effort to understand the differences between routine and "tricky" problem tasks, further analysis was continued. It appeared that when dealing with a routine problem task, the problem situation and question posed were familiar and provided cues to the student as to the formula or principle to be used to solve the problem. Consequently, these types of problem tasks had a low conceptual demand. However, this was not the case for the tricky problem tasks, which were difficult for students and in some cases for the teacher. It appeared that the standard solving procedure previously provided by the teacher was not appropriate or available.

The evidence from participants' responses to my questions and examination of their attempts at solving some of these tricky tasks, led me to isolate five features that individually or collectively, could make a problem task tricky in the eyes of the students. These five features were:

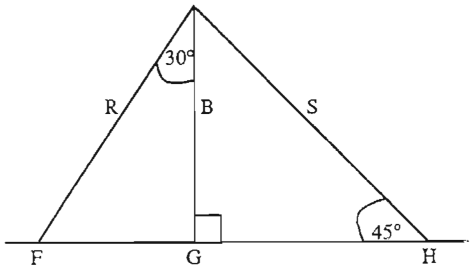
1. *Unfamiliar situation:* the context or problem situation was novel and unfamiliar.
2. *Intermediate steps*: an intermediate variable was required that was not explicitly mentioned in the problem task.
3. *Linking of principles*: there was a choice of principles or a need to link principles in and across topics.

4. *Specific information*: a piece of information had to be recalled from the student's knowledge base which was crucial for solving.
5. *Mathematical manipulation*: Arithmetic manipulation was not sufficient and more complicated algebraic manipulations were required.

These five are not considered the only features of the tricky problem tasks but rather the features that were most prevalent in the problem tasks encountered in this study. In the following paragraphs, each is described in more detail and examples are given.

Firstly, if the problem situation was not familiar but rather was set in a new context, students had difficulty. The problem situation or setting was atypical or unusual compared to the normal routine problem tasks. The student had to try and understand the situation from a new viewpoint and look for and recognise similarities with familiar situations. The task became problematic as opposed to just an exercise as the student did not know what to do. As Jack said, "giving them something that's associated with the law, in a new context" turned the task into problem solving as opposed to a routine exercise. When I questioned the examiner about a particular problem task, which was in a new context, he described the process as one of digging the physics principles out of the problem. In this excerpt he is referring to the tent pole problem (Figure 6-2)

Tent pole B stuck vertically into the ground at G is secured by two ropes R and S as shown.
The tension in rope R is 400 N.



i) What tension must be exerted by rope S so that the top of B does not experience a resultant horizontal force?

ii) If B does not experience a resultant horizontal force when held by ropes R and S, then what conditions must be met concerning the positioning of F, G and H?

Figure 6-2 Problem task: The tent pole.

Examiner	No. There're no new physics principles that have to be applied.. It's just how you apply them and how you dig them out of the problem.
Int.:.	So this tent problem, of the tent pole being held up. Would you consider that a good question.
Examiner	It was a good question.
Int.:	Why?
Examiner	Right. If I could just quote the moderator. He liked the problem because we had two pulling forces and one pushing force and he hadn't come across them before or he couldn't

> recall when he came across them before. We had two guy ropes and a pole. And *he hadn't come across those*. Invariably, you have three things pulling. This was one pushing and one pulling.

The problem task would be difficult because the students were operating on unfamiliar territory and most probably found it difficult to create a mental representation. Therefore, they could not understand what the problem was asking them to do.

Secondly, students found a problem task difficult when there were intermediate steps in the solution process, which were not obvious. In most routine problem tasks, the student could use the variables and quantities provided in the problem statement to directly compute the answer. In some problem tasks, the solution path required a number of steps and the intermediate target variable required was not explicitly stated. When the problem task was structured and a series of part questions were asked, the student was given signposts or steps along the solution path. However, when these steps were not cued by the part questions, students had difficulty. The students recognised this feature as one which caused them difficulty. This following excerpt from an interview with Mark, is indicative of this:

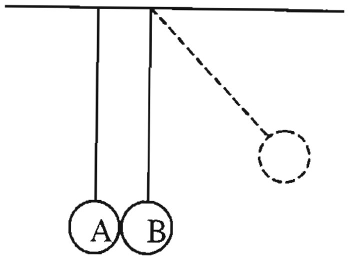
> Int.: Ok. Some questions are more difficult than others. What makes a question difficult.
>
> Mark: Well, the way that some, the way the examiners put the questions. They can try and confuse you or try and trick you. But you've just got to have a basic understanding of science. To understand the question. And you might have *to work a few things out first before you can actually work the answer out.* And that might be difficult sometimes.

Susan also recognised that these intermediate steps would pose difficulties for her students:

> Because it's not straightforward, it's not laid out for them. Once they get into it they may then change their mind. What makes it hard is if they have to determine a value to use further on without ever being asked to calculate the first value. For example they may be given force and mass and asked to find the velocity where they've got to first calculate the acceleration before they can find the velocity, but they're not asked to directly calculate the acceleration. That to them would be hard. (Susan, interview, 23/03)

The third feature of the tricky tasks was the need to use principles from more than one syllabus topic, in order to solve the task. The student was required to link concepts across different parts of the syllabus. One of the characteristics of routine problem tasks was the fact that the formula or principle to be used was cued by the narrow situations in which they were posed. When the situations were broadened and involved more than one principle from different sections of the syllabus, the students had difficulty. They did not know which principle to choose or the conditions under which to use it. Jack was aware of this feature, and saw it as a mechanism for sorting the bright students from other students:

> I endeavour to set my difficult questions that, that require *knowledge from different parts of the syllabus*. For instance, that last one that we, the momentum and kinetic energy one, the two pendulums, and .... the kid who successfully answers that question, has got to marry momentum with kinetic energy in the problems. and ... . your very bright kid can do that, can see the connection. (Jack, Interview, 18/03)



The diagram above shows two hard rubber balls A & B of masses 3 kg and 4 kg respectively, hanging from the ceiling by nylon lines 2m long. Ball B is raised a certain height (dotted lines) and released. It swings down and after striking the stationary ball A at 5,5 $m.s^{-1}$ continues along its original path at 1 $m.s^{-1}$. Calculate the vertical height to which A will rise. (7)

Figure 6-3 Problem task: Pendulum collision

After a number of students failed to answer the pendulum problem referred to above, in which energy principles and momentum principles were used in different parts of the solution, I asked Tom why he had difficulty with it:

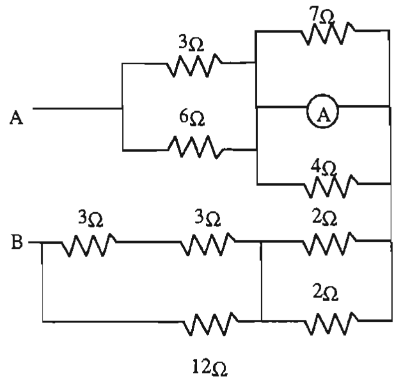
> Mr Jones set the paper, and we've been taught ... and the whole class just been taught by you, and we've just been dealing with the whole thing of energy, and then we suddenly came back,... straight back to momentum. We wondered, hang on a minute, the class wasn't doing that, ..you're not supposed to be doing it that way. But I guess ... it's only one problem. It's not the end of the world. (Tom, interview)

From his response it was obvious that he was expecting problem tasks clearly linked to one particular physics phenomenon and found it unexpectedly difficult when another principle was also involved.

The fourth feature of tricky problem tasks was that they required specific information about a particular phenomenon. A "piece" of information was needed from the solver's knowledge base, that was a crucial factor in the solution. A good example of this was a problem task from a test in which students were asked to calculate the equivalent resistance of circuit. One of the components in the circuit was an ammeter and students had to recognise that it had insignificant resistance and in effect created a short circuit. When I asked Tom why he had got this problem incorrect, he pinpointed this "single fact" as his downfall:

> Oh that. I got wrong because I took into account those resistance.... well the resistance of that.... I forgot about an ammeter not having any resistance at all, ... very little resistance. Well oh, that's just one of the trick questions I suppose. Although, it does take in... quite a minor point. You know what I mean. The fact that,... *the single fact that... an ammeter doesn't have much resistance,* I mean that was worth four marks just knowing that point.

(Examination of this problem task (Figure 6.4 below) indicates that this was in fact a "tricky" problem task. The problem task appears to have been formulated with the sole purpose of catching out the unwary student. It does not appear to have been formulated with the intention of assessing understanding of principles.)



Calculate the total resistance between points A and B.

Figure 6-4 Problem task: Ammeter

The fifth characteristic of the tricky problem tasks was that they required reasonably complex mathematical representations. In most cases when a physical quantity was calculated, this could be done using arithmetic and simple algebra. However, when the setting up and solving of simultaneous equations or the application of transitivity was required, students had difficulty. For example, a kinematics problem task where students were asked to determine when one car overtook another, required the setting up of expressions for each vehicle for the distance travelled at the point of overtaking. Because both expressions equalled the variable, distance travelled, the principle of transitivity could be applied. Difficulty in recognising this route to the solution and applying it, was in all probability the result of poor mathematics skills or as it appeared more likely, an inability to translate the problem situation into a suitable mathematical representation.

All of these features helped to characterise the problem tasks which the students found tricky and which I have labelled as maverick type problems. Basically, when the problem task was novel and there were no familiar cues to which formula or principle to use, a further step in the problem solving process was required. This can be referred to as the "key step" as it unlocks the solution plan, which is hidden from the solver. Any problem task that requires a key step, was more difficult for the students to solve. The key steps revolved around understanding new problem situations, hidden intermediate steps, dealing with multiple principles, critical knowledge or complex mathematical representations.

6.3.6 Commentary

The results of this analysis of the problem tasks are similar in many respects to those reported in other studies. For example, Tobin (1987) reporting on a series of studies in Australian classrooms, concluded that the work was in most instances algorithmic and repetitious with an emphasis on type examples and procedures. This enabled correct answers to be obtained for stereotypic problem tasks in a procedural manner with reduced cognitive demands. He also reported the infrequent use of qualitative problem tasks. Other studies (see for example Contreras, 1992; Gallagher, 1989) report similar findings.

The class of problem tasks which students found difficult and referred to as "tricky" were different to the routine problem tasks and elicited very different responses from the participants. When they were encountered in tests and subsequently were gone over in class, they would be the focus of a lot of attention. Often they would promote discussion or questions from some students and would lead to some emotional comments. It was as if they raised the "temperature" and when discussed raised the level of interaction. Consequently, they became a focus of this study and an attempt was made to uncover their place in instruction and why they were difficult for the students. An analysis of the problem task and the associated solution paths revealed six features that led to them being difficult.

The difficulty of problem tasks has been a topic of interest especially for those involved in the national senior certificate examinations. Schuster, a member of the national panel of moderators, has produced a "Question difficulty scale" to guide examiners in the construction of examination papers (1987). The scale is applied to all the individual questions and components of questions to help the examiner ensure that there is a balance of difficulty distribution across the whole examination. The scale includes the relative percentage of the marks to be allocated to each difficulty level. The percentages were determined by the examination board. Schuster refers to four levels of conceptual demand or difficulty:

(a.) *Basic / Elementary*: involving recall, factual knowledge, minimal reasoning, elementary use of basic knowledge. (20%)

(b.) *Easy*: being routine exercises, plug in problems, usually a seen type of question. (40%)

(c.) *Medium*: problem solving, application, several reasoning steps but of a standard kind, problem situation usually a variation on a seen situation (30%)

(d.) *Hard / Challenging*: unfamiliar or more complex, usually unseen situations, requires insight , may involve putting together various ideas. (10%)

According to this scale, the students were correct in expecting a proportion of the problem tasks in the examination and tests to be difficult and this was found. These difficult problem tasks were part of the published curriculum.

Given this, it was surprising to find how few difficult or tricky problem tasks were used in normal classroom teaching. Given that all participants expected to find them in the examination, it would be reasonable expectation to find them on the worksheets of problem tasks. However, this was not the situation. They were nearly always encountered during tests, when tests were "gone over" and when revision examination papers were done nearer the year-end. It appeared as if the routine problem tasks were instructional tasks and were the means of preparation for the more difficult problems that were assessment tasks. A related finding is that of Gallagher (1989) who found that higher order thinking was present when students were preparing for the examinations. This was because the past examination problem tasks were challenging and stimulated the students to higher levels of thought. This was not the case during normal class where the work was normally of low conceptual demand.

A point that needs to be made here is that this analysis of the routine tasks conceptual demand, only refers to the apparent demand. It was impossible to determine the conceptual demand for each task for each student. For example, there were a small group of students mostly from Susan's class, who did not get involved in learning. As can be expected, for these students the problem tasks never became routine or easy. For them, some of the routine problem tasks were conceptually very difficult, as they had not taken advantage of the opportunities given in class for learning how to solve them. When confronted with an apparent routine problem task, they did not know how to solve it. It was not routine but rather problematic and conceptually very difficult, if not impossible.

It was also surprising to find the limited range of problem tasks. The problem tasks were very similar in format, in the demands made and time required for solving. If the routine tasks were designed for instruction, we would expect to find guiding questions that help either develop a problem solving skill or reveal the underlying conceptual physics or chemistry. Unfortunately, there was little evidence of problem tasks designed to explore phenomena or problem situations. Questions were not asked to help students see relationship between new ideas and their existing knowledge or their daily experiences. Problem tasks were ordered by topic, making them discrete and separate from other topics. There were no problem tasks that attempted to draw attention to the integrated nature of physical science or to explore links between topics. There were no extended problem tasks or in depth explorations of a situation that could stretch over a few periods. There were no problem tasks that were open-ended requiring discussion of the merits of answers. Rather, they appeared to be an accumulation of problem tasks from a variety of sources collected to cover as many different situations as possible. There was firm evidence that the same problem tasks were used from year to year and in a number of schools. I assume that new teachers were simply introduced to the accumulated store of problem tasks, expanding it from year to year by adding multiple examples of the novel examination problem tasks. Unfortunately, the selection of the problem tasks for teaching and learning was, to say the least, lacking in variety and gave no evidence of being carefully designed sets of instructional problem tasks.

6.4 TEACHING HOW TO SOLVE PROBLEM TASKS

Assertion 3: ***The dominant mode of teaching how to solve the problem tasks was for the teacher to explain and model how to solve them, followed by student practice on similar problem tasks. In their modelling, teachers encouraged students to use general strategies. When dealing with particular problem types they encouraged the use of specific strategies. This approach was not effective in teaching the majority of students how to solve anything but the routine problem tasks.***

6.4.1 Introduction

Both Jack and Susan used direct teaching in which they explained how to solve the problem tasks with student interaction limited to asking and answering questions as they were led through the solutions. In this section, I will pay more detail to the actual strategies and techniques used by them to teach the students how to solve the routine and more difficult problem tasks. Both teachers encouraged their students to use a general problem solving strategy. Susan used a "common sense" approach while Jack emphasised an "envisioning" approach. They also provided specific algorithms and procedures for solving topic specific types of problem task. Both Jack and Susan taught their strategies through modelling and explaining how to solve the problem tasks. Students were expected to learn by watching the teacher construct a solution, then practise on similar problem tasks and learn from mistakes they make. The conceptual demand of the work was reduced through the teacher doing the thinking and the students taking a more passive role. In the sections that follow, I will describe these strategies and show that they had some success in teaching the students to solve routine problem tasks but limited success with the more difficult problem tasks.

6.4.2 Instructional strategy.

Assertion 3a *In order to teach their students to solve problem tasks, Jack and Susan used very similar instructional strategies. The main components of the strategy were teachers explaining how to do it, students practising on similar problem tasks and learning from their mistakes.*

Watch carefully how I do it.
In the case of Jack, whether he was introducing a new problem type or going over a problem task that had been attempted for homework or a test, the instruction would fall within a framework that could best be described as " watch carefully while I explain how I do it". For the students, class activities were essentially limited to listening, watching, asking questions and answering questions as Jack worked with the class as a whole, interspersing his presentation with a series of question and answers. His approach is exemplified in the following excerpt from a lesson, where he was explaining how to obtain the correct answer to an electrostatics problem task that appeared on the test. At this stage of the instructional sequence, he had already demonstrated how to solve similar problem tasks, the students had been assigned a few for homework and the solutions had been "gone over" in class:

Mr. Jones: Right, two oppositely charged plates are 20mm apart. How far apart?...
Students: 20mm
Student: $2x10^{-2}$m, 0,02m
Mr. Jones: $20x10^{-3}$ ... 0,02m......
[He draws a diagram of the two plates and starts filling in the information as he speaks.]
A PD of 1500 volts exists across the plates. A particle of mass so much is placed at x. Calculate ....
Mr. Jones: Now this problem was for twelve marks and nine of those twelve marks were gift marks. Now, you must be very, very careful if you look at a problem like this, particularly a structured problem, a structured problem in which you have a b c d. In other words a leads to b which lead to c or there are steps. How many of you looked at the problem and saw the parallel plates and the angle etc and said "Oh my lord. I have not seen something like this problem?" Hands up.
Students: *[About 4 or 5 students put up their hands.]*
Mr. Jones: OK. Next point. How many scored less than nine for this problem?

Students: [11 students put up hands]

Mr. Jones: Right. *I am going to show you* how stupid you are on this one. Watch carefully please. The first nine marks are very, very simple. The last three are difficult but there is no way anybody on higher grade should not get nine for this problem.

[Jack writes. E = v / d   E = f / q   F = m g   on the board. Four or five students start talking in low voices to each other while his back is turned. Two or three are writing in their exercise books, but the majority are looking at the board.]

Right. See those three equations there. Guys, there is a lot of noise please. ....

[Turns to class after writing and points to equations. Those talking stop immediately after his comment and there is silence as he continues.]

Hands up those of you who are not familiar with those three equations or one of those three.

Student: *[No students raise their hands]*

Mr. Jones: Right we have all worked with these equations, on more than one occasion .... those equations on more than one occasion. .... *Right, watch* ......

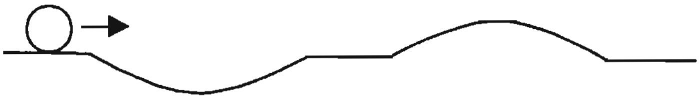
[Starts to write on the board]

A. The electric field intensity between the plates ...... [part] A .... E equals V over D which equals 1500 over 20 x 10 to minus 3 and answer comes to ....?

[Continues with Jack solving the problem on the board and students shouting out answers to calculations].(Jack lesson transcript, 12/05)

This extract is typical of Jack performing. He shows them how to do it. His explanation could be described as “hierarchical” or “expert like" (Touger et al., 1995). He identified the relevant principle, in this case, the three formulae associated with the problem situation, and applied them in a structured way, integrating mathematical and visual representations with related qualitative descriptions. Student involvement was to “watch” and supply information when required, such as data extracted from the problem statement or answers to numerical calculations. Not all students participated, with the majority not asking or answering questions during these performances. Even when the vast majority of the class indicated they had the answer to a problem task correct, he would still go through the solution steps. He would encourage them to ask questions at any time. Jack monitored the success of students and would immediately help any students who had a difficulty in understanding how to solve a problem. Alternatively, he would ask individuals if they now understood and if they did not, he would go through the explanation again. This could involve using the same explanation or an attempt to model the problem practically or sometimes using a different approach.

In virtually all observed lessons where he explained how to solve a problem task, he would refer to the main principle underpinning the solution. The following excerpt illustrates this.



In the diagram above the hollow is as deep as the hump is high. A steel ball (B) is rolling towards the hollow at a speed of 3 m.s^{-1} in the direction shown. If frictional forces are negligible and the ball reached a speed of 4 m.s^{-1} at the bottom of the hollow calculate the speed of the ball as it passed the crest of the hump.

Figure 6-5 Problem task: The dip and hump

He is dealing with the above problem (Figure 6-5) that students attempted in a test and the majority got wrong.

> For homework tonight I want you to do this problem. Now what you have to do here to give you some clues....you have got to work out the kinetic energy there, you got to work out the kinetic energy gain, in other words the kinetic energy gain in dropping down the hump, is going to be the same as the kinetic energy lost going up the hump. So, you work out the kinetic energy. I am not going to explain exactly how to do it You work out the kinetic energy there. From there you can work the kinetic energy gain. Consequently, you can work out the kinetic energy loss and back to your velocity...right that's it. The answer is root 2.. 1,41. I've told you the answer. I want you guys to work it out so you get the right answer. The answer is 1,41. (Jack, lesson, 24/03)

He would always focus on the principle behind the solution but would provide it rather than allow students to determine it. For example, when he discovered that Ken did not understand the answer for a multiple-choice question involving a circuit, that he had just explained how to do, he started again saying, "Watch what I am doing here". He then explained the solution path again, using a different technique. In this case, he redrew the circuit diagram producing an equivalent circuit which all students then were able to recognise from one of their routine problem sets. He completed the solution and asked if all understood, "Let me tell you that electrically speaking, these two diagrams are identical. Is that what you couldn't pick up?" Sometimes he was aware that they did not understand and appealed to them to "believe me for now otherwise you will get the calculations wrong" (Jack, Lesson transcript, 08/02).

Most of his explanations followed a pattern in which he would emphasise the principles necessary to solve the problem task, followed by the identification of the appropriate formulae and then identifying the relevant values of the variables. Once the numbers were allocated, he would leave the arithmetic operations to the students. The students role was limited to following the reasoning behind his solution, providing chorus answers, short individual answers to numerical calculations or confirming Jack's procedure and answers. He gave the clear impression that his strategy was "Watch carefully how I do it" and this will lead to you developing some relational understanding of the problem tasks which will result in you getting to the solutions.

Susan's style was slightly different to Jack's. In much the same way as Jack, she would introduce new topics and new problem types to the students through explaining how to do it. However, her emphasis was normally on how to use the associated formula. This excerpt, from a lesson on acids and bases was typical of the introduction of a topic where Susan would explain how to do a new type of problem task. The following excerpt, taken from a longer transcript (05/08), highlights some of the salient features of her explanations.

> *[She has spent the previous twenty minutes explaining how to do a titration practical, which the class was to attempt the next day. She now had to explain how to calculate the concentration of the substance that was to be titrate]:*
>
> Mrs. Smith: First thing you have to do with a titration calculation is to have a balanced equation. If you don't have a balanced equation, you will not get the answer right, nine out of ten times.
> *[Writes the balanced equation on the board]*
> Now, we are looking at two different things here. We are looking at concentration and we are looking at volume..... OK. The concentration of the hydrochloric acid is what we are trying to find.
> *[Noise from students as she writes on board]*
>
> $$\frac{n_a}{n_b} = \frac{c_a V_a}{c_b V_b}$$
>
> Now you have the formula, number of moles of acid, over the number of moles of base, equals concentration acid, volume acid, over concentration base, volume base.
>
> *[Susan then showed them how to solve by changing the subject of the formula and then substituting in the values. She had to repeat her explanation for the source of the values for n_a and n_b when few were able to tell her the values when requested.]*

This excerpt was typical of her explanations which fit the pattern of being "formula-driven" (Touger et al., 1995). There would be the identification of the appropriate formula to use, values would be assigned to variables, followed by algebraic manipulation. It was rare for her to focus on the principles lying behind the formula. Once this had been done, in the initial introduction to the topic the focus of her explanations would be centred on the use of the formula. There would be many clarification questions asked by students. They would constantly call out questions while she explained. Having dealt with the questions, she would return to her explanation. Susan had many opportunities to interact with individual students, as they would approach her desk to ask for assistance. Susan would nearly always take their exercise book and write the solution steps to the problem task or at least the part they did not understand, explaining to them what she was doing. The overall impression I obtained was that her explanations were directed at promoting instrumental understanding of the solution paths.

Although there were some differences between Jack and Susan in their instructional strategies to develop problem-solving skills, they were based on the teacher explaining and modelling how to do it.

The more I practise the luckier I get

Reference to the hundreds of problem tasks used, makes it obvious that practice at doing problem tasks played an important role in both teachers' instructional strategy. The fact that they were given both a large number of different problem tasks and sets of similar problem tasks indicated the important role played by practice in the instructional strategy. This perception was reinforced by comments such as the following made by Jack when speaking to his class after an examination in which they had not achieved as well as he had expected. He asked one student, who had done very well, how much work he had done. When the student replied "Lots", Jack had the following to say, "It is as Gary Player says, 'The more you practise the luckier you get.' Some of you kids need to listen to Gary Player."

From a closer look at my data, I induced two kinds of practice. First, practice was given on many similar sets of problem tasks (drills) to make the students confident and skilled in basic use and application of the formulae. When asked why the students were given so many similar problem tasks, Jack explained it this way:

> To get them familiar, so that they will have no difficulty in applying the equation in a new situation. So the mechanics, ... in the broad sense of the word, of applying an equation, shouldn't be difficult to them........... Let's take a uniform acceleration problem. Once they have in fact solved the problem, and wind up with a solution, which is S equal V squared minus U squared over 2A, say, then hopefully in fact, once they've got to that point, they merely substitute and take it as purely mechanical. And there shouldn't be any problem there,....umm.... Problem in inverted commas, because they've had a large number of exercises in that. The problem of sorting out U V A T S - what the values are and thereafter, it should be an exercise.
> (Jack, interview 18/03)

Susan had much the same reasoning but she also emphasised the importance of building confidence:

> Int.: There are thirteen questions. Any reason why you didn't just give them four questions?
>
> Susan: Because I think they need practice in this section. It also gives them confidence. I find once they've got, ... once they're doing well in this section, they build up confidence. And the other reason why I've given them so many, is that their equations of motion wasn't very good in their test. And rather than do more worksheets on equations of motion, it incorporates equations of motion to a large extent, so they're getting the practice here.
> (Susan, interview, 04/02)

The students saw it as becoming familiar with particular types of calculations in preparation for the examination. When they were given a similar task, they would only have to cope with the different values of variables. As James put it, the basic use of the equation would become "second nature":

> Because practice makes perfect. As soon as you're given one ... it's the same thing with everything, with driving ... everything you do in life. You can't be expected to do it quickly and effectively the first time round. So the first problem you'll be getting, say it's a truck striking a car, you're going to battle with it, trying to figure where you can fit the information you're given into an equation to find out what you need to know. And then as you do different examples and different situations and different measurements, it becomes easier and easier, until finally at the eighth or ninth problem it becomes second nature. Although what happens to you afterwards, the questions get harder and more difficult and more distorted and require more and more understanding as you go along. So it's probably like an ascent to the problem. You start off with the most basic and the easiest to understand, and as you get the information it starts to build up and the questions get harder and the

> application will be more difficult, but you've already got the good grounding of doing easier ones. (James, interview)

The second type of practice was an attempt to cover as many different situations as possible in which a particular formula or principle could be encountered. James also mentions this in the excerpt above.

Examination of the worksheets showed many of them starting with very similar drill type problem tasks formulated with skeletal situations. These were followed by problem tasks using a variety of situations i.e. variation on a theme. The sets of "pulley problems" given in Appendix F are a good example. While some are simply drills for learning the basic application of the principle, others are variation on the basic trolley with a weight suspended at virtually all the possible positions, followed by friction acting at various points. A further example, supporting the existence of this type of practise, was associated with problem tasks involving the interpretation of graphs. Students were given sets of all the likely graph shapes that they were likely to encounter and an interpretation of them. If they encountered a graph in a test, all that was necessary was to match the graph shape with those previously given as examples. In this particular case, solving a problem task virtually became similar to choosing an answer from a list. This practice reduced the cognitive demand of the work and was part of the instructional strategy as indicated in the following excerpt:

> That is the one I mentioned about the acceleration, I don't think they'll look at the fact that its constant acceleration. They're going to get confused because it is a force displacement-time graph for the rubber ball.......... those two will definitely confuse them, unless they looked at that one sheet I gave them with all the possible options. (Susan, Interview 09/02)

Because students recognised that they would have difficulty with novel situations in the examinations, they would search for problem tasks from a variety of sources especially past tests and examinations. To obtain the desired practice, students would purchase booklets of past examination scripts. These were sold in bookstores and contained the examination questions and model answers from previous years papers from all the education departments. This type of practice was especially emphasised as examinations approached. It was obvious that students saw this as a basic part of the instructional strategy and without it, success was not possible. It appeared that they were hoping to "cover" every possible situation and in this way minimise the chance of getting a novel situation in the examination. When I asked Eric why he was going through the past tests and examinations he confirmed this by replying that it was in preparation for the examination, " so when you get a problem you've seen it before. ...it's just a matter of different figures. You know how to do it".

There was no doubt that Jack and Susan saw practice on similar problem tasks as a strategy for teaching students how to solve the problem tasks that would be encountered in the tests and examinations. When students struggled with particular problem tasks, Jack would often either give another test including similar problem tasks or provide another worksheet with similar problem tasks. After students had difficulty on a test with a particular problem task, he said, "I will endeavour to get one or two similar ones in a worksheet for you tomorrow". When students did badly on a test, I interviewed him about his normal practice of always giving two tests on the same topic:

Jack	And yet I could give them a similar standard test, ...on Friday, and they would do very much better at it.
Int:	So there's something in this practising?
Jack:	Oh look , it's practice and ...... drill for want of a better word, and if you in fact are just drill, drill, drilling, you're drilling for a specific kind of problem. If you in fact are giving vast numbers of problems, somewhere along the line, you do succeed in ..... improving their problem solving ability because they in fact have more practice at the problems, that maybe they're got to think broader, read the question more. How that actually helps them do better the second time round, I can't put a finger directly on it. (Jack, interview, 10/02)

What I found interesting was his firm belief in and commitment to the practice strategy, despite his acknowledgement that he was not quite sure why it worked.

They won't make that mistake again

Both Jack and Susan saw value in carefully going over the solutions to problem tasks after the students had attempted them. One of the apparent reasons for this was for the students to learn from their mistakes. Susan did not spend as much time as Jack on this activity and would often only verbally provide brief solutions and solution paths. However, she felt this was valuable so that:

> The kids can see what sort of train of thought I'm using. Where I'm going and how I get to my answer, not just an answer which is meaningless, and they can also pick up where they've made their mistakes. (Susan, interview, 28/01)

Jack on the other hand was surprised that other teachers did not spend as much time as he did, for example, in "going through" test problem tasks. Again, the value for him was that the students would be able to see their mistakes:

> I also spend a lot longer on going through tests than most people. I would say as a general rule I spend one and a half, two times longer than it actually takes them to write the test on going through it again. If they have a major exam I spend a week on it. And I'm just very surprised that other people can get through it in a period. I think in fact, half the value of a test disappears unless you go through it. I also like to go through the test with them in detail, so that they can actually sit there and mentally kick themselves in the head because they can see how stupid they've been. (Jack, interview, 10/02)

Jack emphasised this instructional strategy as he was convinced that students would learn from their mistakes. For example, after Bruce got a problem task incorrect for the second time, Jack assured me that he "won't do it again". The majority of the students, exemplified by comments from Bruce, were also convinced that this was a good teaching strategy:

> I used conservation of energy for that, because what I did is, I just thought one pendulum carrying on going all the time, and I actually ignored the collision. So I used energy instead of momentum. Now once I've done it, I know I won't ever make that mistake again. You learn from your mistakes. I know now to use momentum instead of energy, because energy obviously ... is going to be transformed, sound and heat.

Another reason for "going over", provided by both Jack and Susan, was that students would inevitably make careless mistakes. In fact, on a number of occasions, both would draw students' attention to a prospective common error, "I'm telling you that you're going to make this careless error". Jack and Susan made it clear that a major factor in any poor performance were the careless mistakes e.g. in gas law problem tasks, they were expecting students not to convert degrees centigrade to Kelvin. They felt that by drawing attention to them repeatedly, while going over the solutions, students would not repeat them in the examinations.

6.4.3 Problem solving heuristics

Assertion 3b: *Jack and Susan encouraged their students to use both general and specific problem solving strategies.*

The emphasis in the previous sections has been on the instructional strategies used to teach problem solving. This section focuses on the problem-solving strategies themselves. Early on in my classroom observations, I perceived two strategies that both Susan and Jack, modelled and encouraged their students to use. The first, I refer to as their general or framing strategy. These were the personal strategies of the teachers and they framed the explanations of how to solve a problem task across all topics and types of problem task. The second I refer to as problem specific procedures as they were limited in most cases to a particular problem type. What follows is a description of these strategies and evidence of their use by Jack and Susan.

Framing strategy

Both Jack and Susan had their own general framing strategies, which they used for the solving of problem tasks and encouraged their students to use. For example, Jack was always emphasising the need to "project yourself into the problem and imagine what is happening". This resulted in many of his explanations having a qualitative component, with time spent on understanding the task qualitatively before moving onto application of the formula. The following excerpt from an interview is one of many occasions when he spoke about this strategy:

> I want them to put themselves in the position, and looking at a pendulum - what causes a pendulum to swing ? - When you have it high, is it going to swing fast. When you have it low, is it suddenly going to accelerate like that? It doesn't, why doesn't it? And...I want them to project themselves into the problem as much as possible. And I think that is the way I teach, that things are very, very hands on. You can project yourself into the problem. And if you can project yourself into the problem to intuitively figure out what is going to happen, then try and do it that way. (Jack, interview, 15/03)

Jack used this problem-solving strategy in his explanations and made it very explicit to the students, often drawing their attention to it. This is clearly illustrated in the next excerpt from a lesson:

> Mr. Jones: What you should do is take ten seconds to look and see what happens ... Try and get an overall view of the problem, what is going to happen.....Putting two mass pieces, one greater than the other - I am choosing a simple example on purpose.
> *[Draws trolley on surface with two objects connected by pulleys one on each side. He refers to this diagram as he continues with his explanation.]*
> In reality what is going to happen here? In reality what is going to happen? Simple. That is going to pull that trolley to the right hand side. Gravity is going to move the whole works clockwise and that is going to hit the ground. And the moment it hits the floor there is no more tension in the string. There is

> no more acceleration ...... constant velocity.
> (Jack, lesson transcript, 18/03)

Susan's approach was different and I have called her method the "common sense" strategy. The strategy could be used when dealing with many situations in school and life in general. She recognised that it was not a specific strategy for school science problem tasks but was also applicable to other situations. Like Jack, she often mentioned it to me when speaking about the problem tasks:

> All the problems, all the calculation type problems that we do in physics, I try and teach them the method. You know, you write down the information you've got, what are you looking for? How are you going to find it? So I don't think it's necessarily restrictive just to physics. Because if they come across any problem, what have they got, what are they looking for, how are they going to get to the end? Whether it's a calculation or whatever. It could be a financial problem. How much have you got? What do you want? How are you going to get there, kind of thing. (Susan, interview, 23/03)

What was interesting was the fact that neither Jack or Susan ever wrote their strategy down on the board, provided a set of notes on its use or provided details of how to develop the skill of applying it.

Both Jack and Susan also emphasised the use of logic and reasoning in their general strategies. Susan felt that her common sense approach arose from simply applying logic to the situation. When I asked her the source of her strategy she replied " I think it came more with time, with trying to use logic more than anything else" (Susan, Interview, 09/02). When he was going over a problem task, especially multiple choice questions, Jack would often take a qualitative approach. He would avoid getting involved in the equations and calculations but rather talk his way through the solution indicating that he wanted to "go by reasoning". This is illustrated in the following extract from a lesson. He is going through a multiple-choice question that was asked in an electricity test, which they had written the previous day:

> Mr. Jones: The one is a 1000 ohm heater and the other is a 2000 ohm heater and...I am not going to use figures to work this out. I am going to go by reasoning on this. Now,..do I spend any time on this sort of thing.
>
> Students: Yes ....Yes
> *[One or two students respond with the rest of class silent then a few more shout, yes].*
>
> Mr. Jones: You bet your bottom dollar on it. I do. I spend a lot of time on this particular aspect.

Both Jack and Susan used diagrams when explaining how to solve problem tasks. They encouraged their students to do the same and often checked if they had used a diagram. While diagrams were an adjunct to Susan's strategy, they were an integral part of Jack's strategy of visualising the problem situation:

> Mr. Jones: In a problem like this what is the first thing I do? Other than read it?
>
> Student: Draw a diagram?
>
> Mr. Jones: Draw a diagram. How many students draw a diagram? I draw a diagram for a very simple reason. As part of my idea of solving mechanics problems that you have to be able to

> visualise.
> (Jack, lesson transcript 25/03)

Susan did not emphasise the drawing of diagrams a much as Jack. As shown earlier, she concentrated on the information provided in the problem task and the associated formula. However, she did encourage the students to use them especially with particular problem types:

> Mrs. Smith: And ... the first thing you do - if possible, you can sketch a diagram. Now, in equations of motion, it's not that serious, but when you come on to something like momentum, it is essential that you have a diagram and you indicate the directions. That will make your life a lot easier.(Susan, lesson transcript, 02/02)

Despite the emphasis placed on diagrams, at no stage were techniques of drawing sketches and diagrams spoken about or were the students given explicit instruction on how to translate a written problem situation into the equivalent diagrammatic representation. Reference was simply made to drawing a diagram or sketch and filling in information given in the problem task.

Specific strategies and heuristics

As each topic was encountered with its sets of similar problem tasks, Jack and Susan would demonstrate how to solve these types of problem task following a particular method or solution path. As indicated earlier, these routine problem sets were very similar and the situation would normally cue the formula or formulae to be used.

In the case of Jack, he did not explicitly list these heuristics or procedures, although one or two were present in the notes provided to the students. For example, the section on acids and bases contained an algorithm for solving titration calculations. However, the presence of algorithms or step by step procedures was atypical. In fact, there was no record of him even referring to it or demonstrating its use. He would concentrate more on his envisioning strategy, with the accompanying diagrams and reasoning, all of which he would model to the students. He would provide particular hints and tips for the different routine problem types. For example when doing pulley problem tasks, he encouraged them to represent them as acting in the same straight line, saying, "Watch what I am going to do here, something very crafty" (Lesson transcript, 03/02). He said this as he changed the diagram from being a pulley with a weight hanging over the table edge to all the connected objects in a straight line. Again, when doing routine equilibrium calculations, he encouraged the students to set the calculations out in a particular columnar format.

Susan on the other hand followed a more structured approach emphasising the need for specific steps, such as writing information down, drawing diagrams etc. This is illustrated by the following extract from a lesson (02/02) in which Susan is explaining how to solve routine problem tasks associated with the equations of motion:

> Mrs. Smith:.: Right. We are going to use these three formulas to do the calculations, and when you are doing calculations - look at the second to last sheet I gave you, I have given you a little list of what to do when you are solving equations. .... It doesn't only apply to these equations. It applies to all equations you are going to be doing.

The list taken from the student notes is reproduced below.

Solving equations

Step 1 If possible sketch a diagram
2. List all the information that is given
3. Write down what you are asked to find
4. Select a suitable equation
5. Change the subject of the formula
6. Substitute
7. Solve

Susan demonstrated this procedure, calling attention to the various steps, as she solved a problem task e.g. “ The next thing you write down is what they want you to find out, what you are looking for” (Lesson transcript, 02/02). Given that she was dealing with a simple task and only had three formulae to choose from, the procedure took the form of an algorithm. However, this was not as easily applied for all the kinematics problem tasks, as many of them would require more than one step. However, the basic strategy, as stated would be used, with variation, as she solved the problem tasks. Although Jack did not use the identical method or refer to a number of steps, he encouraged the use of a very similar procedure. These routine problem tasks, dealing with equations of motion were referred to as UVATS. The students were instructed to write down these symbols for the physical quantities e.g. U = initial velocity, V = final velocity) one under each other and fill in the given information from the problem text. Using this, they were to infer which formula could be used and then solve for the unknown variable.

Susan also used a strategy for obtaining the information needed from kinematics problem situations. Although it could have been useful with a number of different problem types, she only used it when referring to the kinematics problem tasks. She would advise her students to look out for three sources of information, what she referred to as the direct information, the indirect information and constants. This is exemplified in the following excerpt where she is explaining to the class how to solve problem tasks from the section on kinematics:

Mrs. Smith: There are also three things to look for. The three things that you are going to look for are: what they call direct information, which they say to you an object accelerates at 6m/sec; that is direct information; that information is actually staring you in the face. Then they give you indirect information. For example, they are saying to you, an object starts from rest. What does it mean if an object starts from rest? What are they actually telling you?

Student: Initial velocity is zero, is nought *[murmur of voices]*

Mrs. Smith: Initial velocity is?.... Zero. Another kind of hidden information is,.. An object is falling from a high building. What are they telling you there? Sbu? *[directs question at student]*

Student: Acceleration is constant.

Mrs. Smith: Carry on.

Student: *[No response]*

Mrs. Smith: Acceleration? You've got (half?) - they're giving you the acceleration........?

Student: Is constant?

Mrs. Smith: Yes - it's constant .... at 10m/sec. They're actually giving you the acceleration in an indirect way. That's why it's called indirect information. They're using the words in a different

> way. Rather than saying to you, the object accelerates from a tall building at 10m/sec/sec. At that stage you know an object is falling. Things always accelerate at 10m/sec/sec. Right? So if they say to you it's falling, you can assume - you know to use the acceleration as being 10. And the third type of information is if you have to use a constant. Some formulas require you to use constants. For example, later on we'll get onto what is known as Newton's Law of Universal Gravitation, where F = G, M_1, M_2 over R^2, and that is a constant which will be given to you in a data sheet. So that's the third type of information when you are doing the calculations. Right? That's the type of information that you're going to be looking for. What do you do with that information? It's very important. You're going to use that information to solve your problem.
> (Susan lesson transcript 02/02)

For multiple choice questions, Jack had an approach or strategy, which I mentioned above. He wanted the students to read the problem statement and not look at the distracters. They were then to try solve the problem task through qualitative reasoning or use of an equation where appropriate. Only when they had an answer were they to read the distracters and match their answer to one of them. If this did not work, then he advised that as a last resort they should "eliminate those that they know are wrong " and choose an answer from the remaining options. He also emphasised "never leave it blank" implying they must choose an answer even if they were not sure.

6.4.4 The success of the instructional strategy

Assertion 3c: *Students were able to solve routine problem tasks but were not able to deal with the difficult problem tasks. It appeared that the students did not use the general strategies. However, they did use the specific strategies associated with routine problem sets.*

The question of whether the instructional strategies used by the teachers were successful is a difficult one to answer. This is because there are many interpretations or perspectives from which success can be viewed. If the purpose of the strategies was to end up with students who could pass a specific examination, Jack's strategies could be considered very successful while Susan's would not be. However, there was a difference in the academic quality of students in the two classes. Jack's students were all higher grade students and were expected to pass. The question for them was how well they would pass. In Susan's class, the situation was more to do with limiting the number of failures. Consequently, it is difficult to provide definitive measures of success. To get around this problem, I looked for a number of indicators, which would be considered as legitimate from a variety of perspectives. Taken together, I hoped that these indicators would provide an overall picture of the effectiveness of the instructional strategies. The following indicators were chosen as the most appropriate for my purposes: use of problem solving strategies; changes in student marks from year to year; success with routine tasks; and success with difficult tasks. These indicators are discussed in the following paragraphs.

Use of strategies

It was difficult to determine if the students used the strategies that their teachers encouraged them to use and modelled for them. Certainly, there was no explicit evidence that they used the general strategies in a formal and structured way when solving problem tasks on their own. However, there were pointers to the fact that the students did not consider the general strategies useful to them. For example, examination of Jack's student exercise books revealed virtually no qualitative descriptions at all (which could be considered evidence of envisioning) and only a small number of diagrams. Page after page was covered with formulae and calculations. This did not exclude the possibility that students used his strategy. For example, on one occasion he checked to see how many students had used diagrams. When he began berating them for not using diagrams, they responded that they used the diagram provided on the test paper. They did not see the necessity to draw a new one.

However, if they used diagrams as part of their problem-solving strategy, then evidence of this could be expected in their exercise books and examination papers. This was not so, despite the worksheets showing that the majority of problem tasks were not accompanied by diagrams. However, there was evidence that his students were aware of the general strategy and some of them had attempted to use it: For example, when asked about difficult problem tasks, Bruce referred to visualising as one of his strategies. In this excerpt, I had asked him what made some problem tasks difficult:

> Sometimes just the wording. It might be a bit ambiguous at first, and when you read over it a couple of times, and you've got to make decisions about what's actually happening in the problem, visualising. That's probably about the hardest part, actually visualising the problem, trying to decide what's actually happening. (Bruce, interview)

In Susan's class where I had many opportunities to observe students working on their problem tasks, there was little evidence of them using general strategies or drawing diagrams. The exercise books were mostly devoid of diagrams and other evidence of following the steps of the strategies given to them by Susan. Unfortunately, the interview data was not able to confirm this as students gave conflicting accounts. For example, the following excerpt is indicative of some students not using the strategies:

Int.:	When you solve a problem do you think of a, ...do you have a picture in your mind, or do you draw a diagram?
Sbu:	No, I have a picture in my mind........ I just picture this ...... I don't do diagrams.
Int.:	Ok.
Sbu	And I can picture a boy throwing a ball down. And the gravity comes down and ....

However, when speaking to Frances, indicated that she found diagrams useful for understanding the problem situation and did use them:

> Well I think you have to do that. Sometimes like I draw all pictures of my science to make me understand. Because sometimes it's quite hard to imagine the problem because it's not realistic..... And then you just do a picture and you more or less understand. (Frances, interview)

In contrast to the general strategies, there was convincing evidence that the student used the specific strategies associated with routine problem types. For example, they often explicitly listed the variables and equations when doing UVATS problem tasks as instructed. Again in equilibrium type problem tasks, students used the table format showing initial concentration etc. as modelled by their respective teachers. It appeared that where a step-by-step procedure or a format was available, students used them.

Test and examination marks
The second indicator concerned students' test and examination marks. Detailed records were kept in both classes of all tests and examinations for the previous two years. I was able to monitor a student's progress on tests and examinations from their entry into standard nine until their departure at the end of standard ten.

A feature of the students' marks was the lack of significant change from year to year. In fact there was only an average decrease of about 5% from their standard eight year-end result to their standard ten final assessed mark in both classes. However, this does not provide convincing evidence of a lack of progress, as the examinations were not standardised and therefore not comparable. What is interesting is that the standard deviation in Jack's class increased from 8 to 12. This hints at the fact that the gap between those who were able to solve the problem tasks and those who could not, increased as the years past.

Further examination of the mark-record in Jack's class showed that the students who achieved matric marks in the 70-90 % range tended to drop their mark by an average of 4% from Std. 9, while those in the lower range of 45-60 % tended to decrease by an average of 12%. This was an unexpected and significant result. If any change were to occur, I would expect to see the standard deviation to decrease as more and more students became competent problem solvers and were able to deal not only with the routine tasks but also with the more difficult problem tasks. I consider this an indicator that the students were not benefiting from the instructional strategy.

While the average for the higher grade group of students in Susan's class also decreased from Standard nine to ten (53% to 45%), the standard grade group average increased by approximately three percent from 44% to 47%. This could indicate that they were benefiting from the instruction. Given that the standard grade paper consisted of routine problem tasks, it appears that the students were becoming more effective routine problem solvers. An alternative interpretation is that the students were motivated by the high stakes examinations and began to do more practice.

It is recognised that no conclusions can be drawn from these descriptive statistics given the lack of standardisation of examinations and other uncontrolled variables. However, taken as supporting evidence, I feel their presentation is justified.

Solving routine problem tasks
The third indicator was the success at solving routine problem tasks. There was ample evidence that the students were able to solve routine problem tasks especially those provided on their worksheets. Reference to their exercise books in which they did homework showed the majority of the tasks marked correct. When Jack or Susan went over the problem tasks in class there were very few questions asked. Often when they asked who had a problem incorrect, only two or three

would have their hands up. If an assumption is made that at least 70 % of the tests and examinations contained routine problem tasks then the majority of students should pass the examinations. In Jack's class the majority of students passed and the class average for all tests and examinations for the year, referred to as the assessed mark, was 65% with only three students with averages between 45 and 50%. This implies that they were able to deal with the routine problem tasks while the more difficult tasks limited their marks.

This was not the case in Susan's class. The averages of the assessed marks was 50% for the HG students and 45% for the SG students. While most students could deal with the simple routine problem tasks, students had difficulty with any problem that was slightly different i.e. even those referred to as variation on a theme. The consequence was that only eight students had assessed mark above 50%. There were some students who never passed tests and even had difficulty solving the most simple of problem tasks. (For example, seven students obtained less that 40% in the June half-yearly examination.) It appeared as if they simply were unable to engage with the problem situations and did not even know how to follow the procedures taught. Examination of their scripts showed that their marks came from problem tasks involving recall or "learning work" and a few routine problem tasks that were virtually identical to ones done in class. Many tasks in tests and examinations were structured into parts and they obtained part-marks for some of the easier parts.

Solving difficult problem tasks

The students' inability to solve difficult problem tasks was highlighted by a common experimental examination held in a number of schools. Two papers were designed. The first (Paper 1) contained section A with very basic routine problem tasks, and section B with a number of variation on a theme type problem tasks. The second paper (Paper 2) contained section C with difficult problem tasks.

In Jack's class, while the average for the first paper was 70%, the average for paper two was only 40%. The general impression I obtained from my observations, was that there were a group of students, who maintained averages in the eighties, who were able to deal with most of the difficult problem tasks or at least get some way toward a solution. Other students would get some of these problem tasks correct but infrequently. It appeared to be a hit and miss affair. They had done the many practice problem tasks but just never did as well as they hoped or expected on the examinations. Tom was a good example. His final matric mark was a C (60 –69%). However, his test marks fluctuated during the year between eighty percent and fifty percent. In this extract, Tom is explaining why he did not do as well as he hoped in the June examination:

> I suppose that most of the problems, they dealt with things we've done like loads before. All the questions they asked, we've worked on before. All the equations, all the manipulations of equations, you know we've actually done in class. And I did quite well you know, with the mechanic section of work from the beginning, so I didn't find it hard. Because you know , you sort of learn how to go about a problem, and... most of the question we've,.. like we've done almost ... well we've done examples that are almost exactly the same. And I thought it was just, just a case of you know, seeing little things that, ... you know the way you've done before. Why I didn't (do well) , I really don't know. But I didn't feel it was hard paper at all.

What is interesting here is that Tom is not that sure why he did not succeed. He attributes it to "just a case of seeing the little things." It appears as if he is saying that he has done everything asked of him but still cannot get all the problem tasks correct. He was a very motivated student and was active in the lessons asking numerous questions. However, he was unable to consistently deal with the difficult problem tasks.

In Susan's class, the students did so badly on the common examination papers mentioned above, that she did not take the marks into account when determining the term mark. Examination of the student responses to paper C, showed that the spaces provided for the answers were generally left blank. This implies that when confronted with difficult problem tasks they did not know how to start. It appeared as if they had no strategies to implement. Again, the highest mark in the trial examinations later in the year, was 60% with the average for the higher grade being 45%. This is further evidence that her students were unable to deal with the difficult problem tasks and even had difficulty with routine "variation on a theme" tasks.

6.4.5 Commentary

In this section, I have provided a description of the strategies used by Jack and Susan in teaching the students to solve the problem tasks. I have provided evidence to support my assertion that they used both general and specific strategies to work problem tasks. Evidence was provided to show that the students could in general solve the routine problem tasks and they used procedures provided by their teachers. However, they were not able to deal with the difficult tasks and there was limited evidence of them using strategies. I now propose to describe in general the students' approach to solving problem tasks and indicate why their problem-solving strategies were not successful when used with difficult problem tasks.

Dealing with routine problem tasks

As students encountered different problem tasks, students would label or categorise them. They used cues, extracted from each problem situation, to build up a knowledge base of similar sets of problem tasks. The main cues appeared to be the science topic e.g. momentum, the physical objects used e.g. stopping cars, and the physical quantities or the scientific terms e.g. inelastic collision. They would attach to each problem set, the mathematical representations and procedures that could be used to solve those types of problem task. These procedures were demonstrated and practised in normal classroom activities until they became routine. When confronted with a new task, these cues were used by the student, to match the current problem task with a previous routine problem set. Once categorised, the student used the associated solution procedure to obtain the solution. It was a case of "In this well recognised situation I must do this".

Their main problem solving strategy involved i) the ability to associate a task with a problem set, ii) the recall of the previously used solution path and, iii) facility with the routine procedures. To make this a viable strategy, the students did two things. Firstly, they practised with the sets of similar problem tasks to gain facility in the mathematics manipulation and use of procedures specific to particular sets of routine problem task. Secondly, they covered as many different problem situations as possible to enhance recognition of similar problem tasks. I refer to this problem-solving approach as an instrumental strategy (Skemp, 1978). They expected to solve the tasks by employing procedures that had previously been explicitly taught. They expected to identify the superficial cues when they read the problem statement. This allowed them to solve routine problem tasks without fully understanding the physics or chemistry phenomena and associated principles. The structured questionnaire responses added weight to this assertion. 52% of the students in both classes agreed that they obtained the correct answers to *some* problem tasks without understanding the theory or principle, while a surprising 35% of students agreed that they solved *many* problem tasks without understanding the principles or concepts involved.

While this strategy allowed students to cope with the solving of routine problem tasks, it was of limited use when confronted with difficult problem tasks. They would try their strategy of matching with a previous problem and find that it was not working. In what follows I have given some reasons why the students were unable to deal with the difficult problem tasks. I became aware that both teachers' instruction and the students' strategies concentrated on two steps or stages. These were, understanding the problem situation and producing a mathematical representation. These were not necessarily explicitly referred to or identified by the participants as steps, but were implicitly deduced from their problem solving approaches and from the strategies provided and modelled by Jack and Susan.

Understanding the task

The first step dealt with the understanding of the problem task. When the problem task was presented, the problem situation had to be understood. If it was recognised as belonging to a routine problem set then the procedures explained above were followed. If not, students would need to begin asking a number of questions in an effort to create a representation of the problem task. For example: What phenomenon is of interest?; What exactly am I being asked to do?; What are the critical features of the problem task?; What is happening in this situation from a science perspective?; What quantities and variables are involved. What are the situational constraints?; In general, both teachers appeared to accept that there was a need to create an alternative representation of a difficult problem task. This was emphasised as a first step in understanding the problem situation. In response to this need there was an emphasis on producing a diagram and representing all the physical quantities given, onto the diagram. However, it appeared as if the students were not convinced in the efficacy of diagrams or were unable to produce useful diagrams. As previously indicated, evidence from student exercise books showed working that consisted almost exclusively of algebra. This was not unusual. In a similar study looking at student use of diagrams Van Heuvelen (1991a) reported that despite teachers using diagrams in solving problems, only about 10-20 % of students in conventionally taught courses used diagrams when encountering problems in examinations. In the current study, significantly more diagrams were produced on examination scripts. However, where diagrams were used, these did not necessarily appear to contribute to understanding the problem situation. For example in a problem task dealing with a sign hanging from a wall, the majority of students produced a right angled triangle and filled in values such as the forces and angles. Unfortunately in many cases, this information was incorrectly allocated. It appeared that the diagram was more a step in the procedure of creating the mathematical representation than a step in understanding the problem situation.

This analysis is supported by a number of studies (see for example Chi, Feltovich, & Glaser, 1981a; Reif, 1981) that have advocated the need for successively more detailed levels of description as students move from the problem statement in words to the mathematical representation. For example, the student might need to move from a literal representation of the physical objects in the situation to a scientific representation with idealised objects e.g. free body diagram, to a generalised mathematical representation. Unfortunately, the students focuses on the mathematics procedure before they have a clear description of the problem task. Students have a preoccupation with mathematical formulas and equations which Van Heuvelen refers to as "crutches that short circuit understanding" (1991a p.893). He surmises that the lack of effective use of diagrams is due to the fact that students don't understand the concepts and quantities represented in the diagrams and are therefore unlikely to use them. Consequently, they do not have the tools and strategies to understand unfamiliar situations.

Mathematical representations

The second step had as its focus the mathematical representation of the situation. At this stage, the solver would understand what the problem task involved but was not necessarily aware of the scientific principles that apply. If the task was categorised in the first step then the student would simply use the appropriate mathematical procedure associated with these sets of task. However, if the task did not fit exactly i.e. variation on a theme task, then the student would attempt to modify their recalled solution plan to suit the current situation. At this stage, some students who were unable to manipulate or adapt the recalled mathematical representations to suit the changed situation would falter and be unsuccessful. As Johsua (1991) explains, the students become disorientated by minimal differences from the routine problem tasks. This is explained by the fact that as soon as they attempted to combine or adapt bits of partial knowledge, they would move into areas they had not encountered before and become stuck.

It is at this point that the students were likely to categorise the new problem as difficult or tricky. I suspect that they had no explicit approach or set of steps to follow when in this situation. Consequently, they did not know what to do next. Not having other strategies to employ, they would stop or inappropriately apply a mathematical representation from a previously done problem, in the hope that it would be successful i.e. take a guess. Consequently, very few students were able consistently to solve the difficult problem tasks. The only exception to this were a small proportion of students (also found in other studies e.g.(Sweller, 1989)) who were able to generate solutions either through their own efforts or through benefiting from the instruction in some way which was not explicit to all. These students were characterised by the fact that they generally achieved well in most of their school subjects. For example, nearly all students in Jack's class who obtained an "A" in physical science also obtained A aggregates (i.e. the average for all subjects taken in the matric examination).

Apart from this small group of students, I suspect that the students did not develop an effective problem-solving approach to deal with difficult tasks in which they became stuck. We know that students need general problem-solving strategies when moving into unfamiliar areas. Also, when problem-solving, we know they would need to use not only a single strategy in isolation but rather need to employ a combination of strategies. Consequently, they need to have a range of strategies. For example, Dhillon (1998) found ten commonly used strategies, reported in the literature such as envisioning, means-end analysis, problem decomposition, working backward, and heuristic searches. Unfortunately, the students were limited to broad procedures such as picturing what was happening, reasoning and drawing diagrams. Their main strategy was use of analogy i.e. using information from past tasks that were similar.

Unfortunately from my perspective, the reason they did not exhibit these other strategies was because they had never been exposed to this range of strategies in the classroom. The general strategies modelled by Jack and Susan appeared to be of little value. For example, Jack never indicated how to go about "projecting yourself into the situation". It was as if he assumed that the students knew exactly what to do or this was a natural skill that just had to be used. At the same time when Jack or Susan were solving the problem tasks or modelling how to solve, they did not exhibit "stuckness". At no stage were students shown how to deal with that type of situation. Jack and Susan would always know what to do and provide the connections between the novel task and routine procedures. As Jack said " I provide them with the understanding". If they personally used other strategies when dealing with difficult problem tasks, they did not make them explicit and share them with the students. (When Susan was not able to solve one of the difficult problem tasks, her response was to go to a colleague for advice.) It is suspected that they were able to deal with difficult problem tasks in class because they were experienced teachers and simply had a much larger store of problem types and cues to recognise what to do. In all probability, these difficult problem tasks were well recognised situations. When solving them in class, they were not modelling problem-solving strategies but rather modelling procedures for routine problem solving.

CHAPTER 7

WHY ARE THINGS AS THEY ARE?

7.1 INTRODUCTION

This chapter has as its focus the last two guiding questions of this study i.e. "Why are things as they are?" and "What role do external factors play?" In the previous chapter, I have shown that problem tasks are the focus of teaching and learning. The students encounter large numbers of routine problem tasks but have difficulty solving those that are novel or non-routine. One of the main reasons was that Jack and Susan did not model useful strategies to deal with them. Their main instructional strategy was to explain carefully how to solve the problem task. This was not very effective, as many students were unable to take advantage of the instruction and improve their problem solving abilities. In general, the student results were not as high as could reasonably be expected, given the apparent low cognitive demand of the problem tasks and the extensive practice they had.

My focus in this chapter moves from the description of the activities, to finding out why the school science is organised in the manner described. First, I will assert that there was a mismatch between the various participants' understanding of the purpose and role of problem tasks in the teaching and learning of science. These understandings were not shared, or communicated among the participants resulting in tensions within the didactical contract. Secondly, teaching and learning was taking place within a restrictive system dominated by a syllabus, time constraints and examinations. This restrictive system constrained what was taught and how it was taught. In addition, it was the main source of motivation for the classroom activities and for students' involvement in them. Lastly, the teachers and students had an uncritical belief in teacher explanation as an efficacious instructional method for teaching and learning how to solve problem tasks.

7.2 MULTIPLE PERSPECTIVES ON THE ROLE OF PROBLEM TASKS

Assertion 4: ***In the short term, the participants saw the solving of the problem tasks as preparation for the matric examination. In the long term, the participants had different views of the intrinsic value of the problem tasks. The teachers saw the primary role as promoting general thinking skills, the external participants saw it as developing or assessing conceptual understanding but the students saw little or no intrinsic value.***

7.2.1 Introduction

One of the questions that this study was attempting to answer was why problem tasks are used in the teaching and learning of science. It would seem to make most sense if the participants had an agreed role for problem tasks. If students misinterpreted the teachers' intentions, tensions could occur within the teaching-learning situation. A situation could exist where a student was concentrating on getting the correct answer to a problem task while the teacher was more concerned that she was making sense of the underlying scientific concepts or problem solving process. This could result in an ineffective educative experience and frustration for both participants.

In Chapter Two, a number of possible reasons were suggested for the use of problem tasks in the teaching of physical science. For example, problem tasks could be seen as vehicles or tools for developing conceptual understanding within the subject domain. In that case, we would expect problem tasks with structured questions that have an emphasis on qualitative aspects of phenomena, which encouraged discussion. An alternative could be that problem tasks are seen as inherent to science, and are present to be learned for their own sake because educators see value in students being able to do these types of problem. In this case, teachers would provide practice on these problem tasks in the classroom and their presence in tests would be to evaluate if the students could do these useful problem tasks. In trying to uncover why instruction was based on these tasks in Jack's and Susan's classroom, I chose to approach from three different perspectives. First, I considered the teachers' perception, followed by the students' perception. Finally, I looked at the situation from an external perspective i.e. concentrating on those involved in supervising the teaching of science in schools (advisor), setting the examinations (examiner) and moderating the examinations (moderator).

7.2.2 Jack and Susan

Sub-assertion 4a *Jack and Susan saw the primary role of solving problem tasks as promoting general thinking and problem-solving skills for use in students' lives outside of school. While Susan disagreed, Jack also saw the solving of problem tasks as playing a role in developing conceptual understanding.*

It was obvious from the first interviews that both Jack and Susan had previously not given the matter much thought. They were operating within a system in which traditionally students were given problem tasks to solve and they were continuing this practice. In fact on one occasion Jack remarked that the questions I was asking in the interview were difficult and were questions, he should have thought about 25 years previously. However, given the context within which they were operating, it was obvious that the problem tasks were used in instruction as part of the preparation for the examinations. Both Jack and Susan referred on many occasions, both implicitly and explicitly, to the role of solving problem tasks as preparation for the examinations. For example, when I probed the role of problem tasks in teaching during interviews with Susan, the role of preparation for the examination inevitably surfaced at some stage. In the following excerpt, I was probing the role in the teaching and learning of physics as opposed to a more general role she had given earlier in the interview:

> You know, the problem is that by the time you get to matric, its sort of the matric exam orientated. So, it's as many problems as you can, as many different types of problems as you can, as quickly as you can. So, I don't know how much problem solving really goes on. It's more rote, sort of. There is problem solving because you try and give them as many varied questions as possible, so they do have sort of problems to solve, but its all along the basis of the same lines. (Susan, interview, 23/03)

Both teachers emphasised this as the immediate or short-term role of solving the problem tasks. This emphasis is discussed in more detail in section 7.3.4.

Other than preparing the students for the examinations, Jack saw the problem tasks as serving two functions. First, he saw problem tasks as tools for understanding the science and developing conceptual understanding. While he never explicitly stated this while teaching, he did mention it in interviews. The following is one instance were he mentioned this in answer to the question of why he set problem tasks:

> So , so why do I set problems? .... It's applying a law that we've actually discussed. .. and hopefully giving them a greater understanding of what the law is all about. ... so, by doing the problems they are getting a better understanding of the law. Right. .... If we deal with Newton's Universal Law of Gravitation, it's a straight statement, which can be converted by a constant and MKS units into a mathematical expression. ....Now, as far as that is concerned, it's all very interesting to know that .. masses attract masses because it has mass and the inverse relationship and the direct relationship in terms of masses. But, in fact, unless you actually apply it, it has merely an academic interest. .....
> So , so why do I set problems? .... It's applying a law that has been actually discussed. .. and hopefully giving them a greater understanding of what the law is all about (Jack, interview, 18/03)

Explicit in his comment was his belief that by doing the problem tasks the students would get a better understanding of the principles involved. The problem tasks were the means through which the theoretical principles could be applied, discussed and understood. However, as indicated by the following comment in the same interview, he did not seem to be totally convinced of this. I asked him if students were getting a better understanding of the law by doing problem tasks. He did not respond immediately obviously thinking carefully. He then said:

> .... Difficult, that...................., I would say, possibly .... it's giving them a greater familiarity .. with the law,....... It's a means of exposing them,.. to the law.........., I suppose in a way, this is what setting problems and Newton's first, universal law of gravitation is, is that you become more and more familiar with it and hopefully that with the greater familiarity there will be a greater understanding. (Jack, interview, 18/03)

Despite his many years of experience, he appears to be only hopeful that solving problem tasks leads to understanding rather than certain. Perhaps the doubt arose because this was the first time his practices were challenged and he had not thought carefully about the matter before.

Secondly, Jack saw problem tasks as tools for promoting problem solving which he equated with “thinking broadly”. He did not limit this role to scientific thinking but rather saw it in a broader context of developing “thinking” for general life problems. Two excerpts from interviews are given as evidence of this role. Both were responses to questions I asked about the role of the problem tasks:

> They require certain basic factual skills,..., a knowledge of certain facts, scientific facts in order to move from matric to first year fairly easily, and of course to get back to the old bugbear,....umm...., problem solving, the ability to think broadly. (Jack, interview, 18/03)

> Hopefully, somewhere along the way we succeed in teaching them to think. And somewhere along the line they pick up a little science on the way. Does that sound terrible? (Jack, interview, 24/05)

Implicit within the second quote was the view that conceptual understanding of the content was secondary to promotion of thinking skills.

Added to this was an impression I obtained that he was ambivalent about the value of the actual problem situations. When asked about the relevance of a variety of the problem situations, such as pulleys, his response was positive:

> It gives some relevance to everything you do outside, in the same way that the study of biology.... just gives another .... a wider perspective to ... .. to what you do and what you see everyday in life. (Jack, interview, 18/03)

Yet later, when I asked about the relevance of a gravitational problem task he had been working on in class, he replied:

> Does Newton's universal law of gravitation in any way assist them once they leave here at the end of Matric and go out into the outside world? The answer is no, unless they are going to follow a pure physics course. (Jack, interview,18/03)

From Susan's perspective, the problem solving was useful in the development of general problem-solving methods for use in all aspects of life. The following excerpt illustrates this view. When asked why she gave students problem tasks to solve, she replied:

> So that they learn the technique of problem solving. A method, well, not a method but various methods because different problems are solved in different ways and I don't think, I think, I hope that by teaching them the methods that we learn here is actually carried over into their, the rest of their lives, so that if they do come across a problem they have methods to draw on to try and solve their problems. (Susan, interview, 23/03)

Susan emphasised this view in her interviews and on one occasion illustrated her view by providing an example of using problem-solving methods when going on a camping trip:

> It helps them, hopefully, with being able to solve problems other than just Science problems. By looking at ....that's why I try and write down, what have we got. I mean you can solve any problem like that, what have you got? What are you looking for? How are you going to get there? Camping trip. What have I got for the camping trip? What do I need for the camping trip? Okay, how am I going to get...I don't have a tent, how am I going to get a tent, where am I going to get it from? So you're sort of using a similar method of problem solving in your classroom, which you can use, or in your Science calculations as you can use when you get sort of interesting things like going camping. (Susan, interview, 28/01)

For her the long-term value of teaching the students to solve problem tasks was that the same approach could be used to solve other more "interesting" problems relating to everyday life.

I pursued this matter and asked if the ability to do problem tasks pointed to an understanding of the related concepts. Susan indicated that she was not convinced that the use of problem tasks led to conceptual understanding nor were the problem tasks even seen to be related to real life situations:

> Not at all. If I can do the problems then I've understood how to do problems, how to solve mathematical problems. I don't think it leads to understanding, and I think they should try as far as,........ I can see that by the way we say to them "Well imagine what is happening. Is this possible in real life?" And they

> sort of think, well, they hadn't thought of that. They don't sort of associate, as far as the kids are concerned, those numbers they fit into that equation, that problem and that's it. They don't even associate that problem with reality. It's something you do in the science classroom, it's not linked to the wider world around us. We've got to try and get them all the time to think "now, does that happen in real life?" (Susan, interview, 23/03)

In addition, she was not convinced of the value of the science content associated with the tasks as she explicitly told me that "the actual content that they learn, I don't think is very valuable". It appeared that for her problem solving in science had the short-term role of preparation for the examinations and the long-term role of developing general problem-solving methods for use in contexts outside of school.

7.2.3 Students

Sub-assertion 4b: *The students saw the primary role of the problem tasks as preparing them for the matric examination. While most students saw problem solving playing some role in the development of conceptual understanding, a significant number saw little value in the problem tasks. They saw the problem tasks as simply school work to be completed.*

The evidence from fieldnotes, questionnaires and interviews strongly suggests that different students perceived the role of the problem tasks in different ways. However, two views were most dominant. First, the majority of the students had the pragmatic view that the problem tasks played an important role in helping them pass the matriculation examination. The following comments, representative of a large number of similar comments extracted from questionnaires given to students from both classes, provided evidence of an underlying preoccupation and emphasis on the forthcoming examination. From these and other comments, it was obvious that the students' goal was to prepare for the examination and doing the problem tasks was seen as good preparation:

> I think the purpose of this is for me to pass Standard ten and go to university and never see them again (most of them). Some of them are useful. (Anonymous)
>
> The purpose of these activities in the short term is to enable us to pass matric and in the long term I probably won't use it, but I will still have it behind me! (Frances)
>
> Purpose is to increase ability to solve problems for trials /finals. (Kevin)
>
> Their purpose is to clear the fog off my eyes and help me when I would be revising for the end of the year. (Thanda)

I obtained further evidence for this view when I probed the reasons for doing large numbers of problem tasks during student interviews. The following excerpt represents one of the instances where students saw the value in doing the problem tasks as preparation for the tests and examinations:

> They teach you to notice things. They are common... to questions, so we knew those odd 120 questions - we noticed similarities and when you get to the exam or a test, and you get the same type of problem, you know how to deal with it. It's not just totally new to you. For instance the trolleys with the tension. Once you've done a couple of those problems, you know how to do it. You get to a

> test, and you don't have to go in and try to teach yourself during the test. You know what's expected of you. (Bruce, interview)

The second common view expressed by students emphasised the role of problem tasks in promoting conceptual understanding. The following excerpts represent two of many comments indicating that they felt the solving of the problem tasks was the means to understanding the science concepts:

> The first thing .... she or he gives you problems to do in order to understand what you are doing. For example if you say you are doing vectors, she will give you a problem and then you will understand vectors better, if you have done them by yourself. (Sbu, interview)
>
> Problem solving is a skill, not a "gift from the gods?" In this respect practice makes perfect. One problem leads on to the next - like a ladder, so problems actually guide a person towards a better understanding of work covered. (Kevin, questionnaire)

In an interview, James gave a response to my question about why problem tasks are given to them, which I considered the most thoughtful and reasoned response from a student. It was obvious to me that the role of the problem tasks was not self evident to him and he needed to think carefully about his response to my question:

> For what I can see, science is a science. It's investigating natural phenomena that occur around us, explaining them and trying to classify them into certain categories. Then if you take a category, just say momentum - because it springs to mind, pretty arbitrary - you must have .... people have witnessed something happening. Two guys running, let's say in a rugby match. One guy's picking the other guy up and they move at the same speed. The big guy hit the little guy, and they're both going in the direction of the big guy. Now, why does it happen? And it's an explanation given to something that's been witnessed by an observer; it's explained to the best of the ability or the most widely accepted explanation is taken; it's given a way of solving problems - why it happens. You're given the explanation. From that explanation you derive certain formula that can apply to the explanation and help to explain the phenomenon. Then re-explain to us the explanations given to us, to the best of our teacher's ability; it's put across to us so that we can understand how it works. And then the questions, as far as I can understand, are put to challenge our perception of the problem, so that we can .... It's been explained to us - it's quite hard to say this - you're given insight in how to use information, and the problems are put across to us - and they can be solved using the information given - to see our understanding of the actual problem, to see if we can apply what we've learned. (James, interview)

For James, the problem tasks played a role of helping in the understanding of situations from a scientific perspective and also in testing students' ability to apply their understanding to problem situations. Evidence of this role for problem tasks was reinforced by responses from the structured questionnaire. Students agreed that the solving of problem tasks uncovered their misunderstandings (Q 14 – 74%) and built their understanding of science concepts (Q24 –76%). However, only a minority agreed that solving problem tasks improved their problem-solving skills for everyday life experiences (Q23 – 33%) or agreed that the problem tasks gave them skills to solve problems they encountered in life (Q30 – 43%).

Early on in my observations, I had the feeling that there were a significant number of students, if not a majority, who treated the problem-solving tasks as so many school tasks to be completed. It was a feeling that grew on me as the months of my classroom observation passed and arose in my efforts at trying to understand the behaviours of the students. They appeared to attribute no intrinsic value to solving of the problem tasks. The students did not explicitly communicate this view to me but rather I implicitly deduced it from my classroom observations. Later it was confirmed by my analysis of comments made by students and teachers. It appeared that the problem tasks were simply seen as schoolwork that had to be done. In the short term, they were a means to enable them to pass the examinations but in the long term, they were of no value in themselves or as a means to an end.

For example, when I asked Jack's class to respond to a video recording of themselves, in which they talked and generally "fooled around" when Jack was not present in the class, many of the students indicated that this was to be expected. The responses indicated that, for them, it was normal behaviour. Given any opportunity they would stop doing their problem tasks. Although not a typical response, the following quote from a student with above average scores, encapsulates the impression I gained of their attitude:

> As it became evident that Mister Jones was not about to show up, I prepared to and did indulge in a lengthy and loud conversation with my peers, because I had the chance to do so. That is the only reason. Give us the chance to bugger around and we will, because, very few people will be motivated to do pointless 'keep-them-busy' exercises. (Marc, questionnaire)

Implicit within this statement is the view that problem tasks were seen as school work that had to be completed. They had little value in themselves.

Even Susan was aware, and appeared to accept, that the students saw the problem tasks as simply work to be completed. When I was interviewing her (28/01) and probed her about a particular student's experience in the class, I asked:

Int.:	Let us come back to Sipho. He takes down the notes and then you give him the worksheet.. What do you think he thought when he was given the worksheet?
Susan:	Let me do this as quickly as possible so I haven't got homework, because I've got so much biology homework. I'd better get this done so I've got time for biology." I don't know, I don't know what they're thinking. I've never ever thought about what they thought. This is school, its work, they've got to do it, they get it done. Some of them. And Gavin didn't even think about Science. He was busy worrying about the rugby match yesterday afternoon.

Further, when students in Susan's class were assigned problem tasks for class and homework, they would attempt to reduce the number of tasks that they were given by petitioning Susan. There was no discussion as to the value of the problem tasks. All that would be discussed was the amount of work or time that was needed to complete the problem tasks. Moreover, once they had completed a problem, signalled by their answer matching the answer provided, (by the teacher, fellow student or on the worksheet itself), they would move on to the next problem. Once an answer was obtained, the problem tasks were "discarded" and the next task attempted. The moment they had completed all the problem tasks, they would do other work. Their whole attitude expressed by the way they worked in class supported the view that the problem tasks were seen as work to be completed.

Frances, a target student in Susan's class, who I observed closely, exemplified this prevailing attitude. On many occasions Frances, who sat close to me in the classroom, would have a magazine or book on her lap the moment she had completed her assigned problem tasks. However, during the solving of the problem tasks, she would demonstrate that she had little understanding of the underlying principles or concepts. For example, she would call out to Susan, "Must I use little g or big G?", "To convert milliamps, must I divide by ten to the minus three?" and "Which equation must I use?" In one case, when doing a problem task involving gravitational attraction, she had checked the answer supplied at the back of her textbook. Finding that it was different to her answer, she then manipulated the numbers provided in the problem statement until the correct answer was obtained. When I tried to engage her in a discussion about the problem task, because I felt the answer provided by the textbook was not correct, she was very dismissive indicating to me an attitude of "the task is complete. I have the right answer. No need for further discussion". Despite having a limited understanding of the science and what appeared as instrumental understanding of the problem tasks, she did not attempt to use the problem tasks to develop her understanding. She was interested in "finishing". She was not the only student who gave me the impression of operating in this mode.

Added to this, a significant number of students in both classes were dismissive of the long term role or value of problem tasks. They saw them as a school specific task, which had no relevance in later life. The following are two typical comments taken from questionnaires:

> I battle to see the value of science in later life, as I do with most subjects, as I feel that we will never again use the formulae and methods that we have studied in class and for exams. (James)
>
> As for the homework - it bores the hell out of me. I can't see the point in doing endless problems if they are all the same. Problem sums and the like are okay - but simply manipulating the formula is a colossal waste of time. (Phil):

Analysis of the structured questionnaire reinforced this perception. Only about half the students agreed that learning how to solve problem tasks would be a useful life skill (Q2 – 54%) or that what they learnt from doing science problem tasks would assist them in the future (Q32 – 52%). This and other evidence from the fieldnotes, provide a picture of many students seeing problem tasks as simply school work to be completed which had no intrinsic value other than helping them prepare for the examinations.

7.2.4 External participants

Sub-assertion 4c: *The external participants saw the primary role of the problem tasks as tools for developing or indicating conceptual understanding. The examiners also saw problem tasks as tools to rank students.*

In contrast to the other participants, the three external participants, (moderator, advisor and examiner) all appeared to have firm positive views about the role of problem tasks in teaching and learning. What came across was that they had thought carefully about the matter and had definite views. In my interview with the subject advisor, he repeated two related ideas. He saw problem tasks as vehicles for developing conceptual understanding and saw them as assessment tools for the specific purpose of determining conceptual understanding. When told about students concern that the problem situations did not represent real situations e.g. student comments such as "they are not helpful to me in my life", he was very specific in emphasising that the problem tasks were designed for conceptual understanding:

> That's totally true. Our problems are designed to produce conceptual understanding of situations and not to be real life problems. I mean, motor cars don't have perfectly elastic collisions, but if we start to introduce the problems that you have with the crumple effect, which a decent motor car has to absorb part of the impact, then we can't do any problems.
> (Subject advisor, Interview)

In his opinion, even simple problem situations could be effectively used to develop conceptual understanding. He felt that there was no need for complicated mathematics or difficult problem situations:

> I think that by looking at the numbers you can do a lot of conceptual things. If you can keep the mathematics simple and the numbers whole numbers, I think it can explain concepts more easily than mere words can.
> (Subject advisor, Interview)

However, when given in examinations, he saw the problem tasks as a tool for determining if the students had "insight or simply a recall level of learning". When I asked about the role of an examination problem dealing with "pulley problems", which was different to those students would have encountered in their class i.e. a difficult problem task, he replied:

> So it was different. Now, if they actually understood what was going on, then they would have been able to do that problem. If they didn't understand that the purpose of that ... one of the principles being tested there was that the mass of the system must remain constant, then they would have left the M out - the mass of the bob out of the mass of the system. And they would have got a wrong answer for which we gave, hopefully, less than half marks. So in which case, despite having done it a hundred times, they didn't understand.
> (Subject advisor, Interview)

His reply indicated a conviction that the success at solving problem tasks was an indicator of understanding. Consequently, they had a place in examinations as vehicles for evaluating student understanding. He was very adamant about this and was upset when a school challenged the value of the examination. They implied that the examination problem tasks did not assess conceptual understanding but rather rote learning. He responded by saying:

> Maybe it is possible that a kid has been spoon-fed so he does well in the exam but he doesn't know a hell of a lot. But I don't see how a kid can be highly educated and have great depth in understanding but can't pass the exam. I don't see how that is possible. So the guy who says, "My kids are really well educated, but nobody got higher than a D," I'll say, "You're talking bull." Because I don't think ... I think that the two things are mutually exclusive. And I don't think that you will get an A on one of our papers on a higher grade unless you know some Science. (Subject advisor, Interview)

The moderator was very firm in his view that the problem tasks were necessary for the development of conceptual understanding and therefore were a necessary part of learning. In order to understand theory there was a need to " use it, to apply it, to decide how to apply it." He felt that "you can't just sort of absorb the theory without actually working with it, engaging in application of it". Further, he had the following to say:

> I use it more as a means to enable myself...... Curiously enough in the sense of a problem centred approach to teaching,....... it seems that you can best learn the concepts and ideas and theories by applying them and trying to work, illustrate them through problems. So as the students engage with the particular problem the theory is drawn in and the needed parts understood and so a student can learn through problems. (Moderator, Interview)

While it can be seen that he had similar views to the advisor, specifically about the use of problem tasks for developing conceptual understanding, he also emphasised the development of problem solving skills. When I asked if problem tasks were a means to something or an end in themselves, he replied:

> I think they are both. Obviously as an end, problem solving in itself is part of what science is about. And the ability to, it's an, it's an active process. It's an important process which we hope to develop in people...... So yes , it's an end in itself. (Moderator, Interview)

The moderator made two further points. First, he was not convinced that the routine problem tasks encountered in class, or the problem tasks in the textbook were able to achieve the goals he saw for problem tasks:

> My feeling with ordinary textbook problems is they have two limitations. One is they are mainly very often, exercises, calculational exercises. So they only require a limited range of cognitive demand. So both as an end they are limited because they only develop a certain part of problem solving, the more procedural part. As a means they are very limited because they don't illustrate the conceptual understanding that require students to go through qualitative reasoning and various representations and relate them and understand the physical situation. So they fall short for both purposes. (Moderator, Interview)

Secondly, he was adamant that the problem tasks were not useful in themselves but were rather a means of achieving other goals. In this excerpt, he indicates that the problem tasks are a means of guiding students through a learning process:

> Ok, the problem is that the, if a particular exercises or problems chosen then come to have a kind of life, if it's viewed as if in fact somebody has an important skill to be able to calculate whether this thing will move, in an unusual situation of a block on a plane or something. And of course that's unfortunate because I don't believe I've ever had to calculate that in my scientific career. And nor ever will I need to. So the idea that this, the solution of this particular problem is of great interest is, is mistaken. The problem is there in order to guide people through a learning process, in general a simplified situation that principles can be applied to in an apprenticeship kind of way. And that's it's real function here. Here it's definitely a means to an end. No, that particular problem is not an end in itself. Nobody wants to know that. (Moderator, Interview)

He saw one of the consequences of using routine problem tasks was that they could be solved without much higher cognitive activity:

> If you have a problem of a familiar kind, people can recognise it, will know what principles to put down, will be able to write it out algebraically, substitute in the numbers. They have learnt the procedure for a prototypical problem. And now, more routine exam questions encourage that. So it's quite possible to get the numerical answers without the conceptual understanding. Only if it's of a familiar kind. (Moderator, Interview)

Although he expressed this negative attitude toward the routine problem tasks, he felt that students would have developed some skills if they could do these problem tasks:

> You certainly need to know algebraic manipulation and substitutioning and choice of ... selection of the appropriate formulas for the situation, understanding of ... identification of the variables, insertion into equations and solution that's the obvious thing which is very common. I call that quantitative exercises. Mostly of problems of the familiar variety. So those, those kinds of skills are very well developed in students because of the common occurrence of those types of problems. (Moderator, Interview)

The evidence from the examination meetings and the marking of scripts strongly suggests that the examiners saw two specific roles for problem tasks. First, the tasks were a means of revealing students' conceptual understanding. While there were no explicit statements made to this effect, a number of comments indicated this, such as the following during the meeting to review the previous year's examination paper:

> And I regard this as one of the 10% of really difficult questions in the paper, and the kids who did that, they really know what's going on in an electric circuit. I think that was a tough question. This is what I call a problem. If you know what to do - you're doing an exercise. I think most kids saw that and didn't know what to do when they started. Those that worked it out had solved a problem. Many of the other things are just plug-in exercises.
> (Examiner, exam meeting)

Implicit in this comment is the idea that the more difficult problem tasks played the role of revealing understanding but the routine ones did not.

The subject advisor, who played a role in the setting of the examination, supplied added evidence of this view. The following comment made at the same meeting, illustrates that he saw the difficult tasks as indicators that the student knew "what was going on":

> I don't think - sometimes the university people say kids can only do rote learning. Now, while I'm in favour of a certain amount of rote learning - particularly in chemistry there are certain things you must know - I don't believe you can do this problem if you've rote-learned how to do pH. You've actually got to have a pretty good idea of what's going on before you can do this. And when your kids get good marks, I reckon you have every reason to be very proud that you've taught them something more than just rote-learned facts, because I reckon there's no parrot in the land that can score an A on the Higher Grade paper. The kid who gets an A knows some science.
> (Advisor, exam meeting)

Secondly, the examiner saw the role of the examination problem tasks as a means to rank the students. This idea is encapsulated within the following excerpts. The examiner was speaking to the teachers about allocation of part marks for solutions, which were not exactly according to the examiner's model answer:

> What we're trying to do in the exam - we're a norm-referenced exam. If you're in the top 8% you get an A, irrespective of what you scored on the paper, and if you're in the bottom 12% you fail Higher Grade, no matter that you actually got 45% on the paper. So it is important that we get kids in the right rank order, so that those who are in the bottom 12% deserve to be there. So when we mark, we try to give the kid who knows more than nothing more than zero. But at the same time, the kids who knows less than everything on the question must get less than full marks. (Examiner, exam meeting)

He then indicated that in order to achieve this he sets tasks of different difficulty:

> I am required to set questions on the entire syllabus. I am required to set questions that are difficult, medium and easy. So some of the questions there are difficult. They, ladies and gentlemen, were meant to be difficult. I expected them to be difficult. I expected only the top 20-odd per cent to have a reasonable chance of getting them. Ten per cent of the remainder would have got them on a one in four chance. But if the questions are difficult, they are designed to be difficult. (Examiner, exam meeting)

Taken together this explicitly indicates that the examination problem tasks, in particular the difficult tasks, were the means by which the examiners sorted the students.

7.2.5 Commentary

The evidence provided is consistent with a picture of problem tasks serving a number of different roles for the different participants. As this range of views held are very similar to those reported in the literature (see Section 2.3 p.12) it can be taken as given that problem tasks can serve more than one role. It was, therefore to be anticipated that this study would find some participants holding multiple views of the role. Although the assertions were not unexpected, a number of aspects of the findings are problematic and raise issues for discussion.

Reflection: The teachers who were responsible for implementing the published curriculum and organising the educative experiences of the students, showed little evidence of reflection on why they were doing what they were doing. From interviews with Jack and Susan, it was obvious that they had not previously given much thought to why they used problem tasks and they did not have firm opinions but rather tentative ideas. This was typified by Jack's response when I began to probe deeply: "What's interesting about it is, is that you're asking me questions ... that I perhaps I should have asked myself 25 years ago. However, don't let's get onto a philosophical discussion on that." (Jack, Interview, 18/03).

Problem solving skills: Unexpectedly, only the teachers and the moderator saw the problem tasks playing a role in developing problem solving skills. The students did not see this as a significant role. None of Jack's students mentioned the role of problem solving to be "developing thinking" as he had suggested. The only evidence of Susan's students holding a view similar to hers of developing "logical abilities" was a remark from a target student, Kevin, during an interview in which he mentioned that he got the impression that "the problems help your logical abilities". I expected that the teachers' views would be made known to the students and at least some students would adopt their views. However, it remains of concern that both teachers emphasised this role yet students were either unaware or not convinced. The question arises as to whether the teachers are being prevented from emphasising something, which they see as valuable or their strategies were so weak that students did not see them as worth adopting.

Conceptual development: There was a common belief that problem tasks played some role in developing conceptual understanding of principles, laws and general subject matter. However, neither teacher gave the impression that they were totally convinced. Their views are supported by some authors who are not convinced of the efficacy of problem tasks in developing understanding (see p.18.). Unfortunately, whether this belief is an educationally sound one is open to debate because we do not have a good research base to argue one way or the other. This area is recognised as a weakness in current research which focuses more on student knowledge or the problem-solving process rather than on the effect of problem solving on knowledge development (Huffman, 1995). What we do know is that the development of conceptual knowledge is explicitly mentioned as a primary focus in the syllabus documents. Given the manner in which the problem tasks were used in instruction, it is unlikely that they contributed toward the development of the desired concepts. What is more likely is that the role of preparation for examinations took precedence and the syllabus focus was underplayed.

Assessment tools: Those directly involved in the examination system were convinced that the problem tasks acted as assessment tools. This could be criticised as for example Chi (1989 p.148) reported that the observation of how students solve similar problem tasks to those previously encountered is the weakest method to detect understanding as they can be solved by syntactic mapping of the example procedure to the so-called problem. However, from the evidence, I was confident that the examiners were not referring to problem tasks in the examinations that were routine in nature and could be solved by reference to similar problem tasks previously done. According to the examiners, it was the maverick type problem tasks that could not be solved without drawing in the principles and concepts. Examination of these difficult problem tasks showed that they required higher cognitive thinking and could not be answered only through recall of previous procedures. Consequently, this view appears to be legitimate. However, the examiners do not make it clear exactly what role the routine problem tasks play in teaching, learning and evaluation.

Didactical contract: If the assumption can be made that a clearly understood didactical contract must be in place for effective teaching and learning, then a problem exists in the classrooms described in this study. The evidence suggests that the students saw the role of solving the routine problem tasks primarily as preparation for the examination. They had a belief that the routine problem tasks would help them develop some understanding of the science concepts but this was essentially useful for the solving of subsequent problem tasks. The ultimate goal was to solve these types of problem task, not learning science. They were seen as school tasks that had to be completed but which had little relevance for their future lives. Similar results have been suggested in other studies (Gabel & Bunce, 1994; Sweller, 1989). In contrast, their teachers felt the main value was in developing thinking skills or logical thinking. They saw this as being a useful skill in the students' lives both in the present and in the future. As far as the development of conceptual understanding was concerned, this was secondary and in the case of Susan not considered likely. At the same time, the examiners were setting examination papers containing a number of more difficult problem tasks, the successful solving of which they believed would act as indicators of the students' understanding of the science. In addition, they included many routine problem tasks that could be solved by recall of previous examples for reasons that were not clear.

The above description indicates that when it came to the role of problem tasks there were definite tensions in the contract. The only agreement was that they needed to be done in preparation for the examinations. There was no shared vision of the problem tasks contributing to their understanding of science or developing useful problem-solving skills. Rather it led to negative views of school science and problem solving, views which were expressed by many students:

> I learn "off-by-heart" how to solve problems, as all we have to do is apply the methods and formulae. This is because I feel there is no reason to have to know about concentration/time graphs or how to work out the ending velocity after a collision. It has totally nothing to do with our daily lives. Why would I want to work out how much energy was left after a collision in a Pendulum. But it is interesting how it works. I feel less emphasis should be placed on mathematical problems and more on understanding concepts which affect us in our daily lives, so that we may be able to use these concepts to our advantage. (Tony)

7.3 A RESTRICTING SYSTEM

Assertion 5: ***The teachers and students are operating within a tightly bounded system in which the syllabus, time pressure and the senior certificate examination act as boundary constraints.***

7.3.1 Introduction

Science teaching takes place in a complex environment of inter-linked influencing forces. Some of these forces are immediate and obvious while others are remote or operate at different levels and the links to the teaching and learning environment are not apparent. A number of studies have looked at these influences and reported that there is a complex cause-effect relationship between these forces and teacher actions. They report that some of these forces emanate from within the educational system while others arise outside the educational system. Among them are some that are beyond the control or influence of the teacher (Gallard Martinez, 1990 p163; Tobin, 1987; Wood, 1988).

The assumption made in this study was that what we see happening in a classroom is linked to a number of influencing forces. Collectively these forces influence the participants' beliefs about science teaching and learning and have a powerful influence on the shaping of the implemented curriculum. Consequently, recognising and identifying the forces that have a direct bearing on classroom activities are important tasks when studying and trying to understand that system. Some of these are internal such as the teacher subject matter knowledge or classroom resources. Others are external, such as school policies and community values. Although I did not discount the importance of those forces, which could be considered to lie outside the educational system, what I considered here were those forces that arose from within the educational system but were external to the classroom and were essentially beyond the control of the participants. I found that when coming into the classroom both teacher and students entered an environment in which their learning activities and topics were constrained. Three influencing forces, being the final examinations, the syllabus and time, were recognised as obvious constraints on classroom interactions. It was within this framework that I attempted to understand why things were organised in the way they were. In the following sections, I provide a description of these forces and show how they influenced the implemented curriculum.

7.3.2 The Syllabus

Sub-assertion 5a: *The published syllabus determined the discipline specific content topics and the breadth and level to which they were taught and studied.*

One of the constraints or “boundary forces” recognised was the education department syllabus (NED, 1987). It determined what was to be learned and in this way constrained the implemented curriculum. Its influence was pervasive. The following segment from a lesson represents one of many instances in which Susan indicates which topics of work will be dealt with. Susan was handing out pages of typed notes to the students and explaining the order in which to place them in their notebooks:

> Mrs. Smith: It's just a bit of background information relating to equations of motion ....tips and that sort of thing... And then you put the acceleration due to gravity- we have done all this sort of thing already- acceleration due to gravity, free fall, terminal velocity and projectiles, OK? Standard grade do not need to know projectile section. Right. Standard grade can cross out the projectile section if they wish.....Then we go onto first page of Newton's laws of motion and define a force, and then we look at Newton's first law which we have looked at already and ......
> (Susan, Lesson, 18/03)

It is very clear from this extract that the syllabus was used as the arbitrator of what should be learnt and what was to be “crossed out”. Part of the reason for the many explicit references to the syllabus in Susan’s class was because the class contained students from both grades and parts of the syllabus were different. However, even in Jack’s class where all students were doing the same higher grade syllabus, Jack would also refer to its contents on occasion. For example, when I asked Jack why he did not set problem tasks that were more relevant to the students everyday lives, his answer showed that he was very aware of the syllabus constraints and they influenced his choice of problem task:

> I suppose you could move away from that entirely and endeavour to get total relevance, in terms of household circuits and that sort of thing - I accept that. ... Maybe, I’m locked into the syllabus so much myself that I cannot see beyond, the traditional type of circuit diagram ... [4 sec] but the syllabus in fact does not allow all that much lee-way in terms of doing it.
> (Jack, Interview 24/05)

When I asked him why problem tasks were set on the topic of kinematics, his reply again reinforced the idea that the syllabus was a constraint:

> It is expected, in this section for kids to be able to answer relatively simple questions, or problems associated with the laws. It's written into the syllabus, and I suppose, in fact that there could be an approach, where problems of this nature, and an approach…. .. or a total revamp of the syllabus where, you don't set problems, but I must admit that I can't comprehend that...
> (Jack, Interview 18/03)

The emphasis on the syllabus was not limited to the classroom. When a group of teachers attended the examination meeting reviewing the previous years examination paper, the examiner emphasised the value of the syllabus:

> There are two other little things that I think you should know. Listening to visiting teachers in the last couple of weeks, I sometimes think people are teaching the textbooks, especially new teachers, and they're doing all sorts of amazing things that are in the textbooks but aren't in the syllabus. And so I think it's actually quite a good idea to read the syllabus occasionally.
> (Examiner, exam meeting)

However, when the teachers interpreted the syllabus in a narrow and literal sense, the examiners were not happy. Teachers were very quick to complain if problem tasks were set on topics they considered to be outside the scope of the syllabus but the examiners felt that a little liberty was acceptable. For example, in the same meeting, two examination problem tasks were queried by teachers, but in both cases the examiners defended their decisions and tried to justify their deviation:

> We've actually had flack on the Standard Grade for doing this sort of thing, where we've asked a question that wasn't specifically on the syllabus and people have moaned. And our exam board agrees that even with Standard Grade we can expect them to balance two half reactions off the data sheet if we tell them which two half reactions to take. I think even Standard Grade should be able to do this kind of thing.(Examiner, exam meeting)

The examiners made a few disparaging comments about teachers who complained saying they were "splitting a hair" about what's on the syllabus and what is not. In the following excerpt the examiner is reporting on a problem task that involved changing acceleration:

> Despite the fact that I had this whine, the vast majority of kids got two out of three (marks) for this, so the kids didn't have a problem with it. It was only the teacher that had a problem with it. (Examiner, exam meeting)

It was obvious that some teachers had a narrow interpretation of the syllabus and were not happy with problem tasks that were seen to be outside the narrow confines of the syllabus statements. However, the examiners felt that some related problem tasks were acceptable.

Even the students were constantly aware of the influence of the syllabus and applied pressure on the teacher to remain within the bounds of the syllabus topics. They would often ask if a topic were in the syllabus. My observations in both classes indicated that the teachers stuck very closely to the syllabus. However, Jack would on occasion talk around a topic filling in some historical detail or attempt to relate the task or concepts to everyday experiences that he had. Despite this, I was not aware of any occasion where he spent a lesson dealing with a problem task that was not part of the syllabus. However, one of his students did complain: "Its good that Mr. Jones add some extra knowledge into the subject to make it more enjoyable but sometimes too much and the syllabus is rushed at the end of the term."

7.3.3 Time and organisation of periods

Sub-assertion 5b: *Time was a constraint that influenced the pace of coverage of syllabus topics and the instructional activities that were planned.*

Two main consequences were evident because of the time pressure. First, activities were carried out within an environment in which time was considered to be in short supply. The participants viewed time as a constraint. This was essentially because of the need to cover all the topics in the syllabus before the year end examinations. Added to this, there was a need to work at the same pace as the other classes in the school so that common control tests could be held. Both Susan and Jack were very aware of the limited amount of time available to complete the syllabus topics. This was particularly noticeable from examining the many comments recorded in the fieldnotes such as "we are behind" and "we must move on" made by both Susan and Jack to their classes. This sense of trying to cover topics within certain time limits is implicit in the following excerpt from an interview with Jack. The other classes had completed a section of work that was to be examined in the June examination. Jack had planned to give his class a second test on a previous section but now cancelled it. When I queried this, he replied:

> No, I broke the good news to them yesterday. I am too far behind. It would be useful but I have to get ahead. And also as far as the exam is concerned, for everyone else it includes reaction rates and equilibria. They know this. But I at least want to be through with reaction rates. In fact, it is a relatively small section. Relatively quick section to do. There isn't much to it.
> (Jack, interview, 02/06)

This need to cover the topics at the same rate as the other classes was present in both schools. While Jack was always behind the other classes in his school, as soon as Susan discovered she was "falling behind" she would increase the rate at which she covered topics. In the following excerpt from an interview, I asked her if she was concerned about having to cover a section, which should have been completed the previous year:

Susan:	Not yet. Its early days, not yet no. You know there are other sections which you can actually go through quite quickly. I mean electrochemical cells you can do in a double period quite, quite easily. Or we can spend two or three lessons doing it very slowly. So I feel I'll be able to make up along the line anyway so I'm not too worried.
Int.:	So when do you hope to finish?
Susan:	What's today? Thursday, I'll do a few more equations of motion, projectile motion on Monday. And more up and down motion, then we'll go on to Newton's Laws probably on.... Wednesday I have a test, probably next Thursday we'll go for Newton's Laws. And that section, once they've done this section they can master that section. Newton's laws usually goes pretty quickly anyway. (Susan, Interview 23/02)

In both excerpts, Jack and Susan refer to topics in terms of how quickly they can be covered. This sense of limited time to do the work required and cover the syllabus topics was always present in the classes creating a time-pressurised environment.

For some, this time pressure resulted in tension within the classroom environment as evidence by this remark by Frances:

> At the moment. Ok this is what I feel. I feel that matric there is so much pressure and the reason why there is pressure is because there is so much work. And the teachers are feeling the pressure because they've got to get the work done in a short amount of time. And then everyone gets upset because I mean obviously if there is pressure everyone gets upset you know.
> (Frances, interview)

For others, evidenced by the comment from Kevin, the time pressure meant that they had to move on to new sections leaving behind parts of the previous topic which they had not fully understood:

> There's always some problem that I have with say, just the section of tension, and I know that if it's asked in a test, if I can't get it right in the worksheet, I won't be able to get it right in the test. So I try and work through that as well. But you don't always get enough time to go through all the problems that you don't understand. And the teacher always asks the problems that you don't understand. (Kevin, interview)

The second area that time exerted pressure on was the choice of instructional activities. In general, the lack of time constrained the choice, resulting in some beneficial educative activities not being planned because of a fear of falling behind or because of a need to reduce time spent on a topic and in that way catch up. Consequently, the range of educative activities was curtailed. In the two excerpts below, Susan explains why she has not done some practical work with her students and why she does not allow them to construct their own notes, two activities which she acknowledged as having educative value:

> I doubt whether it would have been anything that they couldn't learn, but it is better if they do see it, then they do tend to remember it better. But I just find with practicals it actually takes up so much of lesson time, and preparation time, at the moment I just actually don't have it. (Susan, interview 28/01)
>
> I have tried to encourage them, for like, for example especially my Standard Nines, I often teach a section and get them to make their own notes. But I also find that very time consuming because that sort of notes, you have to check to make sure that they've understood you correctly. And……I honestly don't have the time, so its actually easier, time wise, for me to make the notes and hand them out. (Susan, interview 28/01)

In both cases, Susan uses a lack of time as a reason for not doing the activities. During the same interview, we were discussing students' mistakes in a test and the fact that they seemed to repeat the same mistakes:

> The ideal situation would be to actually be able to sit with each child and go through each example with them, especially in tests and things like that, but we just don't have the time for things like that. (Susan, interview 28/01)

It is obvious that as a consequence of time pressure, she is not doing what she considers to be in the best interests of the students.

Even questions or explanations, interesting to both students and teacher, were often not followed up due to the pressure of time. This was most evident if student questions, asking for clarification, started to take more time than normal or began to move toward a topic, which would not be expected in the examination. Susan often dealt with this by telling students not to get "technical" when they started to probe her explanations asking for detail. Alternatively, she would stop discussion with the announcement that they would not get a question like that in the examination. In virtually all cases, the students would accept this and the lesson would continue.

Jack on the other hand was more flexible and often allowed discussion to continue but would label it as "not for examination purposes" or just for interest. However, he had his limits and would sometimes terminate a discussion abruptly if he determined that the discussion was getting too involved. This is exemplified in the following extract from a lesson in which Jack was explaining how to solve a "pulley"problem task involving a block accelerated by a falling object attached to it. He had spent the previous ten minutes explaining how to do it. Some students had become interested, as evidenced by the number of questions they had been asking about the problem situation resulting in a longer than normal time being spent on the problem. However, the discussion ended abruptly:

Shaun	"Sir ? Is that moving along a frictionless surface?" [refers to block on table]
Mr J.:	"In this instance, yes" [about to further comment but hesitates]. No. I want to get off this one now......A point that is interesting -and because it is interesting I will mention it, but please I don't want to go on further- but if this were not a frictionless surface and there was friction, a point would be reached, where in fact it would have a negative acceleration. Because once that force became equal to the force of friction, acceleration would be zero and once - as it got closer it was less than the force of friction, then it would have negative acceleration". [Shaun puts hand up and Jack shouts]
Mr J.:	"No!"
Shaun	"No, Sir, its a quite interesting question. Would it reach a point somewhere along its journey, where the upward force on it would actually reduce the friction?"
Mr J.:	[interjects] "Oh! Oh!... OK, OK! Very good point but- No further on that! - one nice idea." (Jack, lesson transcript, 03/02)

Despite the potential to explore an area which seemed to interest the students he closes the discussion, essentially because he does not have the time to spend on that topic. As he admitted to me later, as the year progressed he became more focused saying "I diverge a hell of a lot in standard nine when I have got the time, but I don't do it in matric."

7.3.4 Examination system

Sub-assertion 5c: *The senior certificate examination (matric) exerted a powerful focusing influence on the classroom environment, the instructional activities and on the problem tasks chosen.*

Evidence from a number of sources emphasised the powerful influence the senior certificate examination had on the implemented curriculum. Together with the syllabus and the limited amount of time, they created a system within which the teaching of physical science was both focused and constrained. Both teachers saw themselves caught up in the system over which they felt they had little control. This is best illustrated by comments made by Jack:

> We are slotted into an examination system and my express purpose, becomes more and more apparent later on, is exam orientation .... and we are stuck with the system, you are in it - and you have to do the best for the kids.
> (Jack, interview, 24/05)

On various other occasions, he referred to this system saying they were "locked into", or "strapped into" an examination system. I got the sense of Jack seeing the system similar to a journey which is taking place toward a destination which you have no choice, much like "slot racing cars on a track" or "a roller coaster ride". Susan was just as direct indicating that all work was directed towards the examination:

> The aim is that they can become proficient in this sort of a question and that hopefully if they get something on a similar line that's slightly different that they interpret it and answer the questions successfully, in the exam. Basically, that's what you're all really actually working towards.
> (Susan, interview, 04/02)

This constraining examination system can be described best by referring to some of its characteristics all of which help in understanding why it had such a focusing effect on the classroom environment and the instructional practices. In the following sections, I describe each of four characteristics.

Control

The system was considered to be under the control and authority of a group of people referred to as "they". There was constant reference by both students and teachers to these people in control of the system as "they". A number of activities were attributed to them, such as setting the instructional problem tasks, the examinations and the syllabus. Take for example the following excerpts, the first from a lesson in which Susan was introducing the topic of equations of motion and the second from a student talking about doing problem tasks from the worksheets. In both cases, it appears that "they" are seen as responsible for creating the tasks and determining what information was given and what questions needed to be answered:

> There are also three things to look for. The three things you are going to look for, are what *they* call direct information, which is - *they* say to you, an object accelerates at six metres per second. That is direct information. Information staring you in the face. ... Then *they* give you indirect information. ...For example, *they* will say to you, an object starts from rest. What does it mean when an object starts from rest - What are *they* actually telling you? (Susan, lesson 02/02)

> What I do in science from day to day, is come into the classroom, and try to absorb as much information as humanly possible, very much like a sponge. I then go home and see if I can make head or tail of what went on. I enjoy questions which require thought, but they mustn't try and confuse the question using "fancy" language or unrealistic circumstances.
> (Anonymous, questionnaire)

In other situations it was obvious that the "they" referred to the examiners while on other occasions "they" seemed to refer to those that determined what was to be learned in science i.e. the syllabus authors:

> If you go into the exam and you get an A, you've done exactly what they've asked because the exam would have been based on exactly what you've been doing. If you, I think ... if a person can understand everything about science and what they're taught ... I don't think science is particularly hard, but if you try and understand it and, you know, what is taught to you, then you are fulfilling the expectations of what you're supposed to be doing
> (Interview, Tom)

The evidence from the above comments is consistent with the belief that "they" are responsible for setting the tasks and "they" have certain expectations of the students. One of the interesting consequences of these expectations was that the students were convinced that the teachers were sometimes acting in concert with this external authority, "they", to trick students by giving problem tasks which were not as straight forward as those presented in class. Students often commented on more difficult problem tasks, not as a challenge, but rather as a "trick" as illustrated by the following student's comments and those given in Section 6.3 (p.89):

> Well, the way that some - the way the examiners put the questions. They can try and confuse you or try and trick you. (Zuziwe, questionnaire)

Comments by Susan and Jack while referring to problem tasks, such as "that's a sneaky one" and " I knew that would catch you out" reinforced the idea that the teachers were conspiring with "they" to produce difficult problem tasks. From my perspective as observer, this resulted in what appeared to be adversarial relationship existing between the students and "they".

What was clearly evident was that even the teachers held the examiners and others, who constituted the "they", in high esteem. This was exemplified by a comment made by the examiner. He was making the point to me that teachers held examiners in high esteem and were even a little frightened to question them:

> We had been marking for some time and at tea some meek sub-examiner comes to me and says "I think maybe you made a mistake." It was a standard grade paper and we had made a mistake. When I asked the others, some had also picked it up but had said nothing. When I asked "Why did you not say so?".. her whole point was that you are the examiner...you are higher than God or God's assistants... You can't possibly be wrong.......Unbelievable!
> (Examiner, interview, 11/05)

Overall an impression was created by the students' and teachers' language that the examination system was under the control of some high status, unknown and faceless others who had particular expectations of students.

High Stakes Stressful Examination

Parent and community expectations were such that the classroom participants saw the examination as having high stakes. The start of the examinations was always reported in the local press and commentary made on whether results would be better or worse than the previous year. The results of all individuals were published and schools, which achieved good overall pass rates, were mentioned. The community had strong expectations that the students would be prepared by their teachers for this examination. From the student perspective, they required a certain number of points to gain admittance to some tertiary institutions. The higher the mark in the examination, the higher the points allocated. Consequently, success in the matric examination was very important. Jack made a number of comments about his responsibility to help students obtain these important "points":

> Look, one must always bear in mind, that and this might sound terrible to a person who thinks broadly in terms of education, whether we like it or not, we are locked into an examination system. And are likely to be for some time to come. I owe it to my kids, ... in terms of points at university, etc, is to get them to achieve as high as possible. From now until the end of the year, the last three terms of this year. I will be matric - blinkered, oriented, because I owe it to my kids to get them to maximise their symbols. Rightly or wrongly, that's what I'm going to do. Because if I don't do that, I sell them short. I am prepared to diverge .., to expand on the syllabus....umm...., in standard nine and up to this point in standard ten. Because I want to capture them, get them on my side, etc, etc,.. I want them to think that science is a reasonable subject, I want them to enjoy the subject etc. But as from the end of the first term, I'm exam orientated and any teacher who isn't, is selling his kids short.
> (Jack, interview,18/03)

In another interview, he gave the impression that he felt other educationists saw an emphasis on examinations in a negative light. However, he was committed to helping his students obtain good results, something for which he had a good reputation among both the students and the local teaching fraternity. For Jack the examination was of such importance to his students that it would be the focus of his planning, whether this was seen as right or wrong.

For many students, the examination was so important that they were motivated to work although they positively disliked science. The following vignette provides evidence for this view. It involves Eric, who in his first interview explained that he was not interested in science and saw no relevance in it. I interviewed him again after he received some particularly poor results for the June examination. He again admitted that he did not "bother with science" and had not studied for this examination. However, in the excerpt below, it appeared that he had now resolved to do more work, for no other reason than he needed a pass on higher grade to obtain the matric exemption required to get into university:

> It's bad [refers to his mark]. But after this exam, I see that I'm going to have to do some work for the end of the year, just to try and pass it. You see, because what I thought was, with my matric exemption - because I've already got two subjects on the Standard Grade, and they said you could fail one. So I thought if I failed Science, then you could still pass it on Standard Grade if you get 33 or whatever. And then I could still get my exemption, and then I asked Mr Andrews and he said no; you're not allowed to fail any subjects. So now I have to start working because I can't drop to Standard Grade in this subject, otherwise you have three on standard grade and you can't get an exemption. I have to do some work. (Eric, interview)

(Students needed to pass a minimum of four of their subjects at the higher grade level to obtain an exemption, required for entrance to university courses.)

As the matric year progressed, the internal school examinations gained in importance. While the March examinations were only for internal assessment, the June examination results were often submitted to tertiary institutions to obtain conditional entry. Consequently, the June examinations were seen as having high stakes. I took a video of Jack's students having their marked examination papers returned to them. After showing the students the video, I asked for their comments. A common theme was their acknowledgement of the importance of these examination marks. The following represent a few of the many written response received:

> Panic - praying about getting any marks. Fear. Stupidity - disappointment. Your whole future depends on one exam. Stupid. (Burt)
>
> I was extremely nervous on receiving my exam mark. Although everyone (teachers) says that marks are not everything, to us, the pupils, marks are extremely important. For these marks ensure bursaries, and whether or not we get into varsity. Paper two almost killed me!! (Frank)
>
> This is the climax of the term and all that you have achieved / learned / gained is reflected by this mark. The various actions are therefore ways of relieving tension / showing disappointment or lack of any interest due to a poor mark or good one for that matter. (Gary)

The second theme that emerged from students' responses to the video was that they found these examinations very stressful. This can also be seen in the extracts above. I have provide a few more to show the depth and intensity of students feelings about the examination:

> For some the results are good but for others it is a nightmare! For some like myself there is fear building up within worry and tension. I hate getting exam results back! (Ken)
>
> Here I was staring blankly at the board, more concerned with my crap results than with correcting them. I didn't talk much 'cos I was in a bad mood. The exam is past - why bother correcting it. Here I was struck by the futility of existence and exams. I experienced a great and profound melancholy. (Marc)
>
> Immense excitement or disappointment when the truth came out about how well, or badly we did. Feeling of fear passed through the life-blood of my veins. (Bruce)

A further factor which contributes to the high stakes nature of the examination, was the status attached to students' achievements. Among the local teachers, there was a sense of competition, with teachers being congratulated because of the good results, specifically the number of "A's" obtained i.e. the number of students who obtained above 80% in the final examination. This status attached to results was borne out by comments made by the examiner, both informally and in an open meeting of teachers, while discussing the examination paper:

> I've actually told markers, you are marking teachers now - the pupils will do within their ability what their teachers did for them. And there's no doubt about it, that when you are finished marking, you can identify where your better teachers are and where your not-so-hot teachers are.
> (Examiner, exam meeting)

Overall, there is ample evidence that the examinations were seen as having "high stakes" by all participants.

Focused the implemented curriculum

Both Jack and Susan provided overwhelming evidence in their classroom practices and interviews, that the matric examination was the focus of their teaching programme for the year. Assuming that both teachers saw themselves as having responsibility to help students pass the examinations, I would expect them to provide the learning experiences that they felt would be necessary to pass the examinations. This was seen by the emphasis they gave to two aspects of instruction. They placed emphasis on giving tests and examination as practice for the final examination and they focused on examination questions.

Evidence of the pervasive influence of the examinations on the determination of classroom activities was suggested by the large proportion of curriculum time spent on testing. This is represented in Table 7-1, which indicates that in both Susan's and Jack's classes over 30% of all available time was spent on writing or reviewing internal tests and examination. This was consistent across school terms.

Table 7-1 Number of testing sessions per term in each class

	Time period	*Topics completed*	*Actual Periods (35 min)*	*Writing tests*	*Review of tests*
Susan	TERM 1 Feb.-Apr.	Newton's laws, energy, momentum	60	14	7
Jack	TERM 1 Feb.-Apr.	Newton's laws, energy, momentum	57	15	9
Jack	TERM 2 May-June	electrostatics, current electricity, rates of reaction	65	13	17

Jack made it very clear to me that it was part of his teaching strategy to give many tests and to go over them in detail. For him they were an important part of the preparation for the examination. This is indicated in the following excerpt where he is planning the activities which will take place after the term examination:

> After the 22nd I go through the exam with them. We have a week. I have six days to go through the paper ....and I will spend six days on that paper ....and depending on what I see in this test and what I see in the exam ....I might test them again on what they have just been tested on because I always tend to test them twice on the same material and of course this time I have only had the opportunity to test them once so I might test them on the second last day of term .... and go through the test but on the other hand I might not have the time .... I think I mentioned this to you earlier - that I spend a hell of a lot more time going through exams that anyone else I know. They are writing a two hour exam paper, so that means .....four lessons for me .... I see it as a very, very valuable revision tool as far as the section they are doing at the moment . (Interview, Jack , 15/03)

Some of the students were not that happy with this emphasis especially the going over of the questions. For Tom, it appeared that there was more emphasis on the examinations than on normal learning activities:

> It's been useful but it's been a bit laborious as well. I mean... we've had two, well nearly two weeks of just going through the paper. The paper itself takes you two hours to do. Oh well overall three and a half hours to do. And you're going through it for two weeks. You seem to spend more time on the exams than like learning the actual work that you are going to do before the exams. Some of the questions you know you will take heed of what they are saying.

> You know because things you may not know or things you may have fallen short. But, most of the questions, I mean like poor Williams he got 100 percent for the physics paper. And if Mr. Jones is going to sit and discuss the paper for four days. I mean it, if he knows all the paper he doesn't need to discuss it. It seems a bit of waste of time you know, for some people. (Interview, Tom)

This emphasis on writing the examinations in preparation for the matric examinations was supported by the subject advisor. He encouraged the teachers in meetings to test their students a number of times and to finish the syllabus early so that all the work could be tested. He wanted them to practise writing examination papers:

> So I'm perhaps a bit exam-oriented, and I make no apology for it. I believe that kids should write in March on five terms' work in their Matric year. Everything they've done in 9 and the new work they've done in 10. Again in June, on six terms' work. And in trials, on all the work. That way, at least they revise stuff that they would otherwise forget, because after many years out of the classroom, I find I do problems slower now than when I was doing them every day. In other words, practice is absolutely essential. (Advisor, interview)

The second aspect was the emphasis on the problem tasks asked in past examinations. The examination questions over the years had become an important component of the "implemented curriculum". As previously indicated by the moderator, these examination questions seemed to get a life of their own and teaching was organised around these and similar problem tasks. When I asked Susan about the type of problem tasks that were used in her teaching, it was apparent from her answer that the examination questions were very influential in her planning:

> I do use the exam questions to base my teaching on, because that's what they're sort of aiming for unfortunately. And I don't use as many real life questions or examples as one should, really, to, to sort of give them a rounded education. (Susan, interview, 28/01)

There was further evidence in her teaching that the examination was the focus of classroom tasks. For example, if an aspect of a problem situation was not considered examinable, it was ignored:

Mrs. Smith:	The resistance of the whole circuit. OK....This resistance here 6 ohms, that resistance there is 12 ohms, and your effective resistance is 4 ohms -Yes?
Arthur:	Lets say you are given two sets of values -
Mrs. Smith:	[interrupts] You won't!
Arthur:	You won't be using - ?
Mrs. Smith:	[interrupts] You won't be using two sets of values. They might give you two cells in parallel. OK?... In which case, if you have two cells in parallel -what is the situation there? If you are told they are 1.5V batteries - Sorry. Lets rephrase that -1,5V cells put in parallel to form a battery, what is the effective potential

> difference - EMF of the battery?...
> (Susan, Lesson transcript 18/05)

The reason or source of the student's question is not considered. It seems enough to dismiss the question because it is not to be part of the expected matric examination.

There was a great deal of evidence that past examination problem tasks were the focus of much activity. The subject advisor was aware of this emphasis on examination problem tasks and accepted that to a certain extent the examination determined the implemented curriculum of the following year. This is indicated in the following excerpt, where he was talking about a new problem task that students had found difficult in the previous examination:

> OK. So next year maybe the guy sees that. Now he teaches it. So we've increased the content knowledge. Instead of it being a problem now, it's simply recall next time. And hopefully ... in fact, I believe if you look at our exam papers, it's unbelievably harder now than it was ten years ago, because of the fact that people extend their kids by whatever is new in this year's exam. So I think, yes, we are very exam-led. (Advisor, interview)

In addition, students would purchase booklets of examination papers with model answers and do them in their own time. Both Jack and Susan provided time in class near the end of the year for students to do past examination papers. Moreover, during class time, the fieldnotes show many occasions when the teacher would draw students' attention to the fact that a particular question appeared in a past examination paper. The above excerpts yield evidence that the past examination problem tasks had such high status that they had a profound influence on the implemented curriculum.

Examination relevance takes priority

As I watched and listened, it became clear to me that examination relevance took priority over the learning of meaningful science. First, examinations had an indirect influence on the type of responses asked for by questions. For example, despite the advisor feeling that qualitative type responses would be valuable in teaching and learning, they did not use many because they were difficult to mark:

> And I think one of the things that we find when we mark is that, as a rule, as teachers we don't like to set questions where they have to write a description, because we don't like to judge what it's worth out of 10 if he's written a little essay. So we don't do it. The examiner tends ... if the examiner did more of it, the teachers would do more of it, and I think it would be a good thing because I think kids express themselves poorly when they write Science.
> (Advisor, interview)

He implies that if these qualitative responses, which he sees as valuable, were used in examinations then more teachers would use them in their teaching. Unfortunately, the analysis of the examination problem tasks shows little emphasis was placed on qualitative questions.

Secondly, because one of the roles of the final examination is to rank students, the type of problem tasks asked in examinations and therefore found in class, focus on this ranking role rather than the role of developing understanding (see Section 7.2. p.124.) For example, the excerpt below is taken from an interview in which I questioned Jack about a particular problem task he had set in a test, that had resulted in a lot of confusion for the students:

> OK Right. I could have structured the question more. I could have lead them into the correct answer quite happily. I could have said "Right,....umm.... after collision, what is the velocity of ball A ?. What is the kinetic energy of ball A.? To what height will ball A rise?" I could have structured it that way and it then, it was a totally new situation. But it then leads them on in the right direction. .. ... What it takes away, is that it levels the ground for everybody, because it's no longer a difficult question. The kid, in fact, who can look at a problem holistically,....umm...., isn't given the advantage of utilising that skill. ....umm...., So. Yes I could have structured it. It would have made it a simpler, and more kids would have got it right, but it wouldn't have separated the men from the boys. (Interview, Jack, 18/03)

It was apparent that the question had essentially served the role of ranking his students. Because of the importance of the examination type questions, this practice of using sorting type questions even appeared in class tests and internal examinations despite the potential confusion it might cause. It appeared that helping students understand situations took second place to "sorting the men from the boys".

Thirdly, relevant activities were seen as those activities which would assist in obtaining higher marks for the examination. The question of whether it was meaningful science education was not the priority. The following comment from Jack during an interview indicates that he taught sections of work which he recognised as having little relevance to his students' lives, but were taught because of examination relevance. The students were solving problem tasks associated with direct current circuits (DC). I asked how he felt about this topic when he was aware that the alternating current electricity encountered in the home, was not similar to these DC circuits:

> I accept that ... In other words - the odd job husband who wants to replace the brushes in a vacuum cleaner or something like that ... Yes, electric motors are no longer part of the syllabus. And the answer to that is - I discuss a number of things that are not in the syllabus - but on the other hand if I am going to discuss the motor effects in an electric motor, that will be a large diverge away from the syllabus, and come the second term of the matric year, when we deal with electricity - I diverge very little. I diverge a hell of a lot in standard nine, when I have got the time but I don't do it in matric. I don't believe we are doing the kids any favours. We are strapped into an examination system and my express purpose becomes more and more apparent later on ... umm ... is - *exam orientation* ... we are stuck with the system, we are in it - and you got to do the best for the kids. (Jack, interview, 24/05)

Although he sees electric motors to be relevant, he is not prepared to diverge from his examination orientation. The subject advisor had a similar attitude when the question of conflict between understanding the principles versus getting results was discussed. Evidence of this view is provided in the following excerpt:

> And whether we like it or not, to say, "My kids were educated but they couldn't do the exam," doesn't help the kid a hell of a lot when he doesn't get into a tertiary institution. I'd far rather a kid actually passed the exam and the tertiary institution struggles with that he isn't quite as good as his mark says, but at least he's there. And the other way round, where a guy claims, "My kids were brilliantly educated but they couldn't pass the exam." (Advisor, interview)

This statement yields further evidence that passing the examination was the first priority and in this case, understanding was secondary.

What counts as right and wrong.
Value was placed on correct answers and alternative interpretations of situations that produced different answers were devalued. In addition, answers were expected to take a particular format otherwise, they were also devalued. There is evidence that the source of this attitude was the manner in which examination scripts were marked. Some of the discussions that took place among the examiners during the marking process were revealing. Before the questions were marked from a model answer, each of the solutions was discussed and alternatives considered. In one incident, during the examination marking, the markers, the majority of whom were very experienced teachers, argued about the answer to a particular problem. The very act of arguing and discussing the situation indicated to me that it was a situation, which could be seen from different viewpoints. However, the chief examiner would only accept one correct explanation and was particularly blunt about this saying, “If he puts down the wrong answer, you don't read further. No matter what his explanation is, it's wrong.” Later during his interview, I asked the advisor about this incident:

Int.: And the problem that I spoke about, where the pendulum, one where the child obtained the wrong initial answer but gave what appears to be a very coherent reasoning behind it - do you think that's possible?

Advisor: I don't see how you can give a coherent explanation, when your answer's clearly wrong. Like, if you say - in that particular case - “they reached the ground at the same time” ... your coherent explanation is clearly wrong when they don't reach the ground at the same time. It's just not possible for it to be ... It's wrong, even if it's neatly written. [LAUGHS]. The guy has got a conceptual problem, then.

This particular attitude appears to indicate that the examiners devalued students thinking unless it agreed with their “correct” thinking. Answers that matched the model answer were given the highest status even if there was no indication of the procedure. This was queried at the examination meeting:

Examiner: I'd like to just say another thing. When we mark, we actually look at the answer. If the answer's right, it's probably right, and you just glance at the method. (?....?) just asked me - he got 283 by another method. If we can look at his method and see that 283 - which is the answer we want - and his method is not illogical, then it will be full marks. It's as simple as that.

So marking is actually relatively quick. You work backwards from the answer rather than forwards from the top.

Marker: So if you write the answer and no work?

Examiner: Then you get full marks. You write the wrong answer, you get zero.

Marker: But the right answer with no work will get you full marks?

Examiner: Will give you full marks. Yes.

While different solution paths to the correct answer were often accepted, it was rare to find different interpretations of the problem situation to be acceptable. In the same meeting, a discussion arose around an electrostatics problem task:

> Two identical polystyrene spheres A and B have masses of 5 x 10^{-6} kg each and carry identical positive charges. They are placed in a narrow vertical glass test tube with sphere B remaining suspended 50mm above sphere A.
> a) Calculate the magnitude of the charge on each sphere.
> b) What would happen to sphere B if the test tube was gently tilted so it was no longer vertical?
> c) If the charge on the spheres gradually leaked away, what would happen to sphere B during the process? Explain.

The accepted answer for part (c) was that the two charges would move closer together. However, one of the teachers raised an alternative understanding of the situation:

> Ah, but this is very interesting. See? I had somebody phone up and say they have a super bright kid at their school, and this kid said you can't leak away charge from a positively charged body because you can't lose protons or something, so you have to leak charge onto it by gaining electrons. And I thought, you know, when we talk about leaking charge away we mean the positive charge gets smaller. And this very intelligent kids says, "Aykhona. That's not charge leaking away; that's charge leaking in." And this child now will say that because the charge leaks away, it lost its electron and became more positive and moved further apart. (Exam marking)

General agreement was that the student did not have the accepted understanding that charge leaking away meant, "charge gets smaller". However, the student obviously understood the general principle that is emphasised at school that only the electrons would move. Despite what could be considered a meaningful interpretation of the situation, the examiners did not provide marks for this answer.

Other incidents provided additional evidence that answers had to conform to specific examination requirements. For example, during the examination meeting, the question of students writing paragraphs arose. In most cases, where qualitative questions were asked on the examination, the answer would be restricted to 5 - 8 lines. The examiner explained that he dealt with the problem of students writing more than the number of lines requested, by simply crossing the extra lines out and ignoring them. He indicated that the students soon learnt to restrict their explanations. He concluded humorously by saying:

> So you can warn your kids that if we say a short description of something, we really mean that. And this probably, being sexist, applies to girls who sometimes feel that "short" is a page and a half. Try to discourage that. Most of the people who set these papers are men and they can't read a page and a half. (Examiner, exam meeting)

The implication here is that teachers were being encouraged by the examiner to limit students' opportunities to express themselves. The students must give the correct answer but it must conform to the format required by the examiners. Showing their understanding had to take place on the examiner's terms.

Because of the pervasive influence of the examinations, this practice of conforming to model answers also took place in the classrooms. Consequently, the students learnt from their classroom experience, especially from tests and examinations, that there was a "more correct" way of responding to problem tasks. For example, after arguing with Jack about the answer to the pendulum problem, Tom seemed resigned to just giving the examiners what they wanted:

> But I still think it should work both ways. If you, ... under ideal conditions. And I still will... I mean that's my personal feelings towards it. But I suppose you've got to conform with the ideas that *the examiners* want because they are the ones that mark it in the end. (Tom, interview)

Adding to this, alternative solution paths were not always valued but rather considered inferior to the teachers. For example, Jack commented on a number of occasions when a student wanted to demonstrate an alternative solution path "Do we have another wonderful way of coming short?" (an expression for getting it wrong). While he might have been joking, the implied value placed on students solution paths compared to his could not be mistaken.

7.3.5 Commentary

One of the main purposes of this study was to understand from the participants' perspective, why teaching and learning occurs in the way it does. This section has provided evidence to support the assertion that the current syllabus, time pressures and examinations have a major influence on what happens in the classroom. These three constraining and focusing factors are essentially outside the immediate control of the teachers and students but have a profound influence on what happens in the classroom. The participants see themselves "locked into the system" constrained by these three forces. From the analysis, I suggest that the final examination was the most significant constraint. In some senses, it superseded the syllabus and the time pressures. If it were not for the examination, it was unlikely that the time pressure would have been as significant. Also, the examination refined and qualified the syllabus content. While the syllabus was published for all to see, the examination determined what the syllabus was in action. The teachers wanted the students to perform well on tests and to gain access to the next educational level as they saw this as their responsibility to the students and the community. To do this they focused on past examination problem tasks in class. They emphasised getting the work done and covering the content which would be tested in the examinations.

The examination contributes to an environment within which the students experienced learning science as a stressful competitive game where "they" attempted to produce problem tasks which students would find difficult. Because of the high stakes, the students were motivated to work and so practise to cover all possibilities. They were prepared to accept instrumental understanding of the science as long as it helped them pass the examination, with relational understanding relegated to a secondary role. Two further consequences of the constraining effect of the examination were seen. In my opinion these had a direct effect on the quality of the science education. First, there were the lost opportunities for exploring areas that were of interest to students because the teacher felt that either time was not available or the question under discussion, would not appear in the examinations. Secondly, qualitative descriptions appeared to be under-emphasised because they were more difficult to mark. Perhaps it was a case of what could be assessed easily in examinations took precedence over what was considered important for conceptual understanding.

The findings of other studies support the assertions made. Tobin (1987) reported that the assessment system was used to motivate students and had a focusing effect on the implemented curriculum. Teachers constantly communicated what would and would not be examined. They endeavoured to cover the curriculum in the prescribed time whether or not learning occurred. The focus was on covering the planned content so students could do the examinations. In a related study of physics teachers, Deacon (1989) also found that the external examination had a strong effect on the intended and implemented curriculum with past examination questions given the highest status. Although Brickhouse (1993)and Bodner (1992) have reported that shortage of time and pursuit of grades were restraints experienced by beginner science teachers, this study provides evidence that it might be extended to include most science teachers in similar contexts. Supporting studies do not only come from science education but also mathematics education. In an earlier study, Doyle (1983) found that the reward structure operating within classes was an important force. Teachers would constantly motivate students by referring to tests and examinations. If a particular type of problem was emphasised as being important for the examination, students tended to concentrate on that to a greater extent. In addition, Schoenfeld (1992) indicated that, under the pressures of mathematics content coverage, the teacher in his study sacrificed problem-solving goals for the more immediate goals of drilling students in the things they would be held accountable for. In addition, little time was allocated for activities that did not relate directly to potential success in examinations.

Given these consistent findings of the effect that the examination plays in shaping the implemented curriculum, it is surprising that it has not been used as a lever for change. If we ask questions that required students to work in ways that we valued, then the evidence suggests that teachers would be influenced to follow suit in the classroom. For example, Schuster (1993) provides examples of how to go about transforming routine tasks into detailed questions for use as assessment tools. However, their use does presume that assessment is seen as "a formative component of the educational environment, where it can provide a vehicle for shaping learning and teaching" (p.1). This unfortunately was not the view expressed by the examiners in this study.

7.4 INEFFECTIVE INSTRUCTIONAL STRATEGY

Assertion 6: ***The teachers and students had an uncritical belief in the efficacy of whole class explanations. Accompanying this was a belief that success would come with hard work while a lack of success could be attributed to a lack of natural ability. However, analysis of the instructional strategies provides evidence that barriers exist which explain why they are not as effective as expected even with routine problem tasks.***

7.4.1 Introduction

Teachers can deal with the teaching of content and the solving of problem tasks in a variety of ways. In one of the more common approaches, teachers spend time lecturing or explaining the solution to questions and numerical problem tasks. They present the information or solution strategy to the students in an organised and logical sequence. Normally, it takes the form of a teacher-centred expository discourse in which the teacher presents the principles, gives the answers and elaborates how to go about solving the problem tasks. In the previous chapters, I have described Jack's and Susan's classroom practices in which there was a major emphasis on teacher explanation. From this emphasis, it can be inferred that they believed that this was an effective way to achieve their goals of preparing students for the examination problem tasks. We assume that Jack and Susan provided these explanations of how to solve problem tasks, under the belief that learners would absorb the solution strategies. They would then be able to use them on similar problem tasks, especially those found in the tests and examinations. Unfortunately, I have also described how this emphasis on explanation led to students finding the classroom routine boring and the results show that it was not as effective as might be expected.

The following sections focus on my attempts to understand why the teachers used the instructional strategies described earlier. I describe some of the beliefs the teachers held about teaching and learning and reasons they gave to explain why their methods were not as successful as expected. For example, teachers ascribed the limited success of their strategy to students' lack of ability while students concentrated on lack of work as their main reason. However, I will provide evidence to show that there were other barriers present which explained why this instructional strategy with its emphasis on teacher explanations and whole class teaching was not as effective as one might have expected.

7.4.2 Teacher and student beliefs

Sub-assertion 6a: *The teachers and students had an uncritical belief in the efficacy of whole class explanations accompanied by hard work and natural ability.*

Focus on explanations

In the earlier chapters of this study, I have described how direct teaching and the explanation of solution paths is the predominant mode of teacher activity in the classroom. In the case of Jack, if the students were not writing a test or examination then they were most probably listening to him explain how to solve a problem or explaining some new concept or principle. On the other hand, Susan provided the students more time to work on problem tasks but where she interacted with students, the situation was very similar. She would use direct teaching and explain "how to do it" to the whole class. The following extract was taken from an interview where I questioned her teaching approach:

> It was very rushed. I should have used more examples and explained more practically, perhaps not the actual calculation examples but explained more fully where we ..where it applied in our sort of everyday lives and where it's useful and why we do it, I should have done more along those lines. What else could I have done to make it more interesting? Done some demonstrations? I don't know. Measuring current, measuring potential difference, running the time, showing them how much energy is used, I don't know how that would actually work. Perhaps I could have done more along those lines, and actually explained in more practical examples where- why we calculate electrical work, why we calculate electrical power. (Susan, Interview, 28/02)

In response to the above situation, there did not seem to be any emphasis on the students doing something to make meaning of the concepts. For Susan, explanations appear to be reliable in accomplishing what she saw as a goal of getting her students through an external examination and meeting parental, peer and administrative expectations. She conceptualised her major task within the class as "teaching", which played itself out as explaining. In conversations with me, she often used this terminology of "grasping" to represent student understanding of her explanations. The following excerpt from an interview is one of many illustrating this view. Susan was describing one of her student's feelings at getting the answer to a problem task incorrect while another had obtained the correct answer:

> She had trouble with the concept which Steven had grasped and Steven was able to help her and once she had grasped that, she was in the same position that he was. She was in a position to actually explain it to somebody else. ....I think that they often learn from their peers, that they're actually able to explain better to each other, because they talk along the same level. (Susan, Interview, 28/01)

The role of the student was to grasp the information, which was transferred from teacher to student to student, much like a relay runner's baton. The implication is that understanding can be passed from one person to another through explanation.

On the other hand, Jack appeared to have a conception of teaching and learning that was consistent with that of a "meal" (Erickson & Shultz, 1992) in which it was his job to do the feeding and the students role was to eat. The process of feeding was equated with careful explaining and eating with receiving the information or understanding. This conception was encapsulated by the following comment from Jack. He was talking about the pendulum collision problem task where half the class obtained what he considered the correct answer (1,8 m) and the rest, applying another principle which he considered wrong, obtained (1,95 m):

> I was very pleased about the number of kids who got 1,8 metres because they solved the problem the correct way..... .... If they got 1,95 .... it was a conceptual type thing. Or perhaps they rushed into the problem and didn't see it holistically enough. The very fact that a fair number got 1,8 meters means in fact that they've *been fed* the right information, some people possibly just *hadn't taken that mouthful*. (Jack, Interview, 18/03)

Although there were many occasions where the students made comments about the relevance of the content and how boring they found the classroom routine, there were no comments critical of the teaching methods used by their teachers. In fact, many of the students in interviews and open-ended response questionnaires made positive comments about their teachers and their teaching methods. While they might have expressed dissatisfaction at the relevance or the quantity of explanations, they were satisfied that this was the appropriate method of teaching, and listening was the appropriate rôle for a student who wanted to learn:

> Some people are sitting and listening, as they, like myself, would like to learn something, so I can get an "A". Others are messing around and not concentrating, as they are either not interested in science, or think they know everything. Some people may also have known the answer, and saw no reason to listen. (Bruce, questionnaire)

Even if they had difficulty understanding something, there was an expectation that repeat explanations would result in the understanding being passed on. The following excerpt represents one of many instances consistent with this belief:

> And I mean if you go over to her a hundred times and she tells you the same thing a hundred times as long as it gets through to you, it's fine. (Frances, interview)

Alternatively, if the teacher explanation was not that useful then some students were happy to rely on fellow students to do the job of explaining:

> I find it useful to work with someone. Who's got more knowledge than me. Because, especially Sbu. When he explains something I find it easier to understand it. Even, I understand it more if he explains it than I would understand it if the teacher was to explain it. (Hintsa, interview)

I could only find one instance where a student suggested improvements to the instructional method. In a comment on a questionnaire, Frank, a student in Jack's class felt that "one aspect in which science falls short is that more mechanics problem tasks should be done on the board with step-by-step analysis. This will ensure a better understanding." It appears the student wanted more of the same! Overall there was convincing evidence that the classroom participants had an uncritical belief that teacher explanation was an effective instructional method to use.

Success through hard work

While there was this belief that the teachers role was to provide the explanation, it was assumed that the students' role was to listen attentively and "grasp" the explanation. This was to be followed by "working hard". In most cases this referred to solving many problem tasks as suggested by the following comment:

> The best way to get a better mark is to do more problems and try and see if you are getting them right. You have a model answer. And if you're not then see where you mistake is. But the best thing is to do a lot more work sheets, and do more sums. (Mark, interview)

Jack took every opportunity to emphasise the need to practise the solving of the problem tasks. He also indicated that he was certain that the marks would improve as the year progressed and the rate of student work increased as they got closer to the examinations.

Susan also made it clear that something else besides the explanation was required for learning to take place. When discussing student learning she said: "I think they also realise that by me showing them, they're not learning anything. That they've actually got to try it for themselves to learn." For Susan, there was a direct relationship between students doing all the work required and doing well in the tests. The following excerpt illustrates this. She is talking about students in another class that she had taught:

> Yes. In this case it was balancing of equations. And those kids who have done the equations and when I have gone over it with them and marked them correctly, done their corrections, they do well in the tests. The other kids who have left out half the stuff and not bothered to mark it,.......... have failed. It's actually quite amazing. (Susan, interview, 09/02)

When one of her students did not do well despite all the hard work, she was at a loss to explain why this had happened. She seemed to have no further ideas as to how to treat the situation:

Susan	I don't know what I'm going to do with him, I really don't. I mean he works, he works and he works and works.
Int.:	Why do you think that he has a problem?
Susan	Because he works so hard and is not achieving the results, that one expects. (Susan, interview, 23/03)

Explanation followed by the hard work had not achieved the expected results

The students in both classes also had the belief that there was a direct relationship between hard work and success in the examinations and tests. There was a feeling, expressed by students in their interviews, that you got the mark you deserved:

Eric:	Just to test our knowledge. They're not that difficult, if you learned and you know your work like some other people... they get their marks like that.
Int.:	You would say their mark is directly related to -....
Eric:	The amount of work they put in.
Int.:	The amount of work they put in. So someone like Bruce, you would say works really hard ?
Eric:	Yes, he does. .... you deserve your mark.

The same sentiment was expressed for students at the other end of the scale. When I asked Tom why some students obtained such low marks (14%) for a test, he replied:

> Because they deserve it. Because they,.... they are not,... a lot of the guys here, I mean, they don't put in the effort in... in the work they do. You know they think learning the day before, they cheat in class tests and they bugger around and... you know like, they really don't put any effort into it and they expect by learning the week-end before exams it's going to ......you know pass you.

The students who received low marks did not put forward any other reason besides the lack of work to explain their low marks. The following two excerpts represent this student view:

> Out of class, I always complete all of the homework exercises set, between (30min - one hour). In class, I do not work to my full potential and this is the reason for my not achieving potential results for tests. (Pietro, questionnaire,)

Int. :	What could you do if you wanted to get better marks in science?
Hintsa:	I could get better marks if, if I had to study. If I had to do my work, all my work. I could get very good marks. (Hintsa, interview)

The students also had similar expectations to the teachers that if the effort was put in then good results would follow. In the following extract Chris is explaining his feeling when his examination paper was returned to him, an event recorded on video and played back to the students:

> Awaiting for my exam results, I was nervous and scared. Upon receipt, I was shocked and disappointed considering the amount of time I spent studying. (Chris, questionnaire)

Given the time spent and amount of work he had done, he expected to get better results. It appeared that both teacher and students saw a simple relationship between doing lots of work and success at their tests and examinations. When this did not occur they were surprised.

Role of natural ability

Given both teachers' apparent confidence that explanations followed by hard work would achieve their goals, it was interesting to see how they coped with students who were unable to benefit from their explanations and practice. When speaking to Susan about the students' test results and expectations for the year-end examination, she said that poor results could be expected because of the general "level of student" at this school. Her predictions for the final examination were similar to previous years. It was as if she implied that this school produced a particular profile of student and one characteristic was average ability in science. It was apparent that natural ability or intelligence played a role in success. Even if the student did all the problem tasks, this did not guarantee success especially with the more difficult problem tasks:

> They would also have got it from doing sort of simpler problems or different problems, from being able to adapt to different problems. And a little bit of their own intelligence, quite a bit of their own intelligence. But they would have to have done other problems to sort of cope with the more difficult ones. (Susan, interview, 23/03)

At no stage did Susan imply that her instructional strategies might be at fault. If the student failed to do problem tasks it was because they had not grasped the explanations, practised the problem tasks or did not have the natural intelligence required.

Jack also did not seem to feel that the reason for failure to solve problem tasks was a consequence of his teaching. As indicated earlier, he often obtained good results with many A's and B's. However, when referring to the other students, he was convinced that some just did not have what it took to get good results. In the following excerpt from an interview, I asked him why students had been unable to solve a problem that was slightly different to the normal routine problem tasks:

> What do we do, or what is it we don't do? ....(8 seconds).... Right. What your question implies, and I'm not going to answer the question immediately, I don't know if I can. What your question implies, is that every kid has the potential to solve the elegant questions. We just have to give them the tools in order to solve those elegant questions. And I will dispute that. We mentioned it earlier........umm....... I said certain kids have got it and you said "What is it?" And to a certain extent, you can hone that up, you can put an edge on it, you can give them practice to a certain, to a certain point, but I'll still come back to it, ...that there are some kids in that class who could become good physicists. If that's the way they wanted to go. And there were, ... there're certain kids in that class who will never become good physicists. I know I sound very dogmatic, but I believe that. (Jack, interview, 18/03)

While many students felt that all they needed to do was hard work, there were some that agreed with the teachers' belief. The following two excerpts provide evidence consistent with this natural ability view:

> I find science quite interesting, but it is unfortunate that I do not have talent for this subject. In class I try to pay attention as much as possible and find I can grasp most aspects and techniques involved with the subject, but for some reason unknown to me when it comes to a test I go blank and nine out of ten times strike out. (Petrus, questionnaire,)

Int.:	Are you upset that you had to drop to standard grade.
Frances	No. I can accept that I'm an average person in some subjects and you can't be good at everything in life. Most of the science, is like, Miss Smith said, like some of the children that are on higher grade, should not be on higher grade. And I promise you, if they knew...... I mean ok not everybody is an A student in science. Science is like fairly hard you know. And if they could actually accept that they aren't A material they would be so much happier. They're sitting there absolutely struggling

> like you just can't believe. ....And I mean they should really just go down to standard grade as far as I'm concerned. I mean obviously it's their personal choice. But I mean they must be realistic about what they, what they can achieve. (Frances, interview)

As Frances indicated, the belief that they did not have the ability to solve the problem tasks was not necessarily a common perspective. For example, in the previous section, I provided a quote from Hintsa where he indicates that he would obtain good results if he worked hard. Again, when I was asking him after a test in which he did not get good results, what Susan's opinion of him was he replied:

Hintsa:	I think she is thinking about my low marks in the test.
Int.:	So do you think she's saying that you're not good at science or that you need to study more, or that you're not clever, or, that you don't pay attention. What do you think the teacher is thinking about you.
Hintsa:	I think she thinks that .... I'm not clever.

He certainly did not believe that the reason for his low marks was his lack of "cleverness" but suspected this was a belief of his teacher. Overall there was convincing evidence that Jack and Susan had a firm belief that natural ability was a determinant of success. Some of their students were aware of this belief. However, while some students were prepared to accept it, others were not convinced, placing emphasis rather on a lack of work. However, none of the participants felt the instructional strategy was at fault.

7.4.3 An alternative analysis

Sub-assertion 6b: A number of barriers existed which prevented students making sense of teacher explanations.

> After Jack had introduced the problem dealing with the falling blocks and pulley, he carefully explained how to solve it. The students practised on a number of similar problems for homework, which were also carefully explained in class the following day. When the students did badly in their test, Jack carefully explained how to deal with these problems again and gave them another test. When I telephoned Jack and asked him how the students had done on the repeat test, he sighed and there was a pause. Then he said, "You know......, I despair. The results are as bad as before." Despite his careful explanation of the virtually identical problem from the previous test, despite the practice on similar problems, many of the students still could not solve routine pulley type problems. (Fieldnotes, 12/05)

The above incident was a key event in my observation of Jack's classroom. It appeared to me that his strategy of explaining how to do it, followed by practice, was not as effective as he believed even with the routine problem tasks. He had shown the students how to solve the previous test problem in detail. They had practised on at least six or seven similar problem tasks (Appendix F). Given that this was the top set of students, these students definitely had the natural ability to solve routine problem tasks of this nature. While not straightforward, all aspects could be dealt with by using procedures demonstrated by Jack. It was obvious to me that the instructional strategy was not effective, despite Jack's expert-like explanations.

I decided to analyse the situation from a transfer theory of teaching perspective (Fox, 1983) which was in my opinion the closest theory to that held by Jack and Susan. I began to look for reasons why students were not making sense of the solution paths that were demonstrated to them and were unable to solve routine and difficult problem tasks. I interpreted Jack and Susan's use of explanations as efforts to transfer knowledge from the teacher to learner. Once it had been handed over it was the students job to practise. The student was required to learn the procedure (even by rote) and implement it on virtually identical problem tasks. The many "variation on a theme" tasks would then provide the opportunity to manipulate the procedure and gain some facility in applying it in similar situations. The question that puzzled me was why there was such a low success rate using this method. As Jack would sometimes comment, "There is no way anybody on higher grade should not get this correct". Given the low conceptual demands of most of the problem tasks, I expected even the students in Susan's class to have much higher test averages. However, arising from further viewing of the video tapes and analysis of my classroom observations, a number of reasons presented themselves, which I considered barriers to learning, however teachers conceptualised teaching and learning.

Reception
Students did not always "receive" comprehensible explanations. By their very nature, the purpose of an explanation is to describe something in detail, give reasons for an event or phenomenon or show the steps to reach a goal. It is often assumed that because the teacher is behaving as the expert within the classroom that their explanations will be logically structured (Touger et al., 1995) and coherent and therefore comprehensible. This fits with the transfer theory where part of the teacher's role is to package the information into simpler parts for transfer. This unfortunately was not always the case in this study. In the analysis of the data, it became apparent that one of the most likely reasons for students failure to understand some explanations was that they were incomprehensible because of a lack of coherence. This lack of coherence arose for three main reasons; the explanations were not rehearsed or well prepared by teachers, attempts to get students involved disrupted the flow of logic and students missed some steps in the explanations.

Consider the following extract from one of Susan's lessons. It is taken from a lesson in which she had planned to start the section on electric circuits but needed to revise work dealing with resistors in parallel that was done in previous years. Most likely, the purpose of the revision was to construct a sense of shared knowledge on which further explanations would be dependent. She does not work from any notes but explains "off the cuff" having taught this section a few times over the past ten years. Halfway through, her explanation about the calculation of effective resistance, is disrupted by a student asking if they will be given two sets of values:

Mrs. Smith: You won't be using two sets of values. They might give you two cells in parallel. - OK. In which case, if you have two cells in parallel -what is the situation there?..

[Draws a circuit and puts in cells in parallel]....

If you are told they are 1.5V batteries - Sorry, Lets rephrase that -1,5V cells put in parallel to form a battery, what is the effective potential difference - emf of the battery?...
That's 1,5V and that's 1,5V?

Students: Three [chorus]

Mrs. Smith: No! 1,5V.

Student 1: Why?

Mrs. Smith: What's the point of doing it like that? If you want something to burn for a very long time you put two batteries in parallel and they will produce the same amount of energy per coulomb but it will last longer.

Student 1: How come, ma'am?

Student 2: Because the force of one over 1,5 plus one over 1,5 - because when they add up they -

Mrs. Smith: [*Interrupts*] They don't actually add up in this situation. What will actually happen - you will draw current from the one, until the potential alters and then draw from the other . OK They will only draw from the one at a time.

Student 1: And in series?

Mrs. Smith: If it is in series, then you add, if it is series then its 1,5 plus 1,5 3V.

Gavin: Parallel stays the same?

Mrs. Smith: Parallel stays the same. Any questions?

Kevin Yes. If you had two in the top branch, would it be 3V.

Mrs. Smith: Yes.

Gavin: Why are you adding now?

[*A discussion starts in which the idea of emf is mentioned.]*

Mrs. Smith: Any other questions?

Gavin: Yes. What's E.M.F.?

Mrs. Smith: We haven't got to that yet.

Gavin: Whoa! I was getting worried. [*laughter*]
(Susan, lesson transcript, 18/05)

Susan has to explain "off the cuff" how cells in parallel behave. This is clearly an unplanned explanation about the cells and what follows has little coherence. The parts of the explanation certainly do not fit together to make sense to Gavin. One gets the impression of a number of bits of information that are not logically connected, as we would expect in a good explanation.

A further complication, resulting in a loss of coherence, is that questions were being asked by students resulting in a deviation from the original explanation concerning resistors in parallel. Susan encouraged this type of interactive questioning and saw it as a positive part of her instructional strategy, as it indicated that the students were active. Unfortunately, the consequence was that the explanation did not follow a logical path from beginning to end. Rather, it jumped around as Susan developed it in the direction demanded by the students' questions. For many students, the development of the explanation at hand ended up in a confusion of questions about something else. It would have been difficult to keep track of the main topic with these deviations. In addition, examination of lesson transcripts indicated that there were many other interruptions and interactions taking place at the same time. For example, students would call out humorous comments, or derogatory comments about their peers. Sometimes Susan would have to stop in the middle of an explanation to admonish students who were creating a disturbance. Given these additional distractions, it was even more difficult to focus on the explanation steps.

While this was a characteristic of Susan's explanations, the same cannot be said for Jack's. In most cases his explanations were well constructed and filled with detail. There was not the same number of interruptions. Where this did happen he would often ask the student if he could come back to that point when he had finished. However, because of the detail attached to his explanations, they were long. This leads to the third factor.

The third factor, which seemed to prevent many students "grasping" the explanations, was that they missed some of the steps. Most explanations of problem solution paths consist of a series of logical steps leading to a solution. If one step is missing, the explanation is incomplete and it can be difficult to make sense of it. For example, Jack expected the students to pay careful attention to his explanations e.g., "I assume I will have your undivided attention for the next 10 minutes". However, he did not always get the student attention he sought. Examining the video record and fieldnotes shows many instances of students becoming distracted and looking out the windows or looking down at their desktops or exercise books. While they might have been listening to him, they were obviously not watching him point out features of his explanation on the board, where he would refer to particular parts of diagrams or equations. These were essential for comprehension of his explanation. They also missed many of his gestures and facial expressions as he placed emphasis on parts of his explanation, which can be important components in understanding what is going on. Given that many of the lessons were 60 minutes in duration and Jack was talking most of that time, it was not surprising that their attention would stray. The following comment from a student, after watching a video clip from a lesson in which Jack is explaining how to solve a problem task, is revealing:

> The majority of the pupils seem preoccupied and disinterested. We do, however, 'appear' interested and to be listening. The pupils fiddle around and don't seem to actually take great interest in what the teacher is teaching. Majority of the class talk amongst themselves and are infrequently forced to answer a question or make a response. (Stuart, questionnaire)

In addition, the pace of the lesson would often slow down as a consequence of the teacher dealing with the numerous student questions (Carlsen, 1991). These specific questions often led to short one-on-one dialogues between the teacher and the interested student and other students lost attention. The video record in both classes, show that many of the students who were not involved, would become distracted. When the teacher continued the explanation, these students would not all return their attention, as they would either miss the cue that the explanation was to be resumed or would attempt to finish what they were doing. Thus, they would miss a few steps. When their attention returned to the explanation, there was little to prompt them of what had been said except for a few formulae and figures on the board. Complicating the matter was the lack of complete explanations recorded in any form, such as notes, for students to review at a later stage. Examination of the verbal record i.e. transcriptions from audio tapes, showed that the actual explanations were hundreds of words in length but the only written records would be a sketch, a few formulae and some figures recorded on the chalkboard and transcribed into notebooks.

Closely related to this is the fact that when teachers explain how to solve particular examples, they do not provide the student with the complete explanation for the solution path. The solutions to example problem tasks typically contained a sequence of actions some of which were unexplained. One step might require chaining several inferences together and translating them into an equation. Alternatively, the conditions that apply to a particular problem context and solution were not made explicit but rather assumed. When they missed a step, there were limited opportunities to reconstruct the explanation. Consequently, students then need to overcome the incompleteness of the explanation by drawing conclusions and making inferences from the presented information. The majority of the students were not in a position to do this. Students would then have difficulty making sense of the rest of the explanation. Taken together with the lack of coherence due to the disruption from questions and the use of unstructured explanations, it is no wonder that many students failed to "grasp" the explanations.

Thinking behind steps

The thinking behind critical steps in explanations was not always revealed to the students. Through the use of explanations, Jack and Susan were providing a form of systematic modelling (Lavoie, 1995a) or apprenticeship. They were leading the students through the cognitive processing involved with solving a problem by explaining out aloud what they were doing. The students were supposed to learn the cognitive processing involved by following and imitating the teachers' behaviours. Previous evidence suggests that this instructional process was made obvious and was accepted by the students.

Following from this, we know that when experts solve problems, they analyse the problem situation deeply not looking for superficial cues but rather determining which scientific principles are involved in the situation under consideration. If, as I assumed, Jack and Susan were showing the students "how to do it" then I expected to see many references to how they went about choosing a particular principle to guide the solution strategy. Unfortunately, this was not always the case. More often than not, both Susan and Jack would just announce the equation or principle that was to be used. Take the following excerpt, for example, where Jack was explaining how to solve the problem involving the ball rolling into a dip and then over a hump (p.100). Students had attempted the problem, which was for twelve marks, implying some difficulty in producing a solution, and a large number had responded to the surface characteristics of the problem and opted for a simplistic analysis which was unfortunately wrong:

Mr J.:	There are four situations that we can consider. I can laugh off one of them because two of them are identical. *[He then numbers the four positions on the diagram as A B C D].* The velocity here *[points at A]* was 3, here *[points at C]* was....?
Students:	three *[students chorus an answer]*
Mr.J.:	.. and here, *[points at B]* was 4 and some people reason that the increase in velocity is 1 therefore the decrease in velocity from there to there *[points to C and D]* will be one. One from three is two and for that complicated calculation you get 12 marks *[Uses a sarcastic tone and number of students laugh].*

> Now here you are dealing with energy conversions, potential energy to kinetic energy ... Obviously if you wanted to, you could work out what the depth of this hollow is...[Points at B].. The question didn't require it, but you could in fact work it out. ...
>
> *[Continues and solves the problem using energy principles]*
>
> (Jack, Lesson transcript, 25/03)

From a physics point of view it is crucial to recognise that this problem could only be understood through energy conversions and not for example, through kinematics principles which were used by a large number of the class. How Jack determined this, is not provided in his explanation. He highlights the feature but does not model or explain what he did to determine this. For example in another problem, which a large number of students were unable to solve, he started his explanation with:

> Mr. Jones: We are given two instances,.... we can get two equations..... and we solve it that way. I can therefore say -- and I might add that moving on to the step, I am going to do now, requires a bit of a quantum leap in terms of thought. ....
>
> [continues with solution........]
>
> Once your mind does the leap to there being two problems...there and there, and you link the two together, once your mind comes on to that you are fine and what you are dealing with is mathematics...simultaneous equations. (Jack, lesson transcript, 12/05)

He does not model the process of the “mind leaping”. He announces the strategy up front, as if it was an obvious decision, and leaves the students to do the manipulation of formulae and calculations. Because of his experience with similar problem tasks, he is able to determine the required principle. He does the deep analysis or thinking but does not make it explicit in his explanations. This was not an isolated occurrence. It was part of Jack's instruction strategy for dealing with problem tasks that students had difficulty with. Students were left with the easier or more procedural parts of the solution path as illustrated in the following excerpt:

> Now if they've got a clear picture of what the situation is, then obviously that assists them in answering the problem, if I've set a difficult problem,......umm....,.. it was meant to be difficult, say,....umm...., and three quarters of the class didn't have a clue, I will sometimes go through....umm...., and explain the situation, the set up and then I could see the pennies dropping all the way around the class and then I say to them “Right you've got five minutes, now answer the questions”. Because there were a number of steps that they had to do, they had to understand the situation and then answer the question - they didn't understand the situation. So I give them the understanding of the situation, then ask them to answer the questions.
> (Jack, Interview 18/03)

The kinds of thinking and analysing required to determine a solution are rarely modelled. There was no evidence of an explanation showing how a number of paths might have to be explored before finding one that led to the solution. Neither were there occasions in which a range of solution strategies were considered and the most appropriate selected. Overall, the explanations did not provide the students with models of higher order thinking. Students attempts at making sense of the solution strategies were not grounded in an understanding of the principles that led to the solution, attempts to use the same solution strategy were error prone and easily forgotten. It was not surprising that as soon as a different situation or slight change in the problem were given, the majority of students struggled to solve it.

Reflecting and linking

Students were not given opportunities to reflect on the explanations as a whole or to make links to associated concepts and principles. Firstly, examination of the data shows very few planned opportunities during or after explanations to make sense of them as a whole. For example, students might discuss particular steps in an explanation but there were very few occasions where the students were given the opportunity to examine a complete explanation. What follows is a typical excerpt from Susan's classroom. In this example she is introducing the students to the equations of motion and explains how to solve a typical problem.

> Mrs. Smith: Right. The next thing you do is you list all the information given. So I'm going to take an example, work through the example with you, and you'll see what I mean. I'm going to take the first example underneath equation 1. An object is traveling at 5m/sec. It has accelerated to a velocity of 30m/sec in 5s.............
>
> *[Susan solves the problem for the class. She explains how to choose the correct formula base on the information given. She also explains how to change the subject of the formula. In the middle of this she calls to a student who has fallen asleep. She ends her explanation by doing the calculations on the chalk board as she talks.]*
>
> Right. So you're trying to find A..... V - then you substitute, so - sorry - you've chosen your correct formula, you've changed the subject of the formula, then you substitute. Right. What do you substitute? V is 30m/sec, minus U, 5m/sec over the time, which was 5 seconds, and that's going to give you acceleration. 30 minus 5,.......25 divided by 5,...... 5m per sec to minus two, and that is your acceleration, and that is your answer, and that is the way you do a problem. Okay. Is there anybody who has any questions about how to do these calculations? ...
>
> Right. You have a worksheet with 16 calculations. Please go ahead. ... They're very straightforward. Please do the questions in your classwork books. Do not forget you have a test tomorrow on sulphur. [Susan, Lesson transcript, 02/02]

On completion, there is no discussion or reflection on the explanation. The above example involves very simple steps but there are other examples where the explanations of a problem spanned 8 minutes. While the teacher would have a sense of the complete solution strategy, because he/she knows in advance, the students had to attempt to build their picture up as each step was revealed. Unfortunately, some parts passed very quickly for students and would hardly be noticed at the time. Sometimes they would not know what had been said was significant, until they saw later parts. Even when the explanation was well structured, they would have received it in a linear sequence and they might learn it as so many bits rather than as a solution strategy or approach.

To get around this problem, Lavoie (1995a) suggests that students should record the steps of the solution strategy modelled by the teacher and discuss them among themselves and with the teacher, while Wheatley (1995) advises that students should spend time explaining and justifying the solution methods. Unfortunately, this was not what happened in either class. Rather the students had to rely on what they perceived, understood and remembered at the time. In all likelihood, sometimes the logic of the explanation was lost and they were left with a few symbols and diagrams in their exercise books copied from the board. I compared the whole process to the construction of a jigsaw. The students knew they were doing a jigsaw but were not aware of the final picture. They then watched someone choose particular pieces and place them in position. They saw local aggregates of pieces while watching the construction of the picture and glimpsed the final picture, but they did not get a chance to examine and appreciate the complete picture. As soon as it was complete, the puzzle was replaced with another and the process repeated.

Secondly, explanations of the solution paths for problem tasks were treated as isolated learning activities. It is generally accepted that we need a well linked and connected knowledge base in order to successfully solve a variety of problems in a discipline (see p.19). However, the explanations provided by Jack and Susan, made few connections to other events. Once the explanation had been presented the participants moved on to other activities, such as practising problem tasks, activities which did not focus on linking the explanation to other ideas or other means of organising the knowledge. This is seen very clearly in the previous extract where the students move straight on to practise exercises without any reflective activities taking place. This was very common, despite the fact that both Jack and Susan recognised the need to promote connections between topics. For example, when I asked Susan why students needed to solve the particular problem tasks they had done that day in class she responded:

> Well, partly it's learning to solve those problems because they're going to get examined on questions like that. But then, it's also - you can actually extend it further because when you get on to Newton's Law, Newton's Gravitation Law, it's an extension of it, the same sort of thing, and also then you can actually think......... like things like magnetism.... and what I try and do, I don't know if I do achieve it very well, is actually to get them to think about the problem rather than just doing it, rather than plugging it in, because then you can also, they can also realize that it's linked to things like magnetism, any force that acts over a distance. So although we do it in terms of Newton's Law at the moment, it isn't confined to Newton's Law. It actually has anything - any force which acts over a distance has got something along those lines, ...the fact that the force decreases as the distance increases and things like that. So I don't think it's just for these problems, I think it must serve a broader goal . (Susan, lesson transcript, 23/03)

However, although they recognised it as a goal, there was little evidence of any activity that specifically promoted the linking of different topics, explanations or concepts or building of problem schemata. Even the students were implicitly aware that this was a gap in their understanding. When asked to explain what they meant by difficult problem tasks, students would refer to problem tasks requiring the joint application of different principles e.g. a problem involving the joint application of energy principles, such as Newton's Force laws and kinematics equations. There was a complete absence of discussions or arguments about the interrelationships among the concepts with no activities such as concept mapping taking place.

7.4.4 Commentary

To achieve the goals of the syllabus and meet the expectations of students, school and community, most will agree that it is the role of the teacher to intervene in some manner. Driver (1995 p.7) sees this role having two important components. The first component is to introduce appropriate ideas or cultural tools and conventions of the science community to students and secondly to provide the support and guidance for students to make sense of them. What is not always agreed is what the nature of the intervention should be. Evidence from this study and others is that where students were expected to solve particular types of problem, providing explanations of "how to do it" followed by practice on problem tasks and further explanations was a very common practice.

Why explanations?

The question arises as to why we find explanations entrenched as a part of science teaching. Within the context of this study, I have used a broad definition for explanation, as either dialogue or monologue in which the teacher is describing to students how to reach a goal, in this case an answer to a problem. Within the science community, explanations are commonly found as part of practice. In fact the ability to give clear and succinct explanations is one of the measures by which experts assess one another (Touger et al., 1995). Also systematic modelling which involves careful explanations, is recognised as a positive strategy to be employed in the teaching of problem solving (Lavoie, 1995a). Teacher explanations can also be viewed as the modelling and scaffolding needed for students to get started on solving problem tasks by themselves. Although the teacher is doing the talking or explaining, this does not preclude students from constructing understanding through a variety of other processes during or after listening to the explanation. Millar (1989) has argued that particular views of learning do not necessarily entail specific pedagogical practices. Thus it can be expected that we will find explanations used by teachers holding diverse beliefs about teaching and learning. For these and other reasons, it can be argued that explanations have a legitimate place in classroom practice (Ogborn, Kress, Martins, & McGillicuddy, 1996).

Why do they have these beliefs?

How did Jack and Susan's belief in this expository instructional strategy arise? A number of studies e.g. Tobin (1994), have explored the relation between science teacher beliefs and classroom practices and have highlighted the strong links between them. Therefore, it is reasonable to assume that teachers' decisions to use explanations to achieve their goals can be viewed as an expression of their beliefs about teaching and learning. In answer to the question "why do you use explanations so much as a teaching strategy?", the evidence suggests to me that both Susan and Jack would reply that it was working for them and there did not seem to be any other way to teach within their current contexts. It appeared that they believed that "explanation" was the main teaching tool of their trade. Perhaps they saw other strategies, which rely more on student action, as an abdication of their teaching roles or they resorted to explaining in the absence of anything better. It appeared as if they were satisfied with the current state of affairs in their classrooms and considered what was happening as normal and legitimate. They appeared to be content to maintain the status quo within the constraints of their teaching context.

Given its wide-spread use, it seems that this way of dealing with problems has been established over time and accumulated through tradition and represented a strategy that teachers valued (Olsen, 1992). Smith (1996) suggests that the intuitive knowledge that drives teacher behaviours, seems to be related to their own personal history of past teaching success. They have a belief in their ability to have a positive effect on student learning and believe that learning could be enhanced to the greatest extent by presenting the material in a more appropriate manner. He suggests they see themselves as having insight and want to share it with the students. They experience a sense of power or aesthetic satisfaction in being able to explain how to solve a wide variety of problems. While they recognise that effectiveness will vary across different contexts and students, their belief in telling or explaining is robust even in the face of many students being unable to solve routine problem tasks.

From the students' perspective, it made sense to participate in this instructional strategy offered by their teachers. From the evidence presented, we saw that the students accepted teacher explanations as normal and suggested no alternatives. If fact, when they considered that it did not "work" the first time, they would rely on repeat explanations, either from the same source i.e. the teacher or from a peer. They saw a simple relationship between hard work i.e. doing lots of practice problem tasks, and success in the tests and examinations. As in the case of the teachers, their beliefs could also be partly explained by referring to their past experiences. They get many of the routine problem tasks correct using this approach and most passed the examination, so they might question the need to change. Where they saw some students getting high marks, they attributed this to the hard work done by the individuals. This confirmed their belief in the relationship. However, it did not convince all, as some students had experiences of working hard with little success. In this case, they explained the failure, not on the instructional methods, but rather by indicating that perhaps they do not have the natural ability.

There are a number of reasons that can be given for these beliefs in the efficacy of explanations. Students believe that understanding primarily involves knowledge of relevant facts to be remembered or applied in relevant situations (Reif, 1984). They expect to solve tasks by employing procedures that have been explicitly taught, cued by superficial cues obtained when they read the problem statements. It is likely that they had not experienced any other ways of working and alternative ways of learning how to solve problem tasks do not occur to them (Cobb, 1986). Their behaviour and approach to learning appears consistent with students who have constructed instrumental beliefs about solving problem tasks in science (Skemp, 1978) and anticipate that future classroom experiences will fit these beliefs. There is also some evidence that some students are not interested in understanding as they have different didactical purposes. They just want to finish the tasks and so want the algorithmic type rules and how to use them. This is recognised by teachers as indicated in the following comment from Susan when asked to imagine what a student was thinking while solving a problem task:

> Well I know what's going on. I got them all right. Does he understand the concepts? Probably not totally but he can answer the questions and he gets them right. Probably what he thought. I don't think he even thought about "do I understand the concepts?" He just thought "well I'm .. I've got them right, its okay." (Susan, interview, 28/01)

To a student, it may be that knowing the different types of routine problem task, the formulas and how to use them, is their goal. Whether it makes sense is not relevant to them. They operate this way because they think this is the response required, this is what the subject entails (Hammer, 1989). Given the above, putting their faith in teacher explanations would make sense to them.

Why does telling not work?

Despite the teacher and students uncritical belief in the efficacy of this instructional strategy, evidence from this study and others indicates that this expository method is very ineffective (Van Heuvelen, 1991a p895).

If we start with the assumption that the explanation is a teacher's attempt at introducing a new idea or solution strategy or path, it seems obvious that it needs to be clear so that it is potentially comprehensible (Tobin, Capie, & Bettencourt, 1988). From the evidence presented in this study, there are serious reasons for doubting that they are clear. This evidence indicates that a number of barriers are often present which prevent the student even receiving a complete or a coherent explanation. For example, while Ogborn (1996) suggests teacher explanations are well rehearsed or well practised, the evidence suggests that this is not always the case. I have shown that Susan and Jack often had to provide explanations that were in their words "off the cuff" or "off the seat of my pants" and were not always well structured. Adding to this, I showed that there was disruption to the flow of the logic because of the many teacher and students questions, which sometimes resulted in a disjointed explanation which was not clear to all students.

Added to this, I have provided evidence that the teachers do not always provide the thinking behind their solution strategy. Perhaps this was not done because the teacher was actually using routine performance. While they appeared to be problem solving, they were in reality relying on the recall of a well-developed knowledge chunk of the type "in this well recognised situation do the following" (Schoenfeld, 1992 p.352). Consequently, the teacher was not modelling strategy use, but rather, routine recall based on years of doing similar problem tasks. This would not contribute to students learning, but could encourage them to rely more on practice problem tasks so that they could also begin to exhibit the same level of routine performance.

What if the explanations are good?

However, this cannot be the only reason why explanations were not effective, as on some occasions the explanations were complete and well presented and had the potential to be comprehensible. For example Tobin and Gallagher (1987) in their study assert that the explanations were "most informative" and "representing potentially rich means of elaborating the concepts being taught" (p.556). However, they considered that learning was difficult because of the need to engage simultaneously in more than one task e.g. listening to the explanation and write notes. In the current study, the result was the same but the reason were most probably different. For example, the students rarely made notes so should not have been involved in multiple tasks. However, the fact that they did not take notes meant they had nothing to refer to if they wanted to reflect on the explanations which also would make learning difficult.

McDermott (1991) observed that from the teacher's perspective, difficulties students have are not usually due to the failure of the instructor to present the material correctly or clearly, at least as the delivery is viewed from the perspective of a physicist. She observes that what is taught is not usually wrong. However, what the instructor says or implies and what the students interpret or infer as having been said or implied, are not, in her opinion, the same thing. It appears that despite the transmission being efficient, the reception is almost negligible.

However, there are a number of possible reasons that can be put forward for the failure to make sense of the potentially comprehensible explanations. For example, one of the reasons could be that the use of explanation assumes that the student can accept clearly presented knowledge as given. Yet, the student's mind holds many preconceptions that need to be confronted. These would interfere in any sense making activity if they were not addressed (Driver et al., 1995). Besides this reason, I want to add one other significant reason why explanations are not always effective even if they are well constructed and transmitted.

Because of a reliance on instrumental understanding, students do not necessarily listen to the explanations as they are satisfied with instrumental understanding. It is as if the students do not tune in to the underlying principles and links to other areas of science. Hammer (1994) suggests that an instructor may intend an explanation to provide information for students to build into their understanding of phenomena, but some students may think of the explanation as having served its purpose once they are convinced they have the right answer. The consequence is that the student's sense of understanding is probably often premature, giving them a false sense of competence. They then simply tune out. They appear to make no attempt at developing relational understanding of any kind as they do not appreciate the importance of organising their knowledge effectively nor for that matter do they have the tools to organise it effectively (Reif, 1984). The explanation of the problem solution might assist them in remembering the steps to solve the particular problem but without connection to broader ideas, it results in students developing limited understanding. The "new knowledge" does not cohere with existing knowledge, resulting in incoherent understanding and fragmented knowledge (Hammer, 1989; Tobin, 1996). The consequence is that they can at best deal with routine problem tasks.

Why do some students benefit?
If this instructional strategy is as ineffective as presented, the question arises as to why some students do well. There are a number of reasons for this. Reference to the descriptions of classroom interactions in earlier chapters of this thesis, show that many of the good students were also actively engaged in questioning the teacher at every opportunity. McDermott (1993) indicates that they would be considered intellectually active. They questioned their own comprehension, confronted their difficulties and persisted in trying to solve them. She suggests that most students do not bring this degree of intellectual independence to their study of the subject. Again, according to Chi (1989) the good students understood the example solutions because they make a conscious effort to ascertain the conditions of application of the solution steps beyond what was explicitly stated. They know when they do not understand, and respond by examining worked examples carefully and filling in the missing steps. Unfortunately, the poor students did not realise they did not know something, tried to use the worked examples as templates for solutions to similar problem tasks and just skipped over the missing information.

From my perspective I would suggest one reason why this situation exists is that the teachers and students do not seem to have tried to uncover the reality of problem solving. They do not actually know what is required for good performance. They require a more sophisticated conception of understanding which emphasises the ability to use knowledge flexibly in diverse situations (Reif, 1984). It is essential that students understand that competent performance depends on reasonable strategies rather than practice, natural ability or being test-wise

(Holliday, 1992). On the other hand, teachers must appreciate that the effective teaching of higher order thinking and problem solving is likely to require carefully designed instructional strategies.

CHAPTER 8

SUMMARY AND IMPLICATIONS FOR RESEARCH AND PRACTICE

8.1 INTRODUCTION

The purpose of this study was to extend our current knowledge about what happens in physical science classrooms, what the participants did, what activities they were involved in, and the reason for their actions. In particular, there was a focus on the role problem tasks played in this context.

It was not a goal of this study to search for general characteristics of all science classrooms but rather for an understanding of particular classroom contexts in depth, which could in turn lead to a better understanding of the use of problem tasks in science classrooms in general. Others might determine ways in which these findings fit the circumstances of their own situation and determine common characteristics which may, upon further investigation, be found to be pertinent to a wider variety of settings.

The study has drawn attention to many issues such as the lack of practical work, quality of classroom interactions and dominating role of examinations. These are all areas that require further detailed analysis. Sensitive to the knowledge that problem tasks cannot be looked at in isolation, this study has nevertheless focused on the use of problem tasks in science teaching. In this chapter, I provide a summary of the findings, and a metaphor, which I see as useful in understanding the classroom practices found in this study. A discussion of the implications for the teaching and learning of science follow this, with particular reference to the role of problem tasks. I have included some recommendations for professional practice, further research and highlighted opportunities or points of leverage, which can be used to bring about change.

8.2 SUMMARY OF KNOWLEDGE CLAIMS

I have discussed how my findings connect with the work of other scholars and will not repeat it here. What is important to note is that the assertions that have arisen from the analysis of the data are supported by studies in other parts of the world, especially where there is a fixed syllabus and central examinations. Therefore, one can say that while the thick descriptions of the classroom practices are unique to the two schools concerned, the findings are likely to have more general validity, both in South Africa and elsewhere. They will contribute to our knowledge base of science teaching and learning.

At this point, I have brought these knowledge claims together, to provide a single list of the main findings of the study.

Assertion 1: The solving of problem tasks was the primary focus of the teaching and learning activities to the virtual exclusion of other activities. Students found the repetitive solving of problem tasks boring. They encountered hundreds of problem tasks, the majority of which were stripped of real-world complexity. Nevertheless many students found the situations interesting, relevant and linked to their lives.

Assertion 2: The majority of the problem tasks were routine. They were of low conceptual demand mostly requiring quantitative responses. However, some problem tasks appearing in tests and examinations were not routine and students found them difficult. These problem tasks could be identified by particular characteristics.

Assertion 3: The dominant mode of teaching how to solve the problem tasks was for the teacher to explain and model how to solve them, followed by student practice on similar problem tasks. In their modelling, teachers encouraged students to use general strategies. When dealing with particular problem types they encouraged the use of specific strategies. This approach was not effective in teaching the majority of students how to solve anything but the routine problem tasks.

Assertion 4: In the short term, the participants saw the solving of the problem tasks as preparation for the matric examination. In the long term, the participants had different views of the intrinsic value of the problem tasks. The teachers saw the primary role as promoting general thinking skills, the external participants saw it as developing or assessing conceptual understanding but the students saw little or no intrinsic value.

Assertion 5: The teachers and students are operating within a tightly bounded system in which the syllabus, time pressure and the senior certificate examination act as boundary constraints.

Assertion 6: The teachers and students had an uncritical belief in the efficacy of whole class explanations. Accompanying this was a belief that success would come with hard work while a lack of success could be attributed to a lack of natural ability. However, analysis of the instructional strategies provides evidence that barriers exist which explain why they are not as effective as expected even with routine problem tasks.

8.2.1 A train journey

One of the more significant findings was that the senior certificate examination exerted a powerful focusing influence on the classroom environment, the instructional activities and on the problem tasks chosen. It appeared that the ultimate goal of physical science was to solve these types of problem task in preparation for the high stakes examination, rather than the learning of science.

As I watched and listened, I became progressively more aware of the significance of this examination constraint and how it shaped the classroom environment. I developed a metaphor or image for the system as one of my attempts to understand why things were as I perceived them. While none of the participants explicitly expressed this metaphor, their behaviour appeared to me to be consistent with those who unconsciously held such an image of it and used it to guide their practices and decision making. Like all metaphors, the train journey has its strengths and weaknesses and should be viewed in that light.

> I saw the students participating in a train journey with the train racing down the tracks on its path to a destination city. When they arrived at the station, they were assigned a train and a specific compartment. There was no choice. The train follows a strict timetable, stopping at selected stations along the way, but not deviating down any side-tracks. It is guided by the driver who has been instructed where to go, whom to allow on board, at what speeds to travel, where to stop and at what times to do so. The whole train system is controlled by some unknown managers, who decide on the route of the train to its destination and the timetable. They have issued instructions to the driver and expect him to deliver his passengers on time. At times he is not that attentive but the train just keeps going, closing in on its destination. When he gets behind on the schedule he speeds up to make up time. The passengers know the destination but are not aware of the countryside through which they will pass or the stops along the way. They rely on the driver to keep them informed. He has done the trip so many times before that he forgets to point out some of the interesting views along the way. Sometimes when he draws their attention to the view, they are puzzled as to why he should think they would be interested in that view. Some of the passengers are interested in the journey carefully noting where they are going while others wish they were somewhere else. Every now and then, passengers rush to the window and ask, "Where are we?" or "Did I miss something?"
>
> At the same time, there are other trains following other routes but all converging on the same destination city. A crowd of interested people waits for the train at the destination, every now and then, asking for information about its progress. Every year it is the same, except that the passengers and waiting crowd are different. When the train arrives at the station, the weary travellers disembark Some are excited at arriving and seem to know exactly where they are going, while others just follow, caught up in the crowds. Most are just relieved that they have arrived and pass through the exit arches into the city, thankful that they never have to make the journey again. What is disappointing from the perspective of those in charge, is that so many of the travellers are so pleased that the trip is over. When asked if they enjoyed the journey, there are few enthusiastic responses. It seems as if they have missed the beautiful views along the way.
>
> I saw the syllabus as the railway tracks. They are laid down and the train must stick to them, if it hopes to arrive at the destination. Jack's comments about being "locked into" or "slotted into a system" help provide the image of travelling along the rails with no opportunities for deviation. The different compartments are all the matric classes that the "driver" teaches. The emphasis on time pressure was equivalent to the train timetable. This aspect was generated through the comments about not falling behind and need to cover topics in a certain amount of time. The teacher as train driver has done the work so many times before that beautiful views have become mundane and he easily forgets that this is the first time this group is seeing them. The examination is seen as the final station, which is the exit point from the railway system. The students and community want their children to pass through the examination and enter life. It is seen as the climax of schooling and the entry to tertiary education or the job market. Unfortunately, many of the students have missed the opportunity to enjoy or see the value of science. They are only too pleased to be finished never having to encounter it again.

Overall, this metaphor provides an image that helps in the understanding of current classroom practices. While it has the weakness of only focusing attention on some aspects of the practices seen in this study, it does have the strength of helping in understanding why it is so difficult to bring about change within the schools. While we might ask teachers to change their practices, we have seen that they operate under a number of constraints. Just as it is difficult to ask the train driver to make unscheduled stops, to change his destination or stray from the tracks, so it is just as difficult to ask teachers to deviate from the syllabus or ignore the problem tasks found in the examinations. Although they might recognise the deleterious effects of the system, they feel they do not have the power to change. They feel they are doing their best under the circumstances.

8.3 TRANSFORMING TRADITIONAL PRACTICE

The following sections focus on the implications of my assertions and I provide recommendations for research and action.

8.3.1 What it should mean to do science

In answer to the question "What specifically is happening in science classrooms", descriptions are provided and assertions generated that construct a picture of school physical science education that is less than satisfactory. The instructional system has failed to achieve what we desire for our students (Van Heuvelen, 1991a). There is little emphasis placed on developing conceptual understanding of the scientific concepts. This situation is not what we would desire for our science classes. The implication is that many students will continue to leave school with a set of beliefs about science that are not consistent with those we would hope to promote (Hammer, 1994). Students will not see science as a coherent system but rather as a series of isolated topic items with the content of science being lists of definitions and formulae, rather than the structure of concepts and principles that underlie them. They will also see the learning of science as receiving information from an authority source, rather than the constructing of one's own understanding. Problem solving will be viewed as dealing with routine problem tasks rather than a higher-order skill.

While there may not necessarily be consensus about what the science curriculum should look like, there is convincing evidence from the current study and others that a curriculum based on mastering a corpus of facts and procedures to solve routine problem tasks is severely impoverished. The continued use of problem tasks in their present form results in students having a limited experience of science education. The students have every reason to have negative attitudes toward school science as they have not been given opportunities to experience the multi-dimensional nature of science and the richness of scientific knowledge (Bucat, 1997).

Because current practices engender a skewed view of what science is all about, there is a need to change what is taught and learnt and how it is taught and learnt. We need to design instruction carefully, based not only on what we know about what it means to do science, but also on what we know about learning. If, for example, we assume that we want students to be able to provide scientific explanations for phenomena, and learn to solve novel problem tasks both independently and co-operatively, then we need to implement and support a new approach to teaching and learning science.

8.3.2 Design new instructional tasks

Given that the goals we value are different to those met by routine problem tasks, it is clear that we need to design new problem tasks to achieve our goals. The evidence suggests a change to a different role for problem solving in which we move beyond routine application of algorithms and procedures to one which places more emphasis on understanding underlying concepts (Osborne, 1990; Tobias, 1992).

Based on the findings of this study, two actions are suggested. First, the purposes of all problem tasks should be made explicit. When tasks are being attempted in the classroom, all participants should have a shared view on their role and value. In this study, there appeared to be a lack of communication of purposes in the classroom. Contributing to this was the fact that the problem tasks were not clearly labelled either with an explicit label or through their structure that they were for conceptual development, for developing procedures or for assessing understanding, among other roles.

For example, where traditional problem tasks are used e.g. pulley problems, their purpose should be made clear i.e. as an example of how fundamental laws remain applicable even as situations become more complex, in this case moving from one body to two connected bodies. The label will cue the students that this problem task is illustrating the power of general scientific principles to deal with a wide variety of situations. However, it is not suggested that students spend time practising how to solve large numbers of similar problem tasks. This would once again provide an implicit label that the procedure was important rather than the concept.

Secondly, we need to design instructional tasks that are concerned with the qualitative aspects of sense-making and problem solving. This study has shown that the majority of problem tasks used were of low conceptual demand, with an emphasis on quantitative aspects of problem solving rather than focusing on qualitative reasoning and conceptual development. Current research indicates that if certain strategies are implemented, we can use problem tasks to develop students' conceptual understanding (Heller & Hollabaugh, 1992; van Heuvelen, 1992). For example, we know that a well-organised knowledge base is a prerequisite for solving difficult problems (Larkin, 1980). To develop this knowledge base, Van Heuvelen (1991b) has shown that it should be constructed on a foundation of qualitative understandings. However, the present study has shown that qualitative types of question, which could develop and strengthen the knowledge base, are seldom asked. Consequently, we need to design and use tasks based on the range of instructional strategies which research has shown to be effective. These strategies are dealt with in detail in a number of sources e.g. Hobden (1995) and Leonard (1996). Three examples of such strategies are outlined below.

Structured questions: Johsua (1991) recommends the intensive study of a single highly rich situation. Schuster (1993) does this by expanding the appropriate traditional problem task into a comprehensive problem situation with a carefully structured set of questions to promote understanding of the entire situation, while at the same time explicitly addressing different facets of understanding and problem solving. Leonard (1996) suggests a similar process but labels these "extended context" questions.

Multiple representations: Students should be encouraged to use multiple representations such as qualitative descriptions and diagrams together with mathematical representations when solving problems (van Heuvelen, 1992). The tasks should ask students to describe both qualitative and quantitative knowledge about a system. The emphasis must be shifted from numerical answers to making

sense of the problem situation through progressively more detailed representations.
Goal free problem tasks: Students should be given non-specific goals such as to find out all they can about a situation (Sweller, 1984) rather than a specific task such as to find the acceleration. This encourages them to bring all their knowledge to bear on the situation. It helps them learn to access their knowledge base and recognise their current strengths and limitations. It encourages open-ended and creative thinking.

It is my contention that these suggestions would represent the start of the process to transform pedagogically limiting routine problem tasks into learning experiences that begin to fit with our goals.

8.3.3 Problem contexts

While the above strategies will begin to transform the tasks given to students, we also need to transform some of the problem situations themselves. The study shows that many students find the problem tasks irrelevant and the whole experience of school science boring. Examination of the problem situations showed why this was the case. The majority of tasks were formulated using skeletal or stripped situations. These situations do not always provide opportunities for the classroom science knowledge to be transformed to cohere with the students' beliefs or to their actions in the world outside (Tobin, 1996). In addition, other studies (see Gunstone, 1998) have the consistent message that knowledge learned separate from any context is “knowledge that students often cannot or choose not to apply to interpret contexts” (p.115). The implications are that unless we change the problem situations, students will continue to find the science they are learning isolated from their everyday experience. They will continue to show little interest in science and find what they learn of little value.

A two-fold approach is suggested. Firstly, problem tasks should be embedded in the natural world. Because physical science involves the study of the natural world and the search for explanations about natural phenomena, it makes sense to start with relevant situations and problems from reality. These “real” situations could then be used as a point of departure for teaching the concepts of the curriculum. It is acknowledged that many real-world situations might be too difficult and complex to use readily for introductory students. However, part of understanding science and successful problem solving involves taking situations and stripping them down to their essence. Using these situations would provide an opportunity to develop this skill, which is missing from current practice.

Secondly, we should choose those situations which are relevant or of interest to the students. This will involve us in investigating students' contexts outside the school and developing problem tasks using contexts that match their life experiences. This could involve encouraging students to bring their everyday contexts to the classroom and, collaboratively with the teacher, construct problem situations that touch their lives. It makes sense that students will learn things more effectively and permanently if they can make connections between them and other things with which they are familiar.

If these suggested problem tasks are embedded in the natural world and interesting to teenagers and are explicitly labelled so that the students know what their purposes are, they can become points of leverage in changing the type of science education students experience. To implement these suggestions, further research is required into potential situations that students find interesting, and at the same time are appropriate for our curricular goals.

8.3.4 Beliefs about instruction.

It is unlikely that student learning or enthusiasm for science will improve if the problem tasks and contexts alone are reformed. There also has to be a concomitant focus on the learning processes and delivery systems (Coleman, Holcomb, & Rigden, 1998). Susan and Jack's instructional beliefs are consistent with a transmission epistemology (Tobin & Tippins, 1993). They plan teaching so that they have control of the classroom discourse and are able to provide many teacher explanations. Uncritical beliefs in the effectiveness of such instructional strategies are prevalent, and are not only a finding of the current study. The implication of this is that, unless we can change the way teachers organise teaching and learning, the other changes that are recommended will be ineffectual.

It will be difficult to convince teachers of the need to change. They are not likely to be convinced by calls for change for a number of reasons. First, it is their traditional practice and appears to be an effective way for them in their contexts. It is also unlikely that they have experience with other instructional practices. Secondly, teachers are faced with dilemmas and find teaching a conflict filled situation that requires choices for competing values (Lampert, 1985). Their practices are constrained and shaped by the structures and traditions of secondary schooling. Consequently, their current actions make sense to them within the present constraints. Thirdly, the students and community provide implicit support for their prevailing practices.

Two courses of action are suggested, both of which require dialogue with teachers. The first action is to reach a consensus about the most appropriate goals for science education, and make these explicit. It is only then that a meaningful dialogue with teachers, about what counts as successful instruction (Brickhouse, 1993) can occur. Teachers need to agree on the goals and purposes of the science they teach. For example, if the ability to do routine problem tasks is valued as a goal, then teachers could consider their instructional practices as being relatively successful. However, if higher order skills are valued, then the practices are not successful.

Secondly, we need to reconsider the role of direct verbal instruction and explanations in the classroom. Professional development programmes are needed to assist teachers in examining and reflecting upon the implications of this study and other research evidence. In the process, the tacit assumptions guiding their practice will be revealed, and they may come to question the rationale for their practices rather than take them for granted (Briscoe, 1992). During the change process, support is needed to maintain their feelings of efficacy, so that when under the continued pressure of external constraints, e.g. community or student expectations, they will not return to their current mode of teaching.

8.3.5 Didactical contract

Even if teachers are convinced by our arguments to introduce new types of problem task and change their instructional practices, we cannot necessarily expect student experiences or classroom practices to change. Earlier it was seen that student beliefs and expectations about instruction were very similar to those of their teachers. Unless students also change their beliefs about learning, they would resist innovations and thwart teachers' attempts to change.

Because student understandings of the didactical contract are critical, it is my belief that the reconstruction of the didactical contract is also key to bringing about change. For example in this study, the students knew that the explanations were the strategies teachers used to "teach" them how to solve the problem tasks they needed to pass the high stakes examination. Their understanding was that the teacher would provide a detailed explanation and ask questions to make sure they were paying attention. They responded practically, by make efforts to be attentive and make sense of the explanations, responding when called upon to answer any questions asked by the teacher and practise the problem tasks. Given the belief in the authority of the teacher and in the expected roles, they did not question the nature of the science they were learning, or the control exerted over the instruction by the teacher, even when it appeared to be difficult for them to learn. For them, the implicit understanding was that these instructional strategies would result in them passing the high stakes examinations. For the vast majority of students in the study, this was the case. They explained their degree of success in the examination on their level of hard work. From their perspective, this contract was successful.

From our perspective their acceptance of this particular didactical contract is problematic and will act as a barrier to bringing about fundamental change in learning. The students' interpretation of the didactical contract results in a flawed understanding of their role as learners. Students do not understand that competent performance depends on reasonable strategies rather than simply on natural ability. The teachers and students do not seem to know what is required for good problem-solving performance. For example (Linder & Hillhouse, 1996), reported that some physics students perceived understanding in terms of being able to solve end-of-chapter style problem tasks. Both teachers and students require a more sophisticated conception of understanding and problem solving which emphasises the ability to use knowledge flexibly in diverse situations (Reif, 1984).

We need to work with students to elucidate and change this and make beliefs and intentions explicit. They need to come to understand that the classroom is a place where you do something rather than have something done to you. Students should be given the means to take control of their own learning and be convinced of the need to accept responsibility for their learning. They must learn how to access and check their knowledge. Students need to think about what they know, what they do not know, and what they need to know in order to complete a task (Holliday, 1992). In addition, teachers and others need to listen to the students articulating their understandings of what it means to do science and do so in an honest and responsive way. They need to listen to individual students and develop a level of personal relationship with them and create a more supportive classroom atmosphere. In this way, a more flexible and dynamic didactical contract can be constructed.

Some work associated with the changing of the didactical contracts has started (see Hildebrand, 1999). However, bringing about the renegotiation of contracts will require further research on how to make a didactical contract explicit. In addition, research would be needed to isolate the critical factors involved in the didactical contracts in different classroom environments.

8.3.6 Examinations as a leverage point.

This study indicates that the final senior certificate examination exerts a powerful focusing influence on the classroom environment, the instructional activities and on the problem tasks chosen. There are many consequences of this. For example, students accept instrumental understanding of the science rather than relational understanding (Skemp, 1978), as long as it helps them pass their examinations. Overall, the influence of the examination on the quality of the science education appeared to be negative. Given that examinations are powerful tools to influence the implemented curriculum, they could be used as a positive force to bring about desirable change. I suspect that even if a new curriculum framework were introduced, the chances of it changing practices would be low, except if external tests reinforced it. By changing the types of problem tasks on the examination, and including those that promote the types of thinking and learning we value, we would legitimise the new curriculum tasks and they would become a part of normal classroom practice. In this way, we will be using the examinations as a lever for positive change.

Current assessment in tests and examinations involves only a small portion of the range of skills and perspectives associated with science education (Hammer, 1989). Consequently, we need to develop forms of assessment that are more suited to the nature of the abilities we seek to teach, and which would encourage a variety of classroom activities, not only the solving of numerical problem tasks. We should assess students' ability to provide coherent scientific explanations for phenomena, ability to provide clearly reasoned problem solutions to novel problem tasks and ability to use investigative skills.

8.4 FINAL WORDS

There is little value in having published curricula which are difficult for the teacher to implement and are never experienced by the students as originally intended by curriculum planners. In the end, what really matters is the experienced curriculum. Consequently, if we want to inform our attempts at changing classroom practice and move toward using a range of sense-making teaching strategies, we should not undervalue student voices. We should pay attention to what the students are saying explicitly and implicitly.

This study started in the classroom and I propose to close by bringing student voice back in focus with a short vignette. During the first few weeks of my classroom observation I gave the students a questionnaire in which I asked them to describe their feeling about what happens in science class. As usual, I informed the class that they were not obliged to write anything on their questionnaire. One student Marc, picked up the page, wrote something quickly, folded his arms and laid his head on the desk. After a minute or two, he sat up and wrote again. What follows are his comments:

> I respectfully decline from writing anything.
>
> Actually, I have changed my mind.
> I believe school, as it has with all other subjects, has managed to destroy all the interest that is inherent in science - it is, after all, man's attempt at understanding the world around him. But this 'specialness' is lost in boring classroom routine, irrelevant trick questions and such like.

Marc achieved in the top twenty students (out of 150), obtaining over sixty percent for physical science in the matric examination and an overall aggregate of seventy percent. Marc was a “good” student. He was one of the consumers of science education. It is from students like him that we will need to produce the science teachers and scientists of the future. It would be negligent to continue with current practice and ignore the messages that this study shows that Marc and other students are sending us.

REFERENCES

Balacheff, N. (1984). *Cognitive versus situational analysis of problem-solving behaviours*. In H. Burkhardt, S. Groves, A. Schoenfeld, & K. Stacey (Eds.), *Problem solving: A world view. Proceedings of the Problem solving theme group, Fifth International Congress on Mathematical Education, Adelaide* (pp. 168-173): Shell Centre for Mathematical Education, University of Nottingham.

Ball, D. L. (1988). Research on teaching mathematics: Making subject matter knowledge part of the equation (pp. 43). East Lansing: The National Center for Research on Teacher Education.

Bettencourt, A. (1991). Making the future: Daring choices, exciting challenges. In J. Gallagher (Ed.), *NARST Monograph, Number 4. Interpretive Research in Science Education*. Kansas State University, Manhattan: NARST.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education, 63*(10), 873-878.

Bodner, G. M. (1990). A view from chemistry. In M. U. Smith (Ed.), *Towards a unified theory of problem solving* (pp. 21-34). Hillsdale: Lawrence Erlbaum.

Bodner, G. M. (1992, April). The conceptual knowledge of beginning chemistry graduate students. Paper presented at the 65th Annual Meeting of the National Association for Research in Science Teaching, Boston, MA.

Bogdan, R. C., & Biklen, S. K. (1992). *Qualitative research for education: an introduction to theory and methods*. (2nd ed.). Boston, MA: Allyn and Bacon.

Brickhouse, N. W. (1993). What counts as successful instruction? An account of a teacher's self assessment. *Science Education, 77*(2), 115-129.

Briscoe, C. (1992, April). *Everything depends on the teacher: Multiple perspectives on classroom control as a constraint to effective change in science teaching*. Paper presented at the 65th Annual Meeting of the National Association of Research in Science Teaching, Boston, MA.

Brodie, K. (1994). *Classroom talk, interaction and control: an analysis of teaching strategies in a mathematics lesson*. In M. J. Glencross (Ed.), *Second Annual Meeting of the Southern African Association for Research in Mathematics and Science Education* (pp. 36-45). University of Durban-Westville: SAARMSE.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Bucat, R. B. (1997). What is this thinking called chemistry? *Chemeda: Australian Journal of Chemical Education, 47*(11).

Campione, J. C., Brown, A. L., & Connell, M. L. (1988). Metacognition: On the importance of understanding what you are doing. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving* (Vol. 3, pp. 93-114). Hillsdale: Lawrence Erlbaum.

Carlsen, W. S. (1991). Questioning in classrooms: A sociolinguistic perspective. *Review of Educational Research, 61*(2), 157-158.

CASME. (1990). *Physical science senior certificate examination papers from 1989.* Durban: Centre for Advancement of Science and Mathematics Education.

Champagne, A. B., & Klopper, L. E. (1977). A sixty-year perspective on three issues in science education: whose ideas are dominant; representation of women; reflective thinking and problem solving. *Science Education, 61*(4), 431-452.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*, 145-182.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981a). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121-151.

Chi, M. T. H., Glaser, R., & Rees, E. (1981b). Expertise in problem solving. In R. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1). Hillsdale, NJ: Erlbaum.

Chisholm, L. (1992). Policy and critique in South African Educational Research. *Transformation, 18*, 149-165.

Clement, J. (1981). Solving problems with formulas: Some limitations. *Engineering Education*, Nov, 158-162.

Cobb, P. (1986). Contexts, goals, beliefs, and learning mathematics. *For the Learning of Mathematics, 6*(2), 2-9.

Cobb, P. (1995). Constructivism in mathematics and science education. *Educational Researcher, 23*(7), 4.

Cobern, W. (1993a). Contextual constructivism: The impact of culture on the learning and teaching of science. In K. Tobin (Ed.), *The practice of constructivism in science education*. Washington: AAAS.

Cobern, W. W. (1993b, April). *World view, metaphysics, and epistemology*. Paper presented at the 66th Annual Meeting of the National Association for Research in Science Teaching, Atlanta.

Coleman, L. A., Holcomb, D. F., & Rigden, J. S. (1998). The introductory university physics project 1987-1995: What has it accomplished? *American Journal of Physics, 66*(2), 124-137.

Confrey, J. (1990). A review of the research on student conceptions in mathematics, science, and programming. *Review of Research in Education, 16*, 3-56.

Contreras, A. (1988). *Constructing subject matter in high school physics: An ethnographic study of three experienced physics teachers.* Unpublished PhD, Michigan State University.

Contreras, A. (1992, March). *Physics problem solving and its social context in secondary school.* Paper presented at the 65th Annual Meeting of the National Association for Research in Science Teaching, Boston, MA.

Contreras, A. (1993, April). *The situated nature of middle school science teaching: An interpretive study in a ninth grade classroom.* Paper presented at the 66th Annual Meeting of the National Association for Research in Science Teaching, Atlanta, Georgia.

Contreras, A., & Gallagher, J. J. (1989, April). *A discourse analysis of Newton's second law as taught by three experienced high school physics teachers.* Paper presented at the 62nd Annual Meeting of the National Association for Research in Science Teaching, San Francisco.

Deacon, J. (1989). Forces which shape the practices of exemplary high school physics teachers. In K. Tobin & B. J. Fraser (Eds.), *Exemplary practice in Science and mathematics education* (pp. 59-67). Perth: Key Centre for School Science and Mathematics, Curtin University of Technology.

Delamont, S., & Hamilton, D. (1989). Revisiting classroom research: A continuing cautionary tale. In M. Hammersley (Ed.), *Controversies in classroom research* (pp. 25-43). Buckingham UK: Open University.

Dhillon, A. S. (1998). Individual Differences within problem-solving strategies used in physics. *International Journal of Science Education, 82*, 379-405.

diSessa, A. A. (1988). Knowledge in pieces. In G. Forman & P. Putall (Eds.), *Constructivism in the computer age* (pp. 49-70). Hillsdale: Laurence Erlbaum.

Donald, J. G. (1993). Professors' and students' conceptualizations of the learning task in introductory physics courses. *Journal of Research in Science Teaching, 30*, 905-918.

Doran, R. L., Helgeson, S. L., & Kumar, D. D. (1995). Assessment of problem solving in science. In D. R. Lavoie (Ed.), *Toward a cognitive-science perspective for scientific problem solving: A monograph of the National Association for Research in Science Teaching, Number Six* (pp. 112-141). Manhattan, KS: Ag Press.

Doyle, W. (1983). Academic work. *Review of educational research, 53*, 159 -199.

Driver. (1989, March). *Children's Learning in Science.* Paper presented at the British Council International Seminar on Children's Learning in Science, Leeds.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Driver, R., Asoko, H., Leach, J., & Scott, P. (1995, April). *Constructing scientific knowledge in the classroom: a theoretical perspective on pedagogy Enculturation and personal knowledge construction in science: Portrayals from the Children's Learning in Science Research Group.* Paper presented at the AERA Annual Meeting:, San Francisco.

Dufresne, R. J., Leonard, W. J., & Gerace, W. J. (1992). *Research-based materials for developing a conceptual approach to problem-solving in science.* In D. Grayson (Ed.), *Workshop on Research in Science and Mathematics Education* (pp. 93-117). Cathedral Peak, South Africa: SAARMSE.

Dupuis, P. R. (1993). HyperRESEARCH (Windows Version 1.65). Randolph, MA: Researchware.

Ebel, R. L. (1976). The paradox of educational testing. *Measurement in Education, 7*(4), 1-12.

Edwards, D., & Mercer, N. (1987). *Common knowledge.* London: Metheun.

Eisenhart, M., & Borko, H. (1993). *Designing classroom research: Themes, issues and struggles.* Boston, MA: Allyn and Bacon.

Erickson, F. (1982). Taught cognitive learning in its immediate environments: A neglected topic in the anthropology of education. *Anthropology and Education Quarterly, 8*(2), 149-180.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook on research in teaching* (3rd ed., pp. 119-161). New York: Macmillan.

Erickson, F., & Shultz, J. (1992). Students' experience of the curriculum. In P. W. Jackson (Ed.), *Handbook of research on curriculum* (1st ed., pp. 465-485). New York: Macmillan.

Fensham, P. (1995). The burden of examinations: comparative hopes that it can be got right. *Educational Researcher, 24*(1), 33-35.

Fenstermacher, G. D. (1993). The Knower and the Known: The Nature of Knowledge in Research on Teaching. *Review of Research in Education,* (20), 3-56.

Finley, F., Lawrenz, F., & Heller, P. (1992). A summary of research in science education - 1990. *Science Education, 76*, 239-338.

Fox, D. (1983). Personal theories of teaching. *Studies in Higher Education, 8*(2), 151-163.

FRD. (1993). High school education in mathematics and science. In FRD (Ed.), *South African science and technology indicators* (1st ed., pp. 5-16). Pretoria: Foundation for Research Development.

Frederiksen, N. (1984). Implications of cognitive theory for instruction in problem solving. *Review of Educational Research, 54*(3), 363-407.

Gabel, D. L. (1989). *What research says to the science teacher (Vol. 5): Problem solving.* Washington: National Science Teachers Association.

Gabel, D. L. (1994). *Handbook of research on science teaching and learning* (1st ed.). New York: Macmillan.

Gabel, D. L., & Bunce, D. M. (1994). Research on problem solving: Chemistry. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (1st ed., pp. 301-326). New York: Macmillan.

Gallagher, J. J. (1989). Research on secondary school science teachers' practices, knowledge, and beliefs: A basis for restructuring. In M. L. Matyas, K. Tobin, & B. J. Fraser (Eds.), *Looking into windows: Qualitative research in science education* (pp. 43-57). Washington: American Association for the Advancement of Science.

Gallagher, J. J. (Ed.). (1991a). *Interpretive research in science education. NARST Monograph No.4.* Kansas State University, Manhattan: National Association for Research in Science Teaching.

Gallagher, J. J. (1991b). Uses of interpretive research in science education. In J. J. Gallagher (Ed.), *Interpretive research in science education: NARST Monograph No. 4* (pp. 3-17). Kansas State University,Manhattan: National Association for Research in Science Teaching.

Gallard Martinez, A. J. (1990). *Influence of ministry policies on science teaching practices in Costa Rica.* Unpublished PhD, Michigan State University.

Garrett, R. M. (1986). Problem-solving in science education. *Studies in Science Education, 13*, 70-95.

Glover, P. (1992). *Title unknown*. Unpublished Dissertation, Oregon State University.

Goetz, J. P., & LeCompte, M. D. (1984). *Ethnography and qualitative design in educational research*. Orlando, FL: Academic Press.

Grouws, D. A. (1985). The teacher and classroom instruction: Neglected themes in problem-solving research. In E. A. Silver (Ed.), *Teaching and learning mathematical problem solving: Multiple research perspectives* (pp. 295-308). London: Lawrence Erlbaum.

Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. Newbury Park, CA: SAGE.

Gunstone, R. (1998). *The importance of the contextual dimension to physics in years 11-and 12.* In N. S. W. Board of Studies (Ed.), *Science Stage 6 Symposium Proceedings* (pp. 111-116). Sydney, NSW: Board of Studies NSW.

Hammer, D. (1989). Two approaches to learning physics. *The Physics Teacher, 27*(9), 664-670.

Hammer, D. (1994). Students' beliefs about conceptual knowledge in introductory physics. *International Journal of Science Education, 16*(4), 385-403.

Helgeson, S. L. (1993). *Assessment of science teaching and learning outcomes*. Columbus: The National Center for Science Teaching and Learning.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics, 60*, 637-644.

Hennessey, S. (1993). Situated cognition and cognitive apprenticeship: Implications for classroom learning. *Studies in Science Education, 22*, 1-41.

Hewson, P. W., Kerby, H. W., & Cook, P. A. (1995). Determining the conceptions of teaching science held by experienced high school science teachers. *Journal of Research in Science Teaching, 32*(5), 503-520.

Hildebrand, G. M. (1999, April). *Breaking the pedagogic contract: Teachers' and students' voices.* Paper presented at the 72nd Annual Meeting of the National Association for Research in Science Teaching, Boston.

Hobden, P. A. (1992). Physical Science INSET Rationale and descriptive report. In S. Hardman (Ed.), *The Shell Science Centre in INSET 1990* (pp. 14-21). Durban: Shell Science and Mathematics Resource Centre Educational Trust.

Hobden, P. A. (1995, February). *Alternative strategies for teaching problem solving.* Paper presented at the KwaZulu-Natal Science Teachers Conference, University of Durban-Westville, Durban.

Holliday, W. G. (1992, March). *Teaching cognitive strategies to science students.* Paper presented at the 65th Annual Meeting of the National Association of Research in Science Teaching, Boston, MA.

Huberman, A. M., & Miles, M. B. (1994). Data management and analysis methods. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp.428-444) . Thousand Oaks, CA: SAGE.

Huffman, D. (1995, April). *The effect of explicit problem solving instruction on high school students' problem solving performance and conceptual understanding of physics.* Paper presented at the 68th Annual Meeting National Association of Research in Science Teaching, San Francisco.

Jansen, J. (1995). *Measuring the Monkeys: The Limits of Assessment in the South African Context.* In Reports and Issues arising from 3rd Forum on Assessment, Durban. Centre for Advancement of Science and Mathematics.

Johnstone, A. H. (1984). New stars for the teacher to steer by? *Journal of Chemical Education, 61*, 847-849.

Johsua, S., & Dupin, J. (1991). In physics class, exercises can also cause problems. *International Journal of Science Education, 13*, 291-301.

Kennedy, M. M. (1998). Education reform and subject matter knowledge. *Journal of Research in Science Teaching, 35*(3), 249-263.

Koballa, T. R., Crawley, F. E., & Shrigley, R. L. (1990). A summary of research in science education - 1988. *Science Education, 74*(3), 253-407.

Lampert, M. (1985). How do teachers manage to teach? Perspectives on problems in practice. *Harvard Education Review, 55*(2), 178-194.

Larkin, J. (1980). Expert and novice performance in solving physics problems. *Science, 208*, 1335-1342.

Lave, J. (1988). *Cognition in practice: mind, mathematics and culture in everyday life.* New York: Cambridge University Press.

Lavoie, D. R. (1995a). The cognitive-processing nature of hypothetico-predictive reasoning. In D. R. Lavoie (Ed.), *Toward a cognitive-science perspective for scientific problem solving: A monograph of the National Association for Research in Science Teaching, Number Six* (pp. 13-50). Manhattan, KS: Ag Press.

Lavoie, D. R. (Ed.). (1995b). *Toward a cognitive-science perspective for scientific problem solving: A monograph of the National Association for Research in Science Teaching, Number Six.* Manhattan, KS: Ag Press.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex.

Lemke, J. L. (1993a, April). *The missing context in science education: Science.* Paper presented at the Annual Conference of American Educational Research Association, Atlanta.

Lemke, J. L. (1993b, April). *Multiplying meaning: A constructivist agenda for research in science education.* Paper presented at the 66th Annual Meeting of the National Association for Research in Science Teaching, Atlanta.

Leonard, W. J., Dufresne, R. J., & Mestre, J. P. (1996). Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems. *American Journal of Physics, 64*(12), 1495-1503.

Lincoln, Y. S., & Guba, G. (1985). *Naturalistic inquiry.* Newbury Park,CA: SAGE.

Linder, C. J., & Hillhouse, G. (1996). Teaching by conceptual exploration. *The Physics Teacher, 34*(Sept), 332-338.

Madaus, G. (1988). The influence of testing on the curriculum. In L. Tanner (Ed.), *Critical Issues in Curriculum.* Chicago: NSSE.

Maloney, D. P. (1993). Conceptual competition in physics learning. *International Journal of Science Education, 15*, 283-295.

Maloney, D. P. (1994). Research on problem solving: Physics. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (1st ed., pp. 327-354). New York: Macmillan.

McDermott, L. C. (1991). Millikian lecture 1990: What we teach and what is learned - Closing the gap. *American Journal of Physics, 59*, 301-315.

McDermott, L. C. (1993). Guest comment: How we teach and how students learn -- A mismatch? *American Journal of Physics, 61*(4), 295-298.

Merriam, S. B. (1988). *Case study research in education*. San Francisco: Jossey-Bass.

Mestre, J. P. (1991). Learning and instruction in pre-college physical science. *Physics Today, 44*(9), 56-62.

Miles, B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. (2nd ed.). Thousand Oaks, CA: SAGE.

Millar, R. (1989). Constructive criticisms. *International Journal of Science Education, 11*(5), 587-596.

Muller, J. (1988). "Out of their minds": An analysis of discourse in two South African science classrooms. In D. Roger & P. Bull (Eds.), *Conversation: An interdisciplinary perspective* (pp. 313-337). Philadelphia: Multilingual Matters.

Nespor, J. (1990). The jackhammer: A case study of undergraduate physics problem solving in its social setting. *International Journal of Qualitative Studies in Education, 3*(2), 139-155.

Noddings, N. (1988). Preparing teachers to teach mathematical problem solving. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving* (Vol. 3, pp. 245-258). Hillsdale: Lawrence Erlbaum.

Ntshingila-Khosa, R. (1994). *Teaching in Soweto classrooms: observed pedagogical practices and teacher's own meanings*. In M. J. Glencross (Ed.), *Second Annual Meeting of Southern African Association for Research in Mathematics and Science Education* (pp. 314-341). University of Durban-Westville: SAARMSE.

Ogborn, J., Kress, G., Martins, I., & McGillicuddy, K. (1996). *Explaining science in the classroom*. Buckingham, UK: Open University Press.

O'Loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a socio-cultural model of teaching and learning. *Journal of Research in Science Teaching, 29*(8), 791-820.

Olsen, J. (1992). *Understanding teaching: Beyond expertise*. Milton Keynes: Open University Press.

Osborne, J. (1990). Sacred cows in physics - Towards a redefinition of physics education. *Physics Education, 25*, 189-196.

Patton, M. Q. (1980). *Qualitative evaluation methods*. (1st ed.). Newbury Park, CA: SAGE.

Pickering, M. (1990). Further studies on concept learning versus problem solving. *Journal of Chemical Education, 67*, 254-255.

Reif, F. (1981). Teaching problem solving - A scientific approach. *The Physics Teacher, May*, 310-316.

Reif, F. (1984). *Teaching higher-order thinking skills for a technological world: Needs and opportunities* (American Educational Research Association Project: Research Contributions for Educational Improvement). Washington, DC: American Educational Research Association.

Reusser, K. (1988). Problem solving beyond the logic of things: Contextual effects on understanding and solving word problems. *Instructional Science, 17*(4), 309-338.

Sawrey, B. A. (1990). Concept learning versus problem solving: Revisited. *Journal of Chemical Education, 67*, 253-254.

Schoenfeld, A. H. (1988). When good teaching leads to bad results: The disasters of "well-taught" mathematics courses. *Educational Psychologist, 23*, 145-166.

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 334-370). New York: Macmillan.

Schuster, D. (1987, May). *Question difficulty scale (draft).* Presentation to Joint Matriculation Board Examination meeting, Pretoria.

Schuster, D. (1993, January). *Assessment as curriculum in science education.* Paper presented at the First International Conference on Science Education in Developing Countries, Jerusalem.

Schwandt, T. A. (1994). Constructivist, interpretist approaches to human inquiry. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 118-137). Thousand Oaks, CA: SAGE.

Sfard, A. (1998). On Two Metaphors for Learning and the Dangers of Choosing Just One. *Educational Researcher, 27*(2), 4-13.

Skemp, R. R. (1978). Relational understanding and instrumental understanding. *Arithmetic Teacher, 26*(3), 9-15.

Smith, J. P. (1996). Efficacy and telling maths. *Journal of Research in Mathematics Education, 27*(4), 387-402.

Solomon, Y. (1989). *The practice of mathematics*. London: Routledge.

Spradley, J. P. (1979). *The ethnographic interview*. New York: Holt, Rinehart & Winston.

Spradley, J. P. (1980). *Participant observation*. New York: Holt, Rinehart & Winston.

Stanic, G. M., & Kilpatrick, J. (1988). Historical perspectives on problem solving in the mathematics curriculum. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving* (Vol. 3, pp. 1-22). Hillsdale: Lawrence Erlbaum.

Sweller, J. (1984). *Learning and problem solving: Disparate goals?* In H. Burkhardt, S. Groves, A. Schoenfeld, & K. Stacey (Eds.), *Problem solving: A world view. Proceedings of the Problem solving theme group, Fifth*

International Congress on Mathematical Education, Adelaide (pp. 187-191): Shell Centre for Mathematical Education, University of Nottingham.

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of Educational Psychology, 81*, 457-466.

Tobias, S. (1992). *Revitalizing undergraduate science: Why some things work and most don't. An occasional paper on neglected problems in science education.* (ISBN-0-9633504-1-2). Tucson, AZ: Research Corporation.

Tobin, K. (1987). Forces which shape the implemented curriculum in high school science and mathematics. *Teaching and Teacher Education, 3*(4), 287-298.

Tobin, K. (1996, March). *Constraining the Learning of Science: Profiles of Power, Social Forces and Discursive Capital.* Paper presented at the 69th Annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Tobin, K., Capie, W., & Bettencourt, A. (1988). Active teaching for cognitive learning in science. *International Journal of Science Education, 10*(1), 17-27.

Tobin, K., & Gallagher, J. J. (1987). What happens in high school science classrooms? *Journal of Curriculum Studies, 19*(6), 549-560.

Tobin, K., & Tippins, D. (1993). Constructivism as a referent for teaching and learning. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 3-22). Washington, DC: American Association for Advancement of Science Press.

Tobin, K. G. (1993). *The practice of constructivism in science education.* Washington, DC: American Association for Advancement of Science Press.

Tobin, T. (1990, October). *Target students* (What Research Says to the Science and Mathematics Teacher, Number 7). Perth: The Key Centre for School Science and Mathematics, Curtin University of Technology.

Tobin, T., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 45-93). New York: Macmillan.

Touger, J. S., Dufresne, R. J., Gerace, W. J., Harddiman, P. T., & Mestre, J. P. (1995). How novice physics students deal with explanations. *International Journal of Science Education, 17*(2), 255-269.

Van Heuvelen. (1992). *Models of learning and teaching.* In D. Grayson (Ed.), *Workshop on Research in Science and Mathematics Education* (pp. 56-67). Cathedral Peak, South Africa: SAARMSE.

Van Heuvelen, A. (1991a). Learning to think like a physicist: A review of research-based instructional strategies. *American Journal of Physics, 59*(10), 891-897.

Van Heuvelen, A. (1991b). Overview, case study physics. *American Journal of Physics, 59*(10), 898-907.

Webb, J. (1984). *Problem solving in South Africa.* In H. Burkhardt, S. Groves, A. Schoenfeld, & K. Stacey (Eds.), *Problem solving: A world view. Proceedings of the Problem solving theme group, Fifth International Congress on Mathematical Education, Adelaide* (pp. 160-165): Shell Centre for Mathematical Education, University of Nottingham.

Wheatley, G. H. (1995). Problem solving from a constructivist perspective. In D. R. Lavoie (Ed.), *Toward a cognitive-science perspective for scientific problem solving: A monograph of the National Association for Research in Science Teaching, Number Six* (pp. 1- 12). Manhattan, KS: Ag Press.

Wildy, H., & Wallace, J. (1995). Understanding teaching or teaching for understanding: Alternative frameworks for science classrooms. *Journal of Research in Science Teaching, 32*(2), 143-156.

Wolcott, H. F. (1988). Ethnographic research in education. In R. M. Jaeger (Ed.), *Complementary methods* (pp. 187-216). Washington, DC: American Educational Research Association.

Wolcott, H. F. (1994). *Transforming qualitative data: description, analysis, and interpretation*. Thousand Oaks, CA: SAGE.

Wood, T. (1988). State-mandated accountability as a constraint on teaching and learning science. *Journal of Research in Science teaching, 25*(8), 631-642.

APPENDICES

A Concept map representing main areas of research associated with problems

B 1. Introduction to Natal Education Department syllabus

2. Excerpt from syllabus: Bodies in motion

C 1 Structured questionnaire

2 Analysis of questionnaire

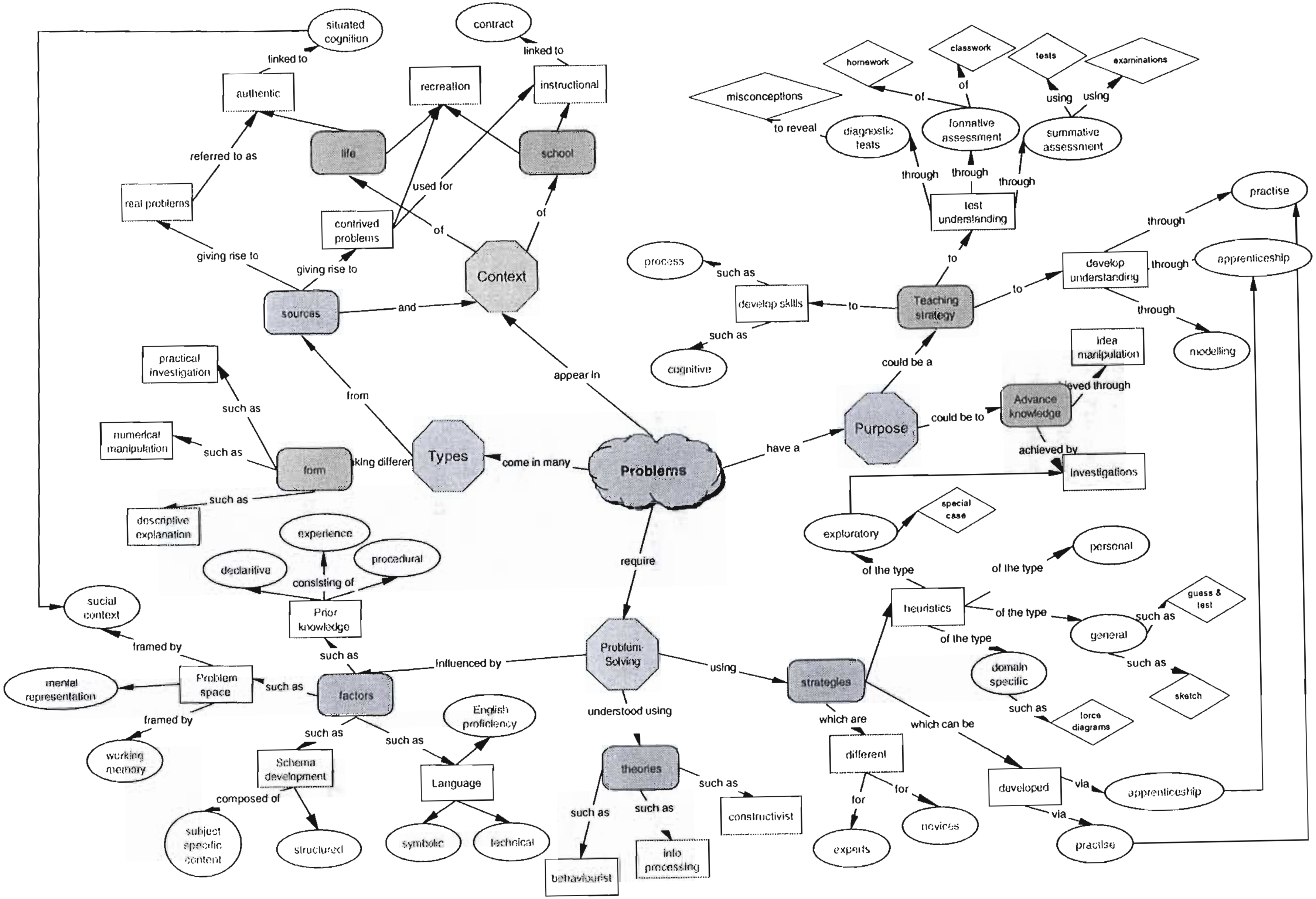
D Lesson transcript of Jack explaining

E Lesson transcript of Susan using direct teaching

F A set of "Pulley" problem tasks

G Examples of problem tasks that became routine

APPENDIX A CONCEPT MAP OF PROBLEM SOLVING RESEARCH



APPENDIX B1 INTRODUCTION TO REGIONAL EDUCATION DEPARTMENT CURRICULUM

PHYSICAL SCIENCE (HIGHER GRADE AND STANDARD GRADE) STANDARDS 9 AND 10

INTRODUCTION

AIMS

A few general or broad aims of Physical Science teaching are the following:

- to provide pupils with the necessary subject knowledge and comprehension, i.e. knowledge of the subject as science and as technology;
- to develop in pupils the necessary skills, techniques and methods of science, such as handling of certain apparatus, the techniques of measuring, etc.;
- to develop in pupils the desirable scientific attitudes, such as interest in natural phenomena, desire for knowledge, critical thinking, etc.;
- to introduce pupils to the scientific explanation of phenomena;
- to introduce pupils to the use of scientific language and terminology;
- to introduce pupils to the applications of science in industry and in everyday life;
- to help pupils obtain perspective in life, for example to develop a reverence for the Creator and an esteem for the wonders of the created universe through contact with the subject matter.

It is left open to the teacher to specify the objectives for each topic and lesson. This implies that the specific objectives are related to specific subject matter, methods and evaluation.

GENERAL REMARKS

In teaching the syllabus it will be necessary to make use of simplifications. The simplifications, however, must not be such that pupils are left with serious misconceptions. Where conceptual models are used to simplify the explanation of certain phenomena (e.g. Rutherford's model of the atom) it must be made clear that these are models and, as such, are not intended to serve as fully acceptable scientific explanations.
SI units and IUPAC nomenclature must be used throughout.

SYLLABUS CONTENT

This syllabus is for HG and SG pupils.
Certain requirements are for HG only. **These are indicated by the use of bold face type**.
The syllabus for Std 9 consists of a compulsory core plus two optional units, which may include either A and/or B or other units of comparable length. Such options should be inserted in the syllabus at appropriate places and must be approved by the Subject Adviser.
There are no optional units in the syllabus for Std 10.

EXAMINATIONS

Separate final examination papers will be set for HG and SG in STD's 9 and 10.
Standard 9 will be examined internally.

The external examination in Standard 10 will be set on the syllabus for Standard 10 as well as sections 1, 2, 7 and 8 of the syllabus for Standard 9, excluding the options.
The length of the Standard 10 examination may not be less than 3 hours.
The same number of marks will be allotted to physics and chemistry in the final Std 10 examination.
Not more than one third of the total marks for the Std 10 examination shall be allocated to questions of the multiple choice type.
It will not be required of candidates to memorise numerical constants or the whole of the Periodic Table. In the examination an approved Periodic Table and information sheets will be provided where needed. No formulas which are statements of definitions or laws, will, however, be supplied.

PRACTICAL WORK
Physical Science is an experimental science. The syllabus gives ample scope for experimental work carried out by the pupils themselves. The main aims of such experimental work are the following:
To help pupils understand the fundamental role played by experiment and observation in establishing and extending the body of scientific knowledge.

- to facilitate the learning and understanding of facts and principles;
- to give pupils opportunities of making simple "discoveries" of their own;
- to provide experience of elementary measuring techniques, and acquaintance with some of the measuring instruments in common use;
- to give practice in the recording and treatment of observations, the drawing of appropriate conclusions and the presentation of results (in this connection, it is expected that pupils will gain some appreciation of what is meant by "significant figures" in recording scientific observations, and of the importance of specifying limits of accuracy).

(Aims 1.5.1.1 and 1.5.1.2. can be achieved by treating experimental work by pupils as an integral part of the course, e.g. by introducing fundamental principles or important extensions or applications of these by experiments carried out by the pupils themselves. Aim 1.5.1.3 can also be achieved in this way, and by the provision of opportunities to carry out simple open-ended experiments.)

NOTE:

Experiments marked T should be carried out by the teacher and those marked P or E by the pupils.
Experiments marked E are examinable.

APPENDIX B2 EXTRACT FROM SYLLABUS: BODIES IN MOTION

CONTENT

4.1 Bodies in motion
(no calculations involving motion on an inclined plane)

4.1.1 Newton's First Law of Motion
Recall earlier concept of force as 'push' or 'pull' causing a change in motion.
Introduction of the concept of intertia.

4.1.2 Newton's Second Law of Motion
The identification of forces acting on an object in a given situation, e.g. a body suspended by a string.
A constant force produces a constant acceleration. Equal forces produce equal accelerations of the same mass.
The force exterted on a given mass is proportional to the acceleration it produces.
The ratio $\frac{F}{a}$ is a constant for a given body and is defined as the mass of that body
$\therefore$F= ma.

4.1.3 **Newton's Third Law of Motion**
If a body A exert a force on body B, then body B exerts an equal and opposite force on body A
Application to simple cases e.g. walking, pressing against a wall, rocket.
Exclude more difficult cases e.g. horse pulling a cart.

4.1.4 Newton's Law of Universal Gravitation
The universal aspect of graviational attraction $F\frac{Gm_1m_2}{r^2}$
Falling bodies; gravitational acceleration (g) ; equations of motion (see std 9 syllabus section 2) applied to free fall: weight = mass x gravitational acceleration
Projectile motion (limited to vertical projection).

4.1.5 Momentum
Momentum as a vector quantity.
Principle of conservation of momentum
Convervation of momentum in straight line conditions (i.e. no oblique collisions).
Change of momentum experienced by an object in a collision e.g. a ball against a wall
Impulse = F Δ t = m (Δv) derived from Newton's second law (limited to constant mass)
Force as the rate of change of momentum

4.1.6 Work, Energy, Power
Revision of work, energy and power and the units in which they are measured.
Derivation of kinetic energy = $\frac{1}{2}m^2$ and gravitational potential energy = mgh.
Conservation of mechanical energy : kinetic energy + potential energy is constant for a freely falling body. Principle of conservation of energy

OBJECTIVES

1. Knowledge
   - (i) define : inertia, force, the newton, momentum, impulse, work, energy, power, weight:
   - (ii) State:
     - (a) the symbols and SI units of the above:
     - (b) Newton's laws of motion (1,2 and 3); law of universal gravitation, the law of conservation of momentum, the law of conservation of energy;
   - (iii) list the formulae : $F = ma$, $(w = mg)$

$$F = \frac{Gm_1m_2}{r^2}, \quad p = mv, \quad F\Delta t = m(\Delta v),$$

$$(F = \frac{mv - mu}{\Delta t}), \quad E_k = \tfrac{1}{2} mv^2, \quad E_p = mgh, \quad W = Fs,$$

$$P = \frac{w}{t}, \quad \text{as well as :} \quad v = \frac{s}{t}, \quad v = u = at,$$

$$s = ut + \tfrac{1}{2} at^2, \quad v^2 = u^2 + 2as;$$

2. Understanding

   Pupils should be able to:
   - (i) Interepret:
     - (a) the formulae in 1. (iii) above;
     - (b) the laws in 1, (ii) above;
   - (ii) perform calculations using the equations in 1. (iii) above;
   - (iii) contrast : mass and weight; g and G; elastic and inelastic collisions;
   - (iv) describe : energy transformations;
   - (vi) **derive : the formula $F \cdot \Delta t = m \cdot \Delta v$**;
   - (vii) prove that:
     - (a) **force = rate of change of momentum;**
     - (b) the kinetic + the gravitational potential energy of a freely falling body is constant

3. Higher abilities

   Pupils should be able to apply some of the above in unfamiliar situations.

Time allocation : ± 30 periods

APPENDIX C1 STRUCTURED QUESTIONNAIRE

Statements on Problem solving in school science.

The word "problem" is used in these statements. It refers here to those problems, and exercises you did this year in class , for homework and in tests. Also included are the examples and worked problems done by the teacher. If you are unclear about the meaning of any statement then please indicate this on the back of this sheet where space has been provided for your comments.

Circle the response which best represents your response to the statement
Strongly agree 1, agree 2, undecided 3, disagree 4, strongly disagree 5

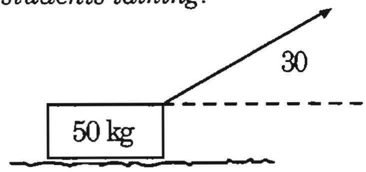
	STATEMENT	RESPONSE Strongly Agree		Undecided		Strongly Disagree
1	Reading and studying my notes helps me to successfully solve problems.	1	2	3	4	5
2	Learning how to solve the science problems I did this year will be a useful life skill.	1	2	3	4	5
3	Solving problems makes the subject more relevant to me..	1	2	3	4	5
4	The majority of problems we do only have one acceptable way of solving them.	1	2	3	4	5
5	I associate problems with applying formula and algebraic procedures.	1	2	3	4	5
6	Studying my notes will be more valuable than solving problems for obtaining a good mark in the matriculation examination.	1	2	3	4	5
7	I solve many problems successfully without understanding the science theory , principles or concepts involved.	1	2	3	4	5
8	I find the problems we do in science class related to real life situations.	1	2	3	4	5
9	The majority of problems we do have only one correct answer.	1	2	3	4	5
10	Doing science problems improves my problem solving skills in other subjects.	1	2	3	4	5
11	I learn "off-by-heart" how to solve particular type problems expected in the examinations.	1	2	3	4	5
12	My success at solving problems is taken as the main indicator of of my understanding school science.	1	2	3	4	5
13	I find the problems we do in science class unrealistic.	1	2	3	4	5

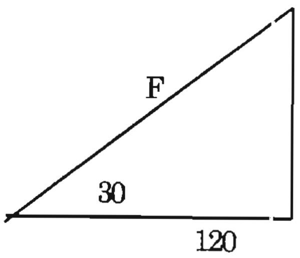
14	Solving problems uncovers my misunderstandings of physics theory/concepts/principles.	1	2	3	4	5
15	Solving problems mostly involves matching previously done problem solutions with the current problem you have to solve.	1	2	3	4	5
16	Most problems require me to engage in equation manipulation.	1	2	3	4	5
17	I find chemistry problems more difficult than physics ones.	1	2	3	4	5
18	Problem solving helps me to recognise how science concepts appear in real-world situations.	1	2	3	4	5
19	Solving problems mostly involves matching a formula to the situation.	1	2	3	4	5
20	I find the problems in science interesting.	1	2	3	4	5
21	Discussing how to solve a science problem with a friend is valuable to me.	1	2	3	4	5
22	Problems I do are mostly numerical or arithmetical in nature.	1	2	3	4	5
23	The problems I do give me skills to solve problems I encounter in life outside school.	1	2	3	4	5
24	Solving problems builds understanding of science theory i.e. concepts, laws and principles.	1	2	3	4	5
25	Watching the teacher "go over" or "work out" a problem solution is valuable to me.	1	2	3	4	5
26	I obtain the correct answers to some problems without understanding the theory/principle.	1	2	3	4	5
27	The problems we do are open ended and a variety of answers are acceptable.	1	2	3	4	5
28	I find chemistry problems more relevant to real life than physics problems.	1	2	3	4	5
29	Learning to solve particular types of problem is the primary goal of school science.	1	2	3	4	5
30	Doing science problems improves my problem solving skills for everyday life experiences.	1	2	3	4	5
31	The majority of problems can be solved by the straight forward application of a single principle (or formula).	1	2	3	4	5
32	What I have learnt from doing science problems will assist me in the future.	1	2	3	4	5

APPENDIX C2 ANALYSIS OF QUESTIONNAIRE

Question number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Frequency	1	14	6	15	1	8	0	4	8	10	5	1	11	3	14	6	11	13	4	5	4	18	8	4	11	22	3	1	4	3	5	3	8
	2	28	23	27	5	20	6	15	23	29	23	11	19	5	26	26	35	18	28	31	30	16	26	14	30	23	25	8	5	21	18	19	20
	3	5	13	6	3	6	8	5	8	8	13	6	13	12	6	10	5	7	8	7	11	12	11	16	5	2	7	12	13	14	13	4	16
	4	5	8	2	30	17	25	14	10	5	9	20	8	28	6	9	2	10	13	10	2	5	7	15	6	4	13	21	20	12	16	24	7
	5	2	4	4	15	3	15	16	5	2	4	16	3	6	2	3	1	6	1	1	7	3	2	5	2	3	6	12	12	4	2	4	3
Average		2.1	2.6	2.1	4.0	2.8	3.9	3.4	2.6	2.3	2.7	3.7	2.5	3.5	2.2	2.6	2.0	2.6	2.6	2.5	2.6	2.2	2.4	3.1	2.2	1.9	2.9	3.6	3.6	2.9	2.9	3.1	2.6
SD		1.0	1.1	1.1	0.9	1.2	0.9	1.4	1.2	1.0	1.1	1.1	1.1	1.0	1.1	1.1	0.8	1.3	1.0	1.0	1.1	1.2	1.0	1.1	1.0	1.1	1.2	1.0	1.1	1.1	1.1	1.1	1.1
Agree		78%	54%	78%	11%	52%	11%	35%	57%	72%	52%	22%	56%	15%	74%	59%	85%	57%	59%	67%	63%	63%	63%	33%	76%	83%	52%	17%	17%	44%	43%	41%	52%
Undecided		9%	24%	11%	6%	11%	15%	9%	15%	15%	24%	11%	24%	22%	11%	19%	9%	13%	15%	13%	20%	22%	20%	30%	9%	4%	13%	22%	24%	26%	24%	7%	30%
Disagree		13%	22%	11%	83%	37%	74%	56%	28%	13%	24%	67%	20%	63%	15%	22%	6%	30%	26%	20%	17%	15%	17%	37%	15%	13%	35%	61%	59%	30%	33%	52%	19%

APPENDIX D TRANSCRIPT OF JACK EXPLAINING HOW TO SOLVE A PROBLEM TASK

1	Mr. J:	Right where did we kick off ?	*All the students appear attentive.*
	S1	57	*Student calls out*
3	Mr. J:	57 ....[5s].......... OK, piece of cake ...... 57.. [3s]	*Jack refers to his worksheet of problems. Pupils open files and exercise books, and turn to homework*
5	Mr. J:	No, not such a piece of cake, because, its not dealing with 0,5 in terms of sine 30 .... [8s]	*Refers to his list of problems and draws crate in silence. Background murmur from students talking.* 
7	Mr. J:	Right, ... what force acting at 30° to horizontal will accelerate a 50 kg crate 50 kg .... over a rough horizontal surface at 2 ms $^{-2}$ if a constant 20 N frictional force is present acting on the crate. Well, let me tell you a 50 kg crate and you've got a constant frictional force of 20 N - that's not a particularly large force for a 50 kaygees being pulled across a rough surface. However, that does not matter.	*Reads problem out to class most of whom have their heads down reading or looking at their homework or the list of problems.*
16		So we have a resultant force of 20 N. Sorry, my apologies, a frictional force of 20 N acting in the opposite direction......Aaaah .... oh . OK... right .... Now.... force equals mass times acceleration, and the question asks ... What force acting at 30°. Now ... [4s]	*Writes on board* $F=ma$
		The force that we have to work out initially, is the force that acts in the direction of movement. Now we haven't got onto this in the past ..... Now this box accelerates that way, as a result of the horizontal component of that force. So once we know the horizontal component of that force, we can then work out that force by simple trig.	*Points to diag & illustrates directions.* *Not all students are watching. Some are looking at their books.*
		So we want to find the horizontal component. So lets find force resultant first of all. Now the force resultant that accelerates 50 kg at 2 ms $^{-2}$ equals.....?.	*Labels diagram* *Writes* $=50 \times 2$
	Ss	???????	*Indecipherable chorus*
35	Mr. J:	2 equals 100 N. Now that is the force resultant. Therefore, the horizontal component equals... hands up....... James, Yes?	= 100 N *Immediately points at James whose hand was first up*
	SJames	120	
39	MR.J:	Very good, James. Now, it is 20 against the	*Writes*

		direction, the horizontal force has to be 100 plus 20 which is 120 N. Lets draw a quick little diagram here..... [9s]...	∴ Horiz. = 100 + 20 
42	Mr.J:	F equals?	
	Ss	138,5 (chorus)	*Number of pupils start to call out*
44	Mr.J:	Lets put in a step	
	S3	cos 30 120 120 over H	*Students call out different answers*
	S_{James}	$\cos 30 = \frac{120}{H}$	*James calls out*
49	Mr.J:	Guys just give me ..	
	S2	120 over horizontal ....Sorry sir	*T sighs breathes deeply*
51	Mr.J:	Does it come to about 145	
	Ss	138	*Chorus*
53	Mr.J:	138	*Writes on board*
	S2	138,5	$F = \frac{120}{\cos 30} = 139$ N
55	Mr.J:	139 Newtons. Wrong, hands up....... Stand up if you got it wrong...... Sit down if your error was purely a trig error... Guys, matric hay! Simple solving of triangles ... standard 8 work. Sit down if you subtracted the 20.	*Puts chalk down and speaks to class. Hands are raised. About 10-12 students stand up. Majority sit down* *Pupils laugh* *Couple sit down leaving one or two still standing.*
61	Mr.J:	Careless error? Do you <u>understand</u> why you got to add. If you don't',... say so now..... Tony? You looking doubtful.	*Emphasis on understand* *Refers to student still standing.*
	S_{Tony}	I don't understand why	
65	Mr.J:	You don't understand? [3s] .... Now ... watch this. Hands off the desk. Now watch .. I am going to put my finger on the disk and I am going to pull the desk. Observe, I am now pulling on the desk. I am actually pulling on the desk with a force greater than 20 N. Wallah! What's happening to the desk?	*Interrupts pupil* *Uses front student desk to demonstrate by attempting to pull it along the floor with one finger. It does not move.*
	Ss	Nothing	*One or two shout out.*
73	Mr.J:	Very good Why not?	*Sarcastic laughs from students*
	Ss	????????????	*(General murmur of responses indecipherable)*
76	Mr.J:	I am not overcoming friction. So what must I overcome before that is going to start moving?	
	Ss	(indecipherable murmur)	
79	Mr.J:	In this instance 20 N... so I have got to have 20	*Makes the desk move.*

		N before it starts moving and any force over and above that 20 N will now accelerate it. Happy? So if I am accelerating it with a 40 N force, the total force I've got to exert, is 60 Newtons. Now look at that... the diagram , are you happy in your own mind ?.	*Points to board*
	S_{Tony}	(nods,)	*murmur from others*
87	Mr.J:	Sure? ...... [10s]............................... Bear in mind that if this was not the case, anything that was not nailed down , the desks in this classroom.... would be filled with, aah.... this classroom would be filled with desks that acted like dodgem cars running all over the place, OK ?	
	S_{Tom}	Sir, has friction got to do with the amount of area the mass is placed on?	*Tom puts up his hand and asks question without waiting forJacks permission.*
96	Mr.J:	I always dislike it when somebody like you asks me a question that I am not 100% certain. Uumm.... [5s] I must actually refer that to Mr B. Now ..... the ...... I am going to come back to you on that one .... The question asked is " Does friction depended on the surface area? " .. There are a number of factors that come into play here .. it is obviously dependent on the nature of the surface area,.... how rough the surface is,.... and its .. the question asks " Is it dependent on the size of that surface?" .. and the other factor that was not asked .. "Is friction influenced by the load that is placed on it?". So if I am pulling a sled, one of those we had last year, with the oxen pulling the piece of wood in Transkei, greatest machines for causing soil erosion, ...um.... if you put a large load does the friction increase? If the sled has got a small surface area in contact with the road does the friction increase or doesn't it?	*Talks to student. General rustling in class as students* *Bell rings for end of first period* *Refers to question from last years examination paper.*
	S?	Yes	*Student response is ignored*
118	Mr.J:	And I will come back to you on that tomorrow. Good question. Any further questions on No. 57? ...... 58? A 8000 kg car pulls a 500 kg caravan so that it accelerates uniformly,... it is obviously the car and the caravan, ...accelerates uniformly to 10 ms^{-1} in four seconds. Calculate the accelerating force a.... equals v minus u over t which comes to?.......	*Reads from the list of questions.*

APPENDIX E TRANSCRIPT OF SUSAN USING DIRECT TEACHING

This extract describes Susan introducing a new section to the class dealing with the topic of Newton's laws. She has just completed a section. She was sitting on a front desk and talking to the class who are nearly all attentive..

Mrs. Smith: Are there any questions about Newton's first law

[There are no comments from the students]

Mrs. Smith: Right, also known as the law of inertia ...... because it starts an object moving and stops an object moving.

Frances: How do you spell inertia?

Mrs. Smith: I n e r t i a [*spells it out for her*]

Right Newton's second law is a quantitative law ..... In other words it involves calculations ..... quantitative. .... If you apply force, objects...sorry I am going to repeat. If you apply a resultant force the object must accelerate. What is going to determine the magnitude of that acceleration?

Student The degree of the force

Mrs. Smith: The size of the force and what else is going to affect the size of the acceleration?...........

[She gets no response so goes to the board and draws two circles representing two objects.]

If I had two identical objects, one made of iron and one made of plastic and I applied the same force to each of them. What is going to happen?

Frances The one is going to go shorter distance and the one is going to go further.

Mrs. Smith: Right. Not necessarily distance. OK. Depends for how long the force has been applied. One is going to accelerate with a high acceleration and one is going to accelerate with a low acceleration. Which one is going to have the lower acceleration?

Students Iron one [Chorus of answers]

Mrs. Smith: Iron one, the heavier one. The one with the greater ?........ mass.

Student Inertia

Mrs. Smith: or inertia. Yes, OK inertia is mentioned but I don't want to get into that. Right. The greater inertia something has, usually the greater mass it has. I actually don't want to get into that. Lets just look at the second law. Right, Newton's second law....

*[Goes to board and writes **F = m a** Some students start to copy down the equation and the definition as she dictates it to them.]*

The greater the force, the greater the acceleration if the mass remains constant. Secondly, the greater the mass, if you apply the same force, to two masses then the mass with the lowest mass is going to accelerate more. And Newton's second law. ...

[tape change so missing two or three seconds of dialogue]

...we are going to do a practical to verify it using trolleys and elastic bands and things...but we will only do that experiment next week.

Student Will we have to know the actual wording of the law?

Mrs. Smith: In the exam

Students [*indecipherable comments and questions from a few students shouting out at the same time.*]

Mrs. Smith: In fact, with Newton's second law, they usually.....you are just involved in calculations. Standard tens. Newton's law as I have said, is a calculations quantitative law involving also the equations of motion. Because what usually happens, you are asked to calculate, for example, force if you are given the initial velocity, final velocity and time. Then you would calculate the acceleration, you would be given the mass and you would calculate the force. OK.

Frances Please could you repeat the law.

Student [indecipherable question to teacher.]

Mrs. Smith: No...unless it was in a prac exam...not in a normal exam. Another situation that they can give you. They can give you the force, they can give you mass and they can give you the initial velocity of something and ask you to find the final velocity. ...... What you would have to do in that instance, is to first use Newton's second law to find the acceleration and then use that acceleration in further calculations. So these calculations involving Newton's second law are very much ... very closely linked to the equations of motion. Right are there any questions.

Frances Can you repeat the second law.

[Ignores request from Frances]

Mrs. Smith: And so because it is linked to equations of motion Std 10s we will have to do worksheets on them.

Students Ahh, no [variety of groans and comments from students]

Mrs. Smith: So in your classwork book, we have a worksheet on Newton's second law and of course the equations of motion.

[Proceeds to hand out worksheets.]

Mrs. Smith: One of these questions involves friction. I want you to try the question on friction on your own first. And then I will discuss it with you. I want you to try and use your imaginations, your own knowledge of friction to solve the problem.

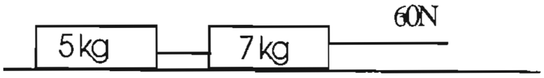
[Students start working on problems. The answers to each problem task were on the bottom of the worksheet. The first few were simple applications of the formula "F = ma" and many students comments about how easy these problem tasks were "I just wrote F = ma".]

APPENDIX F SET OF "PULLEY" PROBLEM TASKS

Textbook Problem

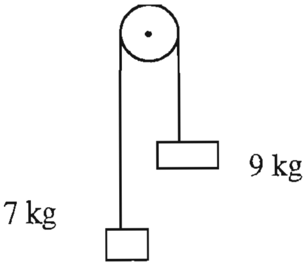
The two blocks shown are on a frictionless horizontal surface. They are joined by a light string. A force is applied as shown.

a) Calculate the acceleration of the blocks
b) Calculate the force exerted by the string on the 5kg block.

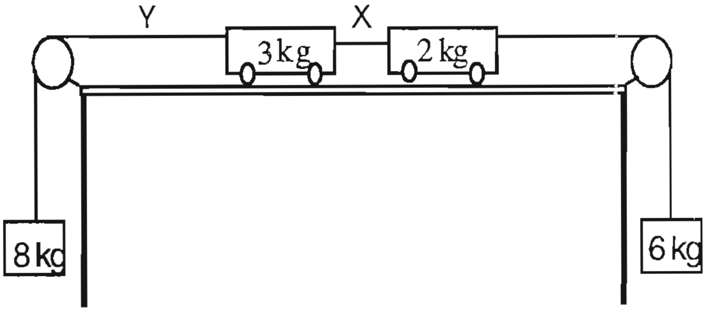


Worksheet (Contained 10 problems similar to these)

Find the acceleration.

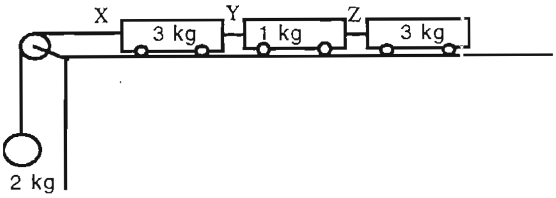


i) Find the acceleration.
ii) Find the tension at X & Y.



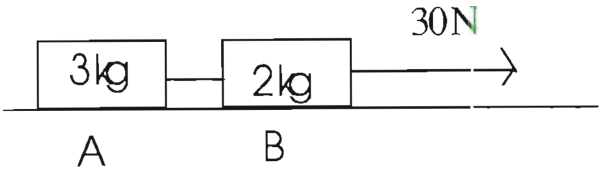
March Test 1

If the pulley is frictionless and each trolley experiences a frictional force of 2N when moving then determine the tensions in the strings at X, Y and Z.



March Test 2

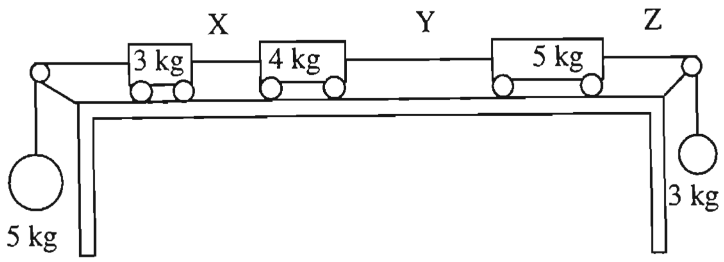
Two bodies A and B on a frictionless surface are joined by a light string as showing the diagram. The system is accelerated to the right by a 30N force acting on body B.



Calculate:

A) the magnitude of the force which the string exerts on body A; and
B) the resultant force acting on body B.

Internal Test

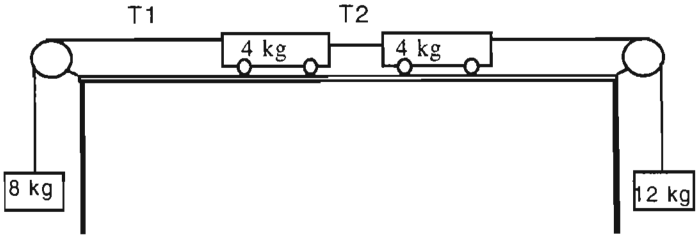


Three trolleys are joined together as shown in the above situation. Each trolley has 4 N friction when moving.
Determine the tension at points X, Y and Z.

June Test

In the pulley system shown, the pulleys are friction free whilst both the 4kg blocks experience 5N of friction each with the table top.
Calculate:

i) the acceleration of the system
ii) tension T_1
iii) tension T_2

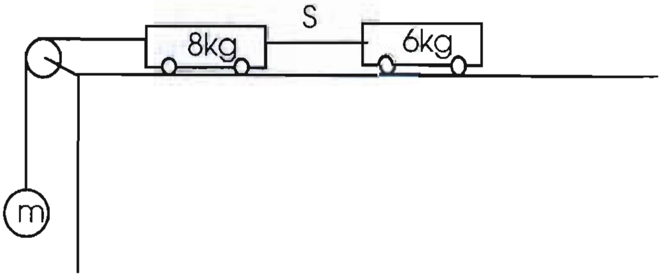


Final Matric Exam

In the system shown above the two connected trolleys of 8kg and 6kg stand on a frictionless surface. The 8 kg trolley is connected by a string passing over a frictionless pulley to an unknown mass m. The system can move freely, tension in string S is 7,5N.

Calculate:

i) Acceleration produced.
ii) Magnitude of mass **m**.
iii) Consider the pulley:
   If it had significant mass how would it affect the answer to (i). Explain.



Appendix G Examples of problem tasks that became routine

1. Momentum (Worksheet)

Car A of mass 800 kg moving at 25 $m.s^{-1}$ has a head-on collision with a 1800 kg truck moving at 15 $m.s^{-1}$. The vehicles become entangled on collision. What is the velocity of the wreckage. (7)

2. Titrations (Examination paper)

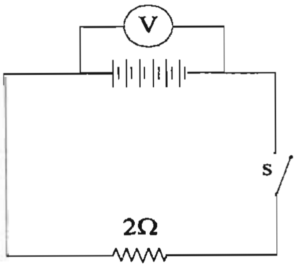
4,4 g Sodium Hydroxide, NaOH, is dissolved in water to make up 500 mℓ (0,5 dm^3) of a standard solution.
Calculate:
a) the concentration of this standard solution; and (4)
b) the pH of this standard solution. (2)
27,4 mℓ of this standard solution is titrated against 24,5 mℓ of oxalic acid, $(COOH)_2$, solution of unknown concentration.
c) Give a balanced equation for this reaction. (3)
d) Calculate the concentration of the acid solution. (3)

3. Mechanics (Worksheet)

A girl and her bicycle have a combined mass of 60 kg.
She accelerates from rest at 2 $m.s^{-2}$ for 4 s and then free wheels for another 6s.
Ignoring friction calculate:
a) the distance covered while accelerating (3)
b) the total distance covered in 10 s (5)
c) the resultant force which produced the acceleration (3)
d) the kinetic energy of the girl and the bicycle after the 4 s of acceleration (3)
e) the work done by the girl during the 10 s trip (2)

4. Electricity (Matric examination)

In the circuit diagram shown, the voltmeter reads 6V when switch S is open. When switch S is closed, the voltmeter gives a reading of 5 V. Calculate the internal resistance of the battery. (6)



5. Solutions (Matric Examination)

19 g $MgCl_2$ and 36 g $MgSO_4$ are mixed together and dissolved in water to make up 2 dm^3 of solution.
What is the concentration of magnesium ions in the solution? (6)