Promotion of Critical Thinking in School Physical Science

by

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requirements for the degree of
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DECLARATION

I, Angela Stott, declare that

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

(ii) This thesis has not been submitted for any degree or examination at any other university.

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ABSTRACT

This dissertation describes an action research study aimed at promoting critical thinking in learners while learning physical science within the South African national curriculum. The data were primarily qualitative in nature, and were collected primarily through participant observation, composed of audio- and video- recorded lessons, interviews, questionnaires, journal entries and written material. Data collection, analysis and interpretation were done in the inductive, cyclic manner of action research. This process was guided by research questions about task characteristics, their position in the teaching sequence, the role of the learning environment, and the need to adjust tasks to fit the needs of different learners, so as to effectively promote critical thinking. A pragmatic approach was used.

It was found that it is possible, using particular strategies and tasks, to promote critical thinking while meeting the curriculum outcomes, although the intense syllabus pressure of the curriculum makes this challenging. Task design characteristics and positioning in the teaching sequence, and conditions of the learning environment, were found to affect a task's effectiveness at promoting critical thinking. Various teaching strategies can improve attainability by a wider range of learners.

An instructional model, *The Ladder Approach*, emerged as being most likely to promote success. This was found to be successful when evaluated against criteria of active engagement and interest by learners, attainability with effort, display of critical thinking traits, and compatibility with the South African curriculum. In this model, an interesting problem is posed at the start of a section, after which direct instruction and learner engagement with the problem run parallel to one another, linked by scaffolding tools which are engaged in individually and collaboratively.

PREFACE

The work described in this thesis was carried out in the School of Science, Mathematics and Technology Education, University of KwaZulu-Natal, from January 2005 to December 2008 under the supervision of Prof. Paul Hobden (Supervisor). Ethical clearance was obtained for this study HSS/0152/07D.

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.

Angela Stott

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Steps have been taken to protect anonymity of those involved. Pseudonyms have been used for the learners to protect their privacy.

Ellipses … Indicate pauses in the speech, sections omitted, or extract continuation.

Citation: The data source is given, enclosed in brackets, indicating the source, type of extract and date, e.g. (J: interview: 27/01/07).

Number counts: The number of coding instances found in the data for a particular trait is often given, enclosed in brackets, after the trait to which it refers, e.g. interest (44), means 44 counts of interest were found in the data for the section referred to.

Unless otherwise indicated, all quotes and transcripts are speakers' exact wording.

ABBREVIATIONS

ANC: African National Congress

AS: Assessment Standard

CCT: Conceptual Change Theory

CO: Critical Outcome

DoE: Department of Education

FET: Further Education and Training

IEB: Independent Examinations Board

IPM: Information Processing Model

LJ: Learner Journal

LO: Learning Outcome

NCS: National Curriculum Statement

OBE: Outcomes Based Education

PBL: Problem Based Learning

PS: Physical Science

SA: South African

RJ: Researcher Journal

ZPD: Zone of Proximal Development

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DEDICATION

This thesis is dedicated to the learners who participated so willingly in this study.

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND AND RATIONALE

South African education has been undergoing radical change during the phasing in of an outcomes based curriculum over the past decade. This new curriculum calls for an emphasis on skills (DoE, 1995), largely absent from previous curriculum documents. One of these is the skill of critical thinking. As I, together with other South African teachers, prepared to implement this new curriculum in the classroom, I was eager to learn how to promote critical thinking in learners. This desire arose partly from having studied the powerful thinking of a high achieving learner during a Masters research study (Stott & Hobden, 2006). This was starkly contrasted to the uncritical thought typical of learners. Desiring to help such learners to benefit from the advantages of critical thought I had observed in this high achiever, and since the new curriculum placed so much emphasis on promotion of critical thought, I became interested in ways to promote critical thinking in all learners during everyday classroom practice.

Abundant evidence was available that science education in South Africa was in need of improvement. This included South Africa being ranked bottom amongst the 50 countries participating in the Trends in International Mathematics and Science Study (TIMSS) in 2003 (Reddy, 2006). Other indications of the need for change included the lack of intrigue evident in school science learning (Hobden, 2000). This seemed to be the result of traditional teaching having deadened the subject. This teaching was directed towards preparing learners for high stakes examinations which focused on equation manipulation rather than conceptual understanding and critical thinking (Hobden, 2000). I looked forward to embracing the new curriculum in an endeavour to improve this situation.

Even before the tide of change reached the further education and training (FET) phase, in 2006, I had shifted my pedagogical approach from a traditional to a more constructivist one. A number of factors had contributed to this. I had been the subject of a Masters case study of my practice (Moodley, 2000), which had demonstrated shortcomings of the traditional pedagogy I had been using. Additionally, as already mentioned, I had performed a research study of my own (Stott, 2002), in which my views of learning were challenged by an in-depth study of a high achiever’s learning of physical science. Further, since I also teach in the senior phase, which had experienced the implementation of the curriculum earlier than did the FET phase, I had attended the first workshops provided by the state to prepare teachers for this transition. These workshops drew clear lines between the old and new systems. The old system was portrayed as involving the teacher lecturing to passive learners according to a rigid curriculum divorced from reality. This was to be viewed as bad education. Instead, teachers were now meant to allow learners to construct knowledge for themselves while working collaboratively in groups on authentic tasks. This would promote critical thinking, we were told. The final contribution to my ideological shift was my involvement in co-authorship of a grade 10 physical science text-book in preparation for the curricular change reaching the FET phase.

These factors resulted in my undergoing a paradigm shift before the curricular changes reached the FET phase in 2006. This involved a shift from an objectivist to a constructivist epistemology, and associated grappling with replacement of traditional by constructivist pedagogy. This personal shift ahead of the curriculum implementation in the FET phase resulted in a good deal of internal tension. This was mainly due to the content-rich syllabus of the old curriculum being incompatible with the time-consuming approach I felt was needed in a constructivist pedagogy. I attributed this tension to a mismatch between my teaching style and the old curriculum’s objectives. Consequently, I looked forward to the phasing in of the new curriculum in the FET phase in 2006. I thought that this would give me the freedom to teach in the style which the training sessions had propagated, without constantly fearing that this would disadvantage learners in the final examination. I also believed that under the new curriculum I would be able to concentrate on promotion of critical thinking rather than having to merely race through a content-rich syllabus.

This was the ideological position, and external environment, in which I found myself in 2005, a year before the implementation of the new curriculum in the FET phase. These were the perfect combination of mindset and situation, I believed, for embarking on this research study. I had spoken to other physical science teachers about my enthusiasm for the phasing in of the new curriculum in the FET phase, and my ideals of promoting critical thinking. Instead of returned enthusiasm, however, I noticed considerable foreboding about the new curriculum, particularly due to a lack of clarity on how it was to be implemented in practise. A study of South African literature on related topics revealed that this lack of clarity was widely felt. I also noticed a general lack of understanding of what is meant by critical thinking, and an apparent incapacity to teach for it. Again, a literature search showed this to be a general problem, not only in South Africa, but internationally. This indicated to me that there was a need for research into the characteristics and implementation of tasks, which are successful in promoting critical thinking within a real school setting. I reasoned that if this could be determined within the context of the South African physical science (SA PS) national curriculum, this may contribute to narrowing the gap between policy ideals and practice. This reasoning inspired me to prepare for, and, at the start of 2006, launch into, this research study.

1.2. RESEARCH APPROACH

Data collection and analysis in this study were guided by the general question and associated specific sub-questions:

How should learning tasks be designed and used in teaching to promote critical thinking within the South African physical science national curriculum?

a) Which design characteristics affect a task’s effectiveness in promoting critical thinking?

b) How does the position in the teaching sequence influence a task's success in promoting critical thinking?
c) What type of learning environment encourages promotion of critical thinking?
d) To what extent do tasks need to be adapted to fit particular students or student groups in order to promote critical thinking?

The study was approached within a pragmatic orientation to research (Cresswell, 2003; Johnson & Onwuegbuzie, 2004). According to this, research is guided by the problem, rather than by antecedent conditions. The criterion of usefulness in solving this guiding problem governs choices about research methods. A solution is recognised as that which is found to work in the desired manner. At the same time, a realist leaning towards ontology and epistemology caused me to be wary of viewing anything which works as truth (Feldman, 2007). I was also wary of my own biases influencing my perceptions and interpretations. Consequently, I subjected these to rigorous scrutiny by myself, participants, peers and superiors. This was done in a manner guided by literature on validity in terms of qualitative research.

The action-research inquiry strategy used in this study is consistent with taking a pragmatic approach to claims to knowledge. This is because action research is primarily concerned with a pragmatic improvement of practice. It aims at praxis, i.e., the integration of theory and practise, (Mc Niff & Whitehead, 2006; Zuber-Skerritt, 2001). During action research, observation and reflection are entered into during an implementation of what is understood to be best practice at the time. Emerging from this, understanding is modified, moving the researcher into new directions, which form the basis of the next cycle of implementation, observation and reflection. The process is repeated until practise had been improved in the required manner (Mc Niff & Whitehead, 2006). Action research is flexible and responsive. It is not bound by a particular methodology, but instead takes a pragmatic view of the research process. This flexibility and responsiveness make action research suitable for researching complex situations (Swepson, 1995), such as those explored in this study.

Also appropriate for researching complexity, is the focus on qualitative data collection and transformation used in this study. The researcher’s powers of observation, analysis and interpretation are central to these processes, since only a human instrument is considered sensitive enough to detect the nuances and richness in such data (Bogdan & Biklen, 1992; Merriam, 1988). Qualitative reporting is focussed on in this dissertation. This is appropriate for providing readers an opportunity to form alternative interpretations and to abstract principles relevant to their local conditions. In this way the value of this study can be extended (Cohen, Manion, & Morrison, 2000; Stake, 1994). Each targeted section of work for a period of three years was approached as a cycle of action and research. This involved almost daily data collection and / or reflection throughout the three-year research period. Initially I based my preparation and implemented of teaching strategies and tasks on a literature-based understanding of how to promote critical thinking. During the implementation period I collected data, and analysed and reflected on it. Guided by this and further literature examination, I altered the strategy taken in subsequent cycles. By conducting this research over such a long period, and by collecting a large quantity and variety of data from all the participants involved, I ensured thoroughness and data saturation and allowed for triangulation (Merriam, 1988). Other practises aimed at ensuring validity, in the sense used in qualitative research, included subjecting the study to scrutiny through a process of critical discourse (Zuber-Skerritt, 2001). This included engaging in discussions with critical friends and a validation group (Mc Niff & Whitehead, 2006).

A variety of data was collected. This included open and closed-type questionnaire and interview items, reflective learner and researcher journals, analysis of learners’ written work, and transcriptions of audio-recordings, aided, in some cases, by video-recordings. Data coding was done according to frameworks which were generated during the research, informed by relevant literature. Inductive analysis was used in the cyclic manner of action research. A software package, NVivo, was used to aid data transformation. This improved the efficiency and effectiveness of pattern searching, and added rigor to the process.

The participants of the study were the learners I taught physical science to in grade 10 and higher as they progressed through school to grade 12. This is consistent with the focus of action research on in situ practise (Mc Niff & Whitehead, 2006). These learners came from a wide variety of cultural and socio-economic backgrounds, with an approximate equal gender representation. This participant heterogeneity is expected to have increased the likelihood that readers will be able to extract naturalistic generalisations appropriate to their particular conditions. Before data collection was commenced, learners and their parents were informed about the research to allow them to decide on whether or not to give consent to the learners' participation.

1.3. THEORETICAL REFERENTS

A number of terms and concepts are central to this study. These are mentioned here, together with the meaning I have attached to them for the purposes of this dissertation. A number of the issues central to the study are also briefly touched on. I begin by looking at the new South African national curriculum in the context of which this study was situated. I then turn my attention to critical thinking, in an attempt to understand how it can be promoted while operating within this curriculum. An understanding of promotion of critical thinking must be informed by what is known about learning, teaching, and tasks, each of which is then discussed.

1.3.1. Curriculum

The South African national curriculum places a high premium on critical thinking, naming it three times in the cross curricular critical outcomes (DoE, 2003a). Critical thinking also features prominently in implicit form within the learning outcomes and assessment standards of the physical science curriculum (DoE, 2003b). As is to be expected in any transitional period, however, the attempt, undergone in this study, to translate these ideals into practice, was riddled with uncertainty and tension. Some of the issues which contributed to the tensions I experienced were the relative stress to be placed on conceptual versus procedural treatments of the subject, the degree of rigidity required in adherence to the curriculum content, and the place each of a traditional and constructivist pedagogy should play in curriculum implementation. The retention of a high stakes examination, without the availability of prior examination papers to serve as guidance, intensified the feelings of anxiety which these uncertainties encouraged. Data collection for this study commenced with the start of implementation of the curriculum in the FET phase, and saw me both eager to explore use of the curriculum to promote critical thinking and uncertain about a number of aspects related to its practical implementation.

1.3.2. Critical thinking

Given that there are many different definitions of critical thinking in the literature, for the purpose of this study Lipman's definition will be used (Lipman, 1989). According to this, critical thinking is "thinking that is reliant on criteria, self correcting, sensitive to context and conducive to judgment"(p.8). This definition incorporates aspects of metacognition, action, and appeal to criteria, which are common to many of the definitions available, and appeals to me as a concise, normative framework for analysing whether thinking is critical or not. Other authors' views on the characteristics of critical thinking were also used to inform a rich understanding of critical thinking. For example, the intellectual standards of relevance, consistency, accuracy, precision, fairness, logic, depth, breadth and significance (Paul, 1993), guided decisions about which criteria should be relied on in order for thinking to be considered critical. Similarly, the criterion of motivation with consideration of both merits and faults, was used for judgement to be considered critical (Paul & Elder, 2001). Some authors, such as Resnick (1987) refer to higher order thinking, rather than critical thinking. For the purposes of this study, higher order and critical thinking are viewed as synonyms. This is justified in Chapter Two. The term critical thinking will be used in this dissertation except where an author's use of higher order thinking is referred to.

Critical thinking is viewed as a trait which any educated person should possess. Its value includes the learning flexibility it allows for, its enablement of rational decision-making, and its empowerment to face every-day problems competently (Cotton, 2001; Mc Carthy, 1992; Nickerson, 1994). Within the context of science education, critical thinking is central to inquiry-learning and a view of knowledge as contested (Lipman, 1991; Mc Dermott, 1993; Ostlund, 1998; Yore, 2001). The emphasis placed on critical thinking by the South African Department of Education (DoE), and its prominence in the new national outcomes based curriculum, has already been referred to.

1.3.3. Learning

In my understanding of learning I take a pragmatic approach using those theories and referents which make sense to me depending on what problematic aspect of teaching and learning I am interested in. However, I am strongly guided by the constructivist understanding of learning (Dirks, 1998; Yore, 2001). According to this learning occurs as a result of sense-making processes undergone by the learners as they interact with new information, influenced by their existing ideas. I find the use of other theories, in addition, helpful in understanding the full complexities of learning. I find three models of learning particularly helpful in understanding learning: two being constructivistic, and the other originating from cognitive psychology. These models are the more recent versions of Conceptual Change Theory (CCT) (Hewson & Lemberger, 2001), Vygotsky’s theory of the Zone of Proximal Development (ZPD) (Vygotsky, 1978) and the Information Processing Model of Learning (IPM) (Niaz & Logie, 1993). Each of these sheds light on a particular aspect of learning which I find useful in deciding on what observations to focus on and how to interpret them. For me, conceptual change theory provides a useful explanation of the sense-making process which occurs during conceptual learning. Vygotsky’s theory of optimal learning occurring in the ZPD emphasises the value of scaffolding, social learning, and the importance of instruction being of an appropriate level of difficulty for the learners at which it is aimed. I find the IPM valuable in its attribution of learning limitation to the limited capacity of working memory.

In addition to the models of learning mentioned above, Schoenfeld's Framework for the Analysis of Problem Solving in Mathematics (Schoenfeld, 1985), appears to be useful for analysing learning behaviour. The components of successful problem solving he identified in this framework are: resources, heuristics, control and belief systems. In the light of this, learning is seen to involve selection and use of resources and learning strategies (heuristics) by metacognitive control processes affected by the learner's belief system.

1.3.4. Teaching

While it is generally accepted that learning occurs by knowledge construction during a sense-making process, teaching practise which is conducive to promoting this is less well understood (Prawat, 1992). Terms relevant to discussing this issue include pedagogy, instructional models, and instructional strategies. Pedagogy refers to ideological principles related to teaching practise. Use of the terms instructional model and instructional strategy are employed in the manner used by Gunter, Estes, & Mintz (2007). An instructional model is a sequenced series of steps adopted by a teacher to achieve a certain purpose. Instructional strategies are "smaller instructional patterns that can be used across models for a variety of purposes with a variety of content" (Gunter et al., 2007, p. 282).

The term traditional pedagogy is used to refer to an authoritarian ideology in which the teacher is seen as a fount of knowledge whose job it is to transfer this knowledge to attentive learners. This is followed by learners practising this knowledge by answering exercise questions. This is referred to as an instructivist pedagogy by Cronjé (2007). In contrast, an ideology which recognises that learners are not passive receivers of knowledge, instead needing to be given opportunities to make sense of new information in the light of their existing conceptions, is called a constructivist pedagogy. Within each of these broad pedagogical categories are numerous variations. For example, proponents of radical constructivist pedagogy view all knowledge as relative, and are therefore concerned only with learners discussing views, rather than reaching a predetermined understanding. Theorists such as Dirks (1998), who take a more conservative view, do, however, acknowledge the importance of learners engaging with stipulated content learning, with this possibly even occurring during a traditional lecture. However, they also acknowledge the importance of the learners' prior knowledge to the learning experience, and require that some sense-making activity occurs in which new and prior knowledge can be actively evaluated and reflected on by the learner.

I began the study informed by a constructivist pedagogical understanding. I aimed at providing learners with sense-making opportunities and tried to encourage them to question and critically evaluate knowledge claims rather than accept them in a traditional, authoritarian manner. However, I approached the study with much uncertainty regarding how this should effectively be done with regards to the every-day practitioner choices which needed making. These included choices about which particular instructional models and strategies should be used, how tasks should be chosen or designed, and how these should be implemented. This uncertainty resulted from the fact that I could find no definitive guidelines on this in the literature, despite a thorough review of the relevant areas. Since the South African curriculum had not yet been implemented, empirically tested guidelines concerning implementation of this curriculum in a manner which promotes critical thinking, were obviously completely absent. The literature review did, however, reveal various debates concerning the promotion of critical thinking. These debates included whether critical thinking should be taught directly or inferentially, separately or infused into subject disciplines, and what the role of collaboration should be in teaching for critical thinking.

This review of relevant literature informed the choices I made at the start of this study. This included the decision to use both direct and inferential teaching of the various components of critical thinking, as well as giving opportunities for learners to integrate these components. Strategies to promote critical thinking would be infused into the normal physical science teaching. It was decided that collaborative learning would be focused on, although not used exclusively. Attempting to transform the class into a community of inquiry (Lipman, 1991) during the course of this study was hoped to create an environment conducive to constructivist learning and critical thinking by all learners. The research attempted to gain a better understanding of the influence of the various components of the teaching and learning environment, the influence of direct and inferential learning, and the value of collaborative learning, on critical thinking.

1.3.5. Tasks

Study of the literature suggests the following task characteristics as potentially critical in determining a task's effectiveness at promoting critical thinking: structure and guidance, context, open-endedness, length, complexity, position in the teaching sequence, and language usage. In order to understand the role each plays in determining task effectiveness it is necessary to realise that each involves tensions which need balancing for optimisation. A review of some of the tensions relevant to this study is given, below. First, however, an aspect relevant to determining optimisation within these tensions, is referred to. This is a task characteristic's effect on a learner's belief system. Closely linked to this are the task characteristics' demands on the learner's working memory, and the learner's motivation.

According to Schoenfeld (1985), learners' belief systems determine their selection and use of resources, heuristics and control strategies, and therefore greatly affect performance. A learner's belief system is affected by extrinsic and intrinsic motivation (Palmer & Goetz, 1988). A learner's motivation and belief system are affected by, and affect, the capacity of utilised working memory, according to the Information Processing Model (IPM) of learning. The capacity of working memory, in which all relationship-formation occurs, is very small, limiting performance. Learners often utilize only a fraction of this space, with motivation affecting how great a portion of the working memory is utilised (Niaz & Logie, 1993). This motivation may be extrinsic or intrinsic. Factors affecting intrinsic motivation include interest, personal standards and goals, and the learner's perceived self-efficacy in relation to the task. Optimum self-efficacy corresponds to the learner viewing the task as falling into their ZPD (Lee & Smagorinsky, 2000). Tasks which fall beyond this, referred to by Margolis & McCabe (2003) as frustration-level tasks, provide so much cognitive load to the working memory that they affect motivation negatively. These concepts are now used to examine the tensions offered by a task's characteristics.

Task structure is taken to mean the degree of scaffolding built into the task design. Guidance is taken to mean the help given the learner by mentors, such as teachers and more able peers. This can also serve to scaffold a task. Scaffolding refers to an instructional strategy in which the task is broken into smaller, more manageable steps (Gunter et al., 2007). On one hand, a high degree of structure and guidance seems important for ensuring a task's success, given the limited capacity of working memory (Niaz & Logie, 1993). On the other hand, as Resnick (1987) says, "We do not recognize higher order thinking in an individual when someone else 'calls the plays' at every step" (p.3). Therefore, a tension exists between giving enough structure and guidance to ensure that learners do not reject the task as too difficult, but not so much as to prevent thinking from needing to be critical.

Research suggests that using real-life learning contexts improves the likelihood that learners will engage in critical thinking (Alvarez et al., 2000; Fraker, 1995; Sparapani, 1998). This can be explained by the greater intrinsic motivation the purposefulness and interest inherent to real-life contexts gives the learner (Brown, Collins, & Duguid, 1989). On the other hand, both a rich context and the tension of formal assessment might reduce the working memory space available for performing the task, and can increase the likelihood that learners misunderstand the task requirement (Bansilal, 2008).

Tasks can be classified as open or closed. An open task has multiple correct solutions, while a closed one has a single correct answer. Critical thinking is required during search for and formulation of questions (Barak & Doppelt, 1999; Lederman & Niess, 2000), is non-algorithmic, meaning that the methods used are not prescribed, and often yields multiple solutions, each with costs and benefits (Resnick, 1987). Therefore it seems that open questions may encourage critical thinking. On the other hand, the variety of options, and the need to make reasoned judgements concerning these, in an open task, may cause a learner to reject the task as falling outside their ZPD.

Critical thinking is complex in that it simultaneously involves substantive and procedural thinking (Lipman, 1991), i.e. it involves thinking about concepts at the same time as using heuristics and exerting metacognition. Therefore it seems reasonable to expect that simple tasks, i.e. those involving few concepts, criteria and possible solutions, may be less effective in inducing critical thinking than more complex tasks are. However, it also seems likely that learners may reject very complex tasks as offering too much cognitive load, and therefore falling beyond their ZPD.

Procedures are referred to in this study as processes which can be reproduced routinely with little flexibility required (Hobden, 2006). This includes manipulation of a formula, drawing a graph, and following a list of directions, if the process of doing this is no longer new to the learner. Procedures reduce complexity and so can become short-cut substitutes for independent thought Paul (1993). However, procedures can also be seen as important for freeing up working memory space for other thoughts. Both of these conflicting considerations suggest expectation that the prominence and timing of a teacher's presentation of procedures, and their stipulations for learner practise of these, may affect the extent to which critical thinking will be engaged in.

The majority of the learners who participated in this study do not speak English as a home language, as is the case in South Africa as a whole, and so at the outset I realised that the language of the tasks used would potentially be limiting. A number of South African researchers, such as Adam (1999), give inappropriate language as a key feature of the failure of tasks to promote critical thinking. On the other hand, some degree of language command and complexity is surely necessary to support the complexity of critical thinking and for learners to explain scientific concepts in a their own words: a key aspect of a critical approach to scientific thinking according to Paul & Elder (2006c).

Informed by considerations such as those briefly outlined above, the initial tasks used in this study were designed to vary in degrees and types of structure and guidance, context, degrees of open-endedness and complexity, position within the teaching sequence, and length. As I underwent the research, I sought to understand the relationship between these variables and a task's effectiveness in promoting critical thinking. Further, I attempted to pay attention to language usage and resource availability, another factor often cited to limit task effectiveness in South African classrooms (du Preez, 1998). In this way I attempted to reduce the limitation these factors may have on the tasks' potential effectiveness. The initial tasks were modified or new tasks designed at the start of each new cycle in the action research process, informed by the findings of the previous cycles.

1.4. STRUCTURE OF DISSERTATION

This dissertation describes action research aimed at determining how to promote critical thinking while teaching physical science within the South African national curriculum. The theoretical framework with which the research was approached is outlined in Chapter Two. In the presentation of this framework, the South African curriculum, critical thinking, learning, teaching, and tasks will be discussed in greater detail than has been done in this introduction. In the discussion on research methodology in Chapter Three, I justify use of the research design utilised, describe how data was collected, analysed and interpreted, and discuss the study's validity and reliability and its limitations. Chapter Four is a description of the development I underwent in my teaching strategies and task usage during the period of this research. Assertions are given in answer to the study's research questions in Chapter Five. The dissertation ends, in Chapter Six, with a summary, a discussion of the limitations of the study and suggestions of implications of this work.

CHAPTER 2
WHAT DO WE KNOW ABOUT TEACHING AND LEARNING CRITICAL THINKING?

The purpose of this chapter is to situate this study within the existing understanding of critical thinking, effective learning and current knowledge on promotion of these, particularly within the context of the South African national physical science curriculum. This provides a literature-based theoretical framework with which data analysis and interpretation have been approached. Inclusion or exclusion of literature in this review was initially determined by relevance and availability. Recurring references within these sources were taken to indicate authority in the field, and attempts were then made to locate and include work by some of these authors. A particular attempt was made to include South African research in the area.

In order to understand the promotion of critical thinking within the South African national physical science curriculum, it is first necessary to examine curricular issues, with a focus on the South African curriculum. After this, critical thinking will be defined and its promotion argued for. An examination of learning, which follows this, leads to the suggestion that critical thinking is a requirement for effective learning. Conceptions of critical thinking and learning together inform an understanding of relevant teaching strategies and task characteristics, with which I conclude the review.

2.1. CURRICULUM

South Africa's curriculum is based on the principle of "high knowledge, high skills" (DoE, 2003, p. 7), with critical thinking featuring prominently amongst the skills to be promoted. However, while this may be the curriculum's intended aim, this does not ensure the realisation of this ideal. The South African national curriculum, with particular emphasis on the physical science curriculum, is discussed, below. This is done in terms of the intended curriculum, my initial perception of this, and the role of assessment in translating curriculum aims into practice. These set the stage for the discussion, in Chapters Four and Five, of my implementation of the curriculum, in the light of these perceptions, and the consequent modification of these perceptions as a result of the process of action research.

2.1.1. Intended curriculum

The intended curriculum is outlined in the education policy documents. Critical thinking features prominently in these. South Africa's ruling political party, the African National Congress (ANC), in preparation for their election to power, in 1994, stated: "Education shall be based upon the principles of co-operation, critical thinking and civic responsibility" (ANC, 1994, p.4). The following year, the first White Paper on Education under the new regime (DoE, 1995) stated: "The curriculum, teaching methods and textbooks at all levels and in all programmes of education and training, should encourage independent and critical thought" (p.17). It seems that this high regard for critical thinking stems partly from a view that critical thinking in all citizens is necessary to lift South Africans of all types out of the apartheid era (Bester & Pienaar, 2002; Higgs, 2002; Lombard & Grosser, 2004).

This high regard for critical thinking has translated into it being mentioned explicitly and implicitly within South Africa's Further Education and Training National Curriculum Statement (FET NCS) (DoE, 2003a), and the physical science national curriculum (DoE, 2003b). Explicit mention of critical thinking is made in critical outcome 1 of the national curriculum: "identify and solve problems and make decisions using critical and creative thinking", critical outcome 2: "collect, analyse, organise and critically evaluate information" and critical outcome 6: "use science and technology effectively and critically, showing responsibility towards the environment and the health of others" (DoE, 2003, p.8). Inquiry, problem solving, critical communication and evaluation are interpreted as involving critical thinking (Hobden, 2002; Lipman, 1989; Ostlund, 1998; Paul, 1993), therefore the thrusts of the assessment standards (ASs) of the first and third physical science learning outcomes

(LOs), could be interpreted as implicitly referring to critical thinking. These thrusts are: conducting an investigation (LO1AS1), interpreting data to draw conclusions (LO1AS2), solving problems (LO1AS3), communicating and presenting information and scientific arguments (LO1AS4), evaluating knowledge claims and science's inability to stand in isolation from other fields (LO3AS1), evaluating the impact of science on human development (LO3AS2), and evaluating science's impact on the environment and sustainable development (LO3AS3) (DoE, 2003b).

2.1.2. Perceived curriculum

As a physical science teacher, the perception of the curriculum with which I began this study was based partly on the curriculum documents referred to above, partly on the preparatory training sessions I had attended, partly on stipulated assessment requirements, partly on my general pedagogical outlook, and partly on practical pressures in the classroom. In an attempt to tease out some of these complexly intertwined influences to my perceptions, I discuss some of the tensions I experienced in my understanding of what the curriculum required of physical science teachers. These tensions include a process versus product focus to learning, procedural versus conceptual learning, flexible versus rigid syllabus coverage, and traditional versus constructivist pedagogy.

Process versus Product Learning

My experience of South Africa's previous curriculum was that it was very strongly focussed towards the learning of the product of science, rather than its process. The product was generally taught and assessed as an undisputable body of knowledge to be learnt without question. The process of doing science was sometimes touched on, for example when the history of the atom was taught. However, this was generally viewed as an unnecessary waste of science teaching time since sections such as this did not feature prominently in the examination. Further, this was regarded as being history, and therefore not relevant to a learning of science. I interpreted the new curriculum's outcomes as suggesting that process-based teaching should feature more strongly than it did in the past. LO1 refers to investigation, and LO3AS1 to the contested nature of science. Both of these suggest a focus on the planning, implementation and critical evaluation of the process of doing science.

On one hand, it seems reasonable that a process-based approach should contribute towards the promotion of critical thinking. This is because a process-based approach exemplifies the scientists' evaluation of empirical data in the light of assumptions, to lead to inferences which answer questions within a point of view and which have implications. In other words, it exemplifies the elements of critical thought identified by Paul and Elder (2006a). On the other hand, one can ask what caused the processed-based modules designed by the post-war UK and US scientists to fail, to a large extent, on implementation in the classroom (Atkin & Black, 2003), and from this wonder how successful a process-based approach would be in South African classrooms. Further, teaching the product, rather than the process, is easier and quicker to do. It is also highly likely that the kind of assessment required to encourage process-based learning would need higher language skill levels than it is reasonable to assume South African learners are capable of. If this is so, then the kinds of assessment which it may be reasonable to provide in an external examination might suggest that a process-based approach is an unwise usage of limited teaching time in preparation for such an examination.

Procedural versus Conceptual Learning

The old South African curriculum focussed on numerical computation skills, often learnt by rote, or with minimal understanding, and practised through answering multiple routine exercises (Hobden, 2000, 2005). In contrast, conceptual understanding was largely viewed as a desirable, but rarely attained, and minimally assessed, extra. Procedural fluency has a number of aspects to it. This includes drawing of graphs, following lists of instructions, and manipulating equations (Hobden, 2006). The latter has particularly been stressed in the old curriculum (Hobden, 2005), and so is focussed on in this discussion. At the outset of this study, I interpreted the new curriculum as placing more emphasis on conceptual learning than on the manipulation of equations. However, I felt unsure of the exact balance of emphasis which was required between these two. This resulted from a number of factors, discussed below.

The emphasis on equation manipulation, according to the physical science curriculum statement, can be interpreted to be ambiguous. This contributed to my lack of clarity on the balance required between procedural and conceptual foci. To me the curriculum statement seemed to suggest a more drastic de-emphasis of equation manipulation than I considered likely to actually occur in implementation. However, what I viewed as a dishonest interpretation of the curriculum seemed likely to justify a heavier emphasis on equation manipulation than I perceived the curriculum wording actually implied. Naturally, this caused confusion in my perception of how the curriculum should be implemented. The details of this possible ambiguity are outlined below.

In my interpretation, only one of the ten assessment standards for physical science, namely LO1AS3 (DoE, 2003), seems to refer to equation manipulation. For grade 10 this states: “apply given steps in a problem-solving strategy” (p. 20). The grade 12 version seems less obviously related to equation manipulation, stating that learners should be able to “select and use appropriate problem-solving strategies to solve (unseen) problems” (p. 21). This assessment standard forms part of Learning Outcome 1: Investigation, which does not seem to be an appropriate placing for it, since equation manipulation seems to have more to do with knowledge than investigation. Knowledge is the focus of Learning Outcome 2. However, the wording of the assessment standards associated with this outcome seem, to me, to refer only to knowledge recall and to conceptual explanation, not to manipulation of equations. This seemed not, though, to be the conception of a number of physical science teachers and administrators with whom I discussed the issue. Amongst them I perceived a general acceptance that equation manipulation can also be included in LO2AS3. While the grade 10 wording of this AS could still pass as referring to equation manipulation, my understanding of the grade 11 and 12 wording excludes equation manipulation. For grade 10 this AS is stated as: “apply scientific knowledge in familiar, simple contexts," (p. 26). For grades 11 and 12, the wording is: "apply scientific knowledge in every-day life contexts" (p.27). To me this suggested a requirement for using a conceptual understanding to explain phenomena observed in every-day life. It seemed to me to be rather contrived to force equation manipulation into every-day life contexts, particularly the type of equations prescribed in the physical science curriculum. However, I considered it likely that equation manipulation questions would be cloaked in the language of every-day life contexts so that they could be passed as LO2AS3 questions. This suspicion was supported by a number of factors, as discussed below.

The following factors suggested that equation manipulation would be given a more prominent place than my reading of the curriculum suggested it should: the stipulated weightings between the outcomes, inertia to change, and the poor language capabilities of the majority of South African learners. The curriculum statement initially stipulated that equal weightings should be assigned to each of the three LOs (DoE, 2003b). This was modified slightly in later versions (DoE, 2005, 2008) to place more stress on LO2. These weightings suggest that equation manipulation questions cannot feature prominently, as long as one interprets such question as being represented only by LO1AS3. In contrast, allowing such questions to be included as either LO1AS3 or LO2AS3 questions would enable equation manipulation questions to make up high percentages of final external examinations. This seemed, to me, likely to happen. This was partly because it seemed unlikely that a drastic change from the old system which had focused heavily on equation manipulation would occur immediately. Additionally, a strong de-emphasis of equation manipulation seemed unlikely given the fact that the majority of South African learners answer the physical science examinations in a language which is not their home tongue, and so might be disadvantaged by a more language-rich focus.

While these considerations suggested that considerable emphasis should still be placed on developing procedural fluency in learners, other factors tipped the balance of my perception to the side of conceptual focus. Foremost amongst these was my desire to promote critical thinking. Meaningful learning involves higher order, or critical, thinking (Nickerson, 1994; Resnick, 1987).The ability to operate qualitatively with concepts is crucial to critical thinking, and over-emphasis on procedures can short-circuit critical thinking (Paul & Elder, 2006c). Further, the Independent Examinations Board (IEB), under which my school fell, gave the following advice to teachers:

> In their efforts to ensure learners achieve similar results to that in the past, teachers are tempted to drill and practise content to help their learners answer questions typical of past examination question papers based on content. The quantity of subject content knowledge listed in the NCS document makes this approach impossible in the teaching time available. Teachers should therefore rather focus on helping their learners develop the skills and attitudes they need to use their knowledge in new contexts. (IEB, 2007, p.32)

These guidelines suggested that conceptual understanding, rather than procedural drill, should be the focus of instruction. However, practical considerations made me doubt the feasibility of the ideals it expressed. I knew from experience that without drill learners did not develop procedural fluency. And without procedural fluency, the cognitive demands of much problem solving become prohibitive. This is because procedural fluency frees up working memory, enabling learners to engage in more cognitively demanding tasks (Kirschner & Sweller, 2006; Niaz & Logie), such as those involving conceptual engagement and critical thinking. As stated in the extract above, however, the heavy syllabus pressure of the NCS does not allow for a traditional approach of procedural drilling. This is particularly so if conceptual understanding is also strived for. Unfortunately, though, emphasis on conceptual understanding does not ensure transfer of knowledge to new contexts (Bransford, Brown, & Cocking, 2000). This means that it seems wishful to hope that a focus on developing conceptual understanding in learners will translate to them not requiring procedural drilling to prepare them to perform well in numerically focussed questions.

Curriculum ambiguity and limitations imposed by learner abilities and time availability, have been discussed above. These caused me to approach this study with an uncertainty as to the required and feasible balance to be used between procedural and conceptual foci (Stott & Hobden, 2008). The absence of previous examinations to serve as guidance contributed to this lack of clarity concerning how this aspect of the curriculum was meant to be perceived.

Flexible versus rigid syllabus coverage

As in the case of my understanding of the balance required between procedural and conceptual foci, my perception of the degree of flexibility allowed in the implementation of the curriculum, was confused by conflicting messages I received. The South African Revised National Curriculum, which applies to grades R to 9 provides for flexibility by providing only loose guidelines for content requirements, and requiring that 30% of what is taught comes from content not specified by the curriculum (DoE, 2002). Having worked with this part of the national curriculum for the past few years, I assumed that its implementation in the FET phase would, similarly, be open to flexible interpretation. Consistent with this, the physical sciences National Curriculum for the FET phase, similarly, provided only loose stipulation of content (DoE, 2003b). However, the supplement to this document, released in June 2006 (DoE, 2006), removed this flexibility by stipulating exactly what should be taught, providing a schedule so tight that flexibility in content became impossible. In this study, I refer to this curriculum as content-rich, meaning that it requires a large amount of content to be covered in a stipulated time.

This newly perceived curricular inflexibility and content-richness seemed inconsistent with much literature on effective teaching. John Dewey championed the idea that school should be an extension of life so that learning would be relevant to children (Bransford et al., 2000). This suggests that it might be necessary to let learners have a say in what they would like to learn, and that the curriculum should not be so rigid as to prevent teachers following avenues of learner interest or issues of current – possibly local – relevance. Atkin and Black (2003) support this view, arguing that “the less teachers are able to play to their strengths and interests, the less effective they are likely to be with students” (p. 151). Similarly, Prawat (1992) suggests that the curriculum should not be seen “as a course to be run”. Instead it should be thougth of it as “a network of important ideas to be explored” (p. 382). He states that such a conception enhances the likelihood of teachers employing instructional practises consistent with constructivism. These views made me doubt whether I should yield to this perception of rigidity and content-richness in grades not presided over by external examination. On the other hand, the risk associated with such a departure from the stipulations of the curriculum seemed daunting.

Traditional versus constructivist pedagogy

The preparatory training sessions offered to teachers stressed that implementation of the new curriculum required a shift from traditional to constructivist pedagogy. A traditional pedagogy is based on an authoritarian view of teaching (Dirks, 1998). In such a pedagogy, the teacher presents knowledge to the learners, mainly through direct instruction. Learners accept this knowledge with little or no question, and practise it with the aim of mastery. A constructivist view of teaching, on the other hand, emphasises the importance of learners undergoing sense-making activities, by means of which they manipulate concepts, and in so doing construct understanding (Dirks, 1998). Various versions of constructivist pedagogies exist. Social constructivism, such as that propagated by Vygotsky (1978) stresses the importance of learners undergoing sense-making processes within social settings. It was apparent that such a view was adopted by the authorities responsible for the preparatory teacher training sessions I attended. These sessions placed a great deal of emphasis on group work. These moulded my perception of pedagogy relevant to the new curriculum as revolving around sense-making group work, with little direct instruction involved. On the other hand, this conception posed tensions, particularly in the light of the curriculum crowdedness, referred to in previous sections, and assessment pressures, referred to below.

2.1.3. <u>Assessment</u>

Classroom practise is often driven more by external assessment than by policy (Hobden, 1995). This is because teacher effectiveness and learner capability are seen to be indicated by learner performance on external tests. While the validity of this premise is questionable (Atkin & Black, 2003), it is a strong motivating factor for teachers to teach towards the exams. Unfortunately, controlled, time-restricted, high-stakes, externally set examinations are poor settings for testing certain skills, reducing the likelihood that these will be tested, and therefore reducing the likelihood that these will be taught towards (Atkin & Black, 2003). Also, unfortunately, some styles of questioning discriminate against second-language learners, reducing the likelihood that these will be used in testing, therefore reducing the likelihood that the kind of thinking they promote will be taught towards. There seems to me to be a high likelihood that the implication of the issues just discussed might be that some of the curriculum aims, particularly promotion of critical thinking, might not be realised in actual practise. Further, there is the problem that while assessment drives change, it cannot itself change too rapidly without leading to disaster (Atkin & Black, 2003), and hence there is the danger that teachers who interpret the curriculum literally will be disadvantaging their learners by bringing about change within their classrooms ahead of the national external assessment's implementation of change. These considerations were particularly applicable in the FET phase due to the presence of a high-stakes final examination. Further, stipulated categories of assessment tasks to be done in addition to this final examination did limit flexibility to an extent.

2.1.4. Summary

In this section I have described the prominent place the writers of the South African curriculum in general, and the physical science curriculum in particular, intended critical thinking to occupy. I have discussed some of the tensions and influences which affected my perception of how the curriculum should be implemented, and, particularly, how critical thinking should be promoted. I now turn the discussion to an analysis of this central aspect of this study: critical thinking.

2.2. CRITICAL THINKING

In this section I define critical thinking and discuss ways of recognising when it takes place. I explore the value of critical thinking, the need for promoting critical thinking in formal education, and mention its place within the South African national curriculum. I then look briefly at successes and difficulties in attempts to promote critical thinking in educational settings.

2.2.1. Definition

For the purposes of this study, it is necessary to define critical thinking in a way that is consistent with available literature and useful for guiding the recognition of critical thinking's occurrence. A large number of definitions of critical thinking are available. These include "reasonable and reflective thinking that is focused upon deciding what to believe or do" (Ennis, 1992, p. 2); "the art of thinking about your thinking while you are thinking in order to make your thinking better: more clear, more accurate, or more defensible" (Paul, 1995, p. 521), "the disposition to provide evidence in support of one's conclusions and to request evidence from others before accepting their conclusions" (Hudgins & Edelman 1986, p. 333 in Bester & Pienaar, 2002), "the process of determining the authenticity, accuracy and worth of information or knowledge claims" (Beyer 1985, p. 276 in Bester & Pienaar, 2002).

In addition, the term higher order thinking appears to be used occasionally as a synonym of critical thinking (Hobden, 2002), and occasionally as inclusive of critical thinking (Lipman, 1991). In Bloom's taxonomy it refers to analysis, synthesis and evaluation (Bloom, 1956). Resnick (1987), after a literature review on higher order thinking, could not produce a definition. Instead she highlighted particular characteristics such as being non-algorithmic, complex, self-regulated and effortful. A weakness in use of the term higher order thinking is that it implies the incorrect notion that lower level thinking, such as recalling, is less important than higher level thinking (Hobden, 2002), and that learning proceeds sequentially from lower to higher levels (Prawat, 1992; Resnick, 1987).

In the light of the above, higher order thinking is taken as a synonym of critical thinking, but the term critical thinking, rather than higher order thinking, is used. Lipman's definition, "thinking that is reliant on criteria, self correcting, sensitive to context and conducive to judgment" (Lipman, 1989, p. 8) is used, as will be argued for below. However, this definition appears to be incomplete in terms of Bailin's (2002) assertion that the defining characteristic of critical thinking is its normative dimension. Lipman's definition seems to lack a normative dimension for deciding whether the criteria relied on should be acceptable as critical or not. Similarly, for judgement to be classed as critical judgement, it seems necessary to add some normative dimension to Lipman's definition.

To mitigate this shortcoming, as well as to inform a richer understanding of critical thinking, I approached this study with a cognisance of characteristics of critical thinking as described by other authors. These are, particularly, the characteristics listed by Resnick (1987), and the intellectual standards and criteria for critical judgement, given by Paul (1993). I used the latter to guide decisions about whether the criteria used during thinking should be considered to be critical or not. According to this, the criteria which were considered acceptable are borrowed from Paul's (1993) intellectual standards, namely relevance, consistency, accuracy, precision, fairness, logic, depth, breadth and significance. Similarly, judgement which were considered acceptable had to be objective and substantiated by reasons which consider both merits and faults (Paul & Elder, 2001).

This expounded version of Lipman's definition incorporates aspects of metacognition, action, and appeal to criteria, which are common to many of the definitions available, and suggests a concise, normative framework for analysing whether thinking is critical. For these reasons, it was chosen to guide recognition of whether the thinking observed was critical.

2.2.2. <u>Promotion</u>

Value

The high premium placed on critical thinking by the curriculum writers has already been discussed. Further, it is commonly accepted that the ability to think critically is a valuable skill in an educated person. Critical thinking is viewed as necessary for developing flexibility in people, enabling them to cope with the modern demands of a changing workplace, face every-day problems competently, preserve a democratic way of life, make rational and moral choices, and reach their full potential as human beings (Cotton, 2001; Mc Carthy, 1992; Nickerson, 1994). Resnick (1987) and Paul & Elder (2001) equate successful learning with the use of critical thinking.

While the development of critical thinking has always been the aim of the education of the elite, today it is generally regarded as a desired outcome of mass education (Nosich, 2005; Resnick, 1987). Within the context of science education, critical thinking has moved into the spotlight with calls for inquiry-learning, which requires learners to be more active and critical in their evaluation of scientific phenomena (Lipman, 1991; Mc Dermott, 1993; Ostlund, 1998; Yore, 2001). This is coupled with the current drive towards an emphasis on the contested nature of science, which requires learners and teachers to engage in critical thinking (Yore, 2001). In contrast, science has traditionally been taught as a “logically bound and internally coherent body of knowledge which the learner has to receive with no possibility of compromise or negotiation” (Watts & Bentley, 1984, p. 309), Under such a pedagogical regime, it would be expected that critical thinking would not have been as desirable a trait in learners as is the case with current views of science learning. Finally, the rationale for an emphasis on critical thinking includes the development of thinking skills believed to be transferable to everyday life, improving the relevance of scientific instruction beyond that of knowledge acquisition (Williams, Papierno, Makel, & Ceci, 2004).

Need

Despite the value of critical thinking, previously referred to, researchers generally find low levels of critical thinking and little understanding of what is meant by the term, amongst children as well as adults. This applies to international research (e.g. DeMolli, 1997; Fraker, 1995), as well as South African findings. Kaminsky (2004) found low levels of understanding and use of critical thinking amongst grade seven learners, their parents and teachers. Ankiewicz et al. (2001), in a case study of technology teaching in a South African class, found little critical thinking happening. Mashike (2000) observed limited ability to interpret results, draw valid conclusions, and evaluate arguments, and an inability to identify assumptions and select pertinent information, among grade 11 physical science learners in a school in Soweto. Neither is this problem confined to an inability of school learners to undergo critical thinking. Lombard & Grosser (2004) found very low levels of critical thinking skills among prospective South African teachers, Madolo (1998) found the same amongst South African nursing students, and van den Berg (2000) among South African university students.

In addition to the evident lack of critical thinking skills in the South African population, there is also evidence that teachers do not know how to remedy this situation by promoting critical thinking in the classroom. Msimanga & Lelliot (2008) found that while learners were overheard to expect their peers to support claims in casual conversation outside the classroom, discussions within the classroom were devoid of critical argument, with teachers seeming unsure how to alter their approach to allow for this. Similarly, Jina & Brodie (2008), in a case study of a grade 10 mathematics teacher’s use of questions, found that the teacher had difficulty in altering his style of instruction to include questions which would promote critical thinking. The fact that so little is known about critical thinking and its promotion, despite the high value placed on critical thinking, suggests that intervention strategies for the promotion of critical thinking are necessary, as well as strategies to overcome obstacles to their effectiveness.

Obstacles

Researchers have exposed a number of obstacles to attempts to promote critical thinking. These include student and teacher attitudes, lack of relevant resources, pressure from curriculum schedules and assessment requirements, workload, and an inappropriate atmosphere (Barak, 2004). Ankiewicz et al. (2001) explained the low levels of critical thinking they observed in South African technology classrooms in terms of difficulties of the multiple languages present in the

South African classroom, poor correlation between learners' language abilities and language used in the tasks, low question wait-times, closed-ended questioning, poorly defined task instructions, and a misconception that the teacher should take on a passive role during group work. Other South African research confirms these problems. Mashike (2000) refers to negative attitudes to thinking, as well as language barriers, as obstacles to critical thinking amongst physical science learners. Language is mentioned as a limiting factor by Scholtz, Hodges, Koopman & Braund (2006) in their study of the training of teachers to engage in argumentation. Further problems include prominence of closed-ended, mainly recall, tasks in our classrooms (Jina & Brodie, 2008; Msimanga & Lelliot, 2008; Pudi, 1999), lack of resources (du Preez, 1998) and lack of use and understanding of critical thinking by parents and teachers (Kaminsky, 2004).

Other obstacles include the difficulty associated with a change in existing practice and perceptions. This includes difficulties teachers experience in changing their instructional methods, partly due to overload (Stoffels, 2005a) and partly due to the lack of clarity of how this is meant to be done (Harrenkhol & Guerra, 1998; van Rooyen & de Beer, 2006). Pudi (1999) found that the common practise of use of models and recipe-style assembly instructions stifled critical thinking in technology classes. Existing cultural practice and perceptions also serve as barriers to critical thinking promotion. These include the traditional perception of the role of external authority and the value of consensus, in general, in African cultures (Tabulawa, 1997). Additionally, the traditional understanding of education as delivering correct answers, rather than justifying choices and posing alternative views (Scholtz, Sadeck, Hodges, Lubben, & Braund, 2006; Scholtz, Watson, & Amosun, 2005), also poses an obstacle to the promotion of critical thinking in a South African classroom.

Finally, research indicates that the promotion of critical thinking is neither an easy nor a short-term endeavour. Lubben, Scholtz & Fish (2008) reported that minimal exposure to an argument framework did not translate to spontaneous use of this to enhance critical thinking, suggesting that the promotion of the required skills takes time and persistence. Further, Molefe (2008), in a case study of a learner who produced a silver-medal-winning project for the national Expo for Young Scientists, showed that the learner was not able to demonstrate critical thinking despite engagement in this quality level of inquiry, further suggesting that critical thinking is difficult to promote. This can be seen as an obstacle to critical thinking promotion if disillusionment results when interventions do not reveal rapid and easily obtainable results. Aware of the obstacles discussed in this section, I approached the study fully expectant of a long term struggle ahead. Balancing this, however, was an optimism that promotion of critical thinking is possible. This hope was supported by successes cited in literature, as discussed below.

Successes

Gains in critical thinking in response to intervention programs include reports from international sources (Barak, 2004; Barak & Doppelt, 1999; Jimenez-Aleixandre, Rodrigues, & Duschl, 2000; Milton, 1993; Williams et al., 2004; Zohar & Nemet, 2002), as well as a number from South African researchers. Du Preez (1998) reported a significant increase in Biology teachers' use of strategies aimed at promoting higher order thinking after receiving in-service training focusing on these strategies. Kaminsky (2004), Madolo (1998) and Maskhike (2000) each reported a rise in critical thinking or, at least, attitudes towards critical thinking, following short-term intervention programs amongst primary school, tertiary nursing, and high school physical science, students, respectively. Further, Scholtz et al. (2006), Scholtz, Hodges et al. (2006) and Lubben et al. (2008), reported some evidence of improvement made by grade 10 learners, teachers, and university students, respectively, in argumentation quality in response to intervention strategies. Such findings encourage the pursuit of an understanding of how to promote critical thinking, since they suggest that this will not be in vain. This shows the need for an examination of the existing body of literature on strategies for promotion of critical thinking, given below.

Strategies

When discussed in the literature, the concept of critical thinking is often decomposed into a number of components to aid understanding. The following components are often referred to in the literature: knowledge, skills, procedures, heuristics, dispositions and criteria. However, critical thinking is more than the sum of its parts (Lipman, 1991; Nickerson, 1994). For this reason, although some authorities promote the teaching of critical thinking through teaching its components (Barak & Doppelt, 1999; Hindes & Bakker, 2004; Milton, 1993) others think that this kind of teaching is of very limited value, and instead critical thinking should be improved by learners being given numerous opportunities to think critically (Smith, 1992, cited in Kaminsky, 2004; Lipman, 1991).

One consequence of decomposing critical thinking into its constituent parts is that a large number of programs have been developed focussing on each of these components (Cotton, 2001). Some of these focus on the skills and procedures of critical thinking. De Bono (1985 in Milton, 1993), the developer of one of these programs (CoRT) states that it is necessary “to unscramble thinking so that a thinker is able to use one thinking mode at a time - instead of trying to do everything at once” (p. 199). A number of developers of critical thinking programs similarly argue that decomposing critical thinking into enabling skills makes its teaching more tangible (Hindes & Bakker, 2004; Lee, 2003). Furthermore, these programs generally claim success (Cotton, 2001; Milton, 1993), although the authenticity of these claims, particularly with respect to transfer to other contexts, may be questioned (Resnick, 1987).

Heuristics are another of the components of critical thinking which some programs focus on. These are “guides to discovery and learning and rules of thumb that help learners proceed along empirical lines to find solutions or answers” (Lee, 2003, p. 1). A large number of heuristics, such as means-ends-analysis, sub-goaling, considering extreme cases, thinking of counterexamples, chunking, summarising, predicting, questioning, etc. (Nickerson, 1994; Perkins & Salomon, 1989) have been identified and taught. Unlike algorithms, heuristics do not guarantee that the desired solution will be reached if applied correctly. Algorithms are rules specific to the domain, whereas heuristics are generally applicable tools. According to Resnick (1987), algorithmic thinking is not critical thinking. On the other hand, heuristics are important components of critical thinking (Bailin, 2002).

Finally, criteria and dispositions, also named as components of critical thinking, are the focus of other programs. Bailin (2002), argues for this, saying that it is critical thinking's normative dimension which differentiates it from other thinking, and therefore is at its core. Further, she argues that teaching for skills and procedures is problematic given the unobservable nature of skills and the fact that following procedures does not ensure critical thinking. Paul (1993) seems to place a similar stress on the criteria and dispositions of critical thinking. He calls the criteria against which thinking which is critical assesses itself, intellectual standards, and lists these (Paul & Elder, 2006d). Additionally, he provides a list of what he terms affective dimensions or intellectual traits. These seem to correspond with Bailin's term dispositions.

2.2.3. Summary

While the variety of definitions of critical thinking available inform the rich understanding of the term in this study, for the sake of brevity the definition "thinking that is reliant on criteria, self correcting, sensitive to context and conducive to judgment" (Lipman, 1989, p. 8) will be used. Further, I view the elements of thought and intellectual standards referred to by Paul and Elder (2006a) as particularly useful in identifying critical thinking in action. The discussion given in this section shows the value of and need for a study such as this one. Evidence for this includes the high regard for critical thinking shown by the ANC and Department of Education (DoE), coupled with the obvious need by South Africans for clarity on what critical thinking is and how it can be taught and assessed. This lack of clarity is a natural consequence of a lack of definitive research and empirically tested exemplars to guide South African physical science teachers and text-book writers on what critical thinking tasks should look like within the new curriculum. Further, evidence that critical thinking can be promoted by educational intervention suggests that this study will not be in vain in its quest to undertake the required research and produce much needed empirically tested exemplars.

One of the benefits of critical thinking is the role it plays in effective learning. Since this study sought to understand instructional practise which promotes critical thinking, and therefore effective learning, it was important to begin the research with a clear understanding of theories of learning. I now turn to an examination of such theories, with an emphasis on effective learning.

2.3. LEARNING

In this section I discuss the three theories I find particularly useful in understanding learning. These are the Information Processing Model of Learning (IPM), Conceptual Change Theory (CCT), and Vygotsky's theory of the Zone of Proximal Development (ZPD). After this, I examine what is generally meant by effective learning in the light of these learning theories and through the lens of Schoenfeld's framework for analysis of problem solving (Schoenfeld, 1985). I then point out some obstacles to effective learning.

2.3.1. Theories of learning

Drawing from Cognitive Psychology, I find the Information Processing Model of Learning (IPM) (Gagné, 1985; Glynn, Duit, & Britton, 1995; Mayer, 1988) useful in its explanation of cognitive load as the limitation offered by working memory. Its weaknesses include its potential for suggesting that information can be absorbed, and its inability to explain the value of meaning negotiation within social contexts. I turn to Constructivism, particularly to Conceptual Change Theory (CCT) (Dykstra, Boyle, & Monach, 1992; Hewson, 1996; Hewson & Lemberger, 2001) and to Vygotsky's theory of the Zone of Proximal Development (ZPD) (Vygotsky, 1978) to better understand these areas. Taking a pragmatic approach, I do not find it inconsistent to use both the objectivist IP model and the constructivist conceptual model and concept of the ZPD to aid my understanding of learning. As a pragmatist, I consider it appropriate to utilise those theories which are most helpful in reaching an understanding within the particular context of this study (Cresswell, 2003).

The Information Processing Model of Learning

I regard the IPM's main value to be the attention it draws to the role of the short term memory's limited capacity in learning. Figure 2.1, below, taken from Mayer (1988), summarises the IPM. It provides us with a warning that as teachers we cannot provide a large amount of information or complex problems to learners without providing some support to minimise the load on the working memory. According to this model, some of the information presented to a person's extremely short sensory memory (SM) is selected by attention being paid to it, and this is passed on to the short term memory (STM) where it is lost after a short time if not rehearsed or linked. During rehearsal, links are formed within the components of this new knowledge. While the new knowledge is in the STM, pre-existing knowledge may be accessed from the long term memory (LTM) and, during a process of comparison and evaluation, transformations may occur either in the new knowledge, or the pre-existing knowledge, or both. Links between the new and prior knowledge are formed. The new knowledge may then be stored in the LTM within a knowledge schema. This may be accessed and brought into the STM for output at a later stage.

The capacity of the STM (also called working memory), is considered by many authors to be the limiting factor in learning (Kirschner & Sweller, 2006; Niaz & Logie, 1993). James Clerk Maxwell recognised its importance in the 19th century: "I quite admit that mental energy is limited … and efforts of attention would be much less fatiguing if the disturbing force of mental distraction could be removed" (reprinted in Niaz and Logie, 1993, p. 511).

Viewers of this model might consider that the information processing it describes is automatic, suggesting that learning can occur by transfer. However, I view this interpretation as erroneous. Instead, processing of information involves effortful thinking by the learner as meaning is constructed. This process of knowledge construction is more clearly highlighted in the next model to which I turn. This model, called Conceptual Change Theory, can leave readers with no doubt that information transfer is a fallacy.

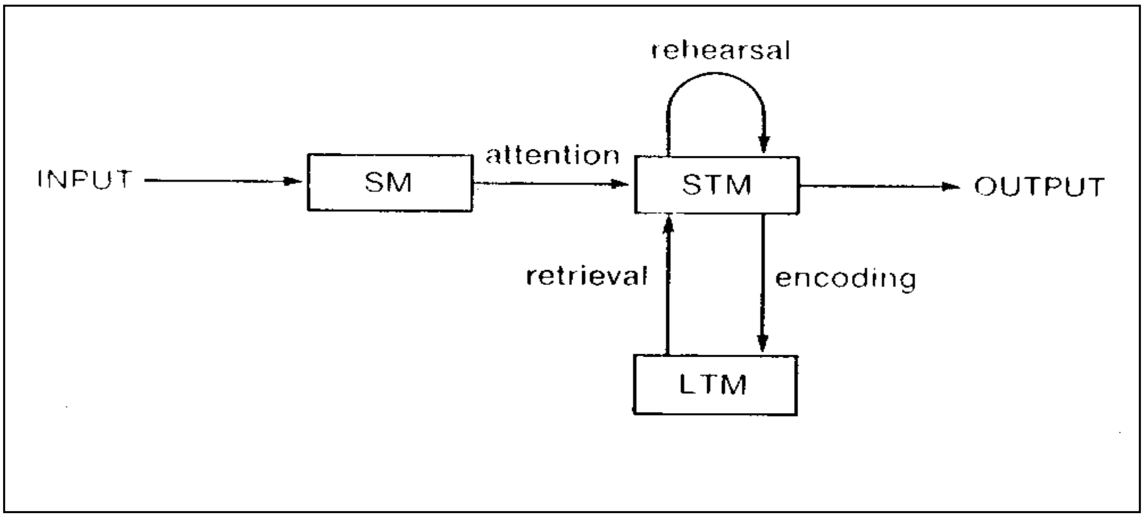

Figure 2.1: Schematic representation of the human information processing system. (From Mayer, 1988, p. 15)

Conceptual Change Theory

While the IPM is useful for understanding cognitive overload, it is less helpful in understanding the need for the conceptual-manipulation process of sense-making during learning. For this I turn to Conceptual Change Theory (CCT). CCT is based on the assumption that individuals construct their knowledge as a result of personal choices they make, and is therefore constructivistic in nature (Kramer, 1999). As referred to in Chapter One, a variety of understandings of constructivism exist. Common to all is a view of learning as a process of knowledge construction from perceptions arrived at through interpretation of information using existing knowledge and sense-making strategies (Cobern, 1995; Wheatley, 1995). As can be seen by the description given in the quote, below, learning is therefore seen to be an active process on the part of learners, with prior learning playing a significant role in learning:

> A constructivist view of learning perceives students as active learners who come to science lessons already holding ideas about natural phenomena, which they use to make sense of everyday experiences. Learning science, therefore, involves students in not only adopting new ideas, but also in modifying or abandoning their pre-existing ones. Such a process is one in which learners actively make sense of the world by constructing meanings. (Scott, cited in Moodley, 2000, p. 15)

CCT suggests how knowledge is constructed and what influences a learner's choices during this construction (Hewson & Lemberger, 2001). Piaget's terms assimilation and accommodation are often used in describing conceptual change (Dykstra et al., 1992). These correspond to Hewson's (1996) terms conceptual enlargement and conceptual exchange respectively. In order to explain learners' possession of multiple versions of a concept, each of which is resorted to under specific contextual conditions, conceptual status is referred to. This is determined by the individual's perception of the intelligibility, plausibility and fruitfulness of the concept within a specific context (Hewson and Lemberger, 2001). Learners assign a status to each of a set of competing concepts for each of a variety of contexts in which the concept might be used. This is done as a result of an evaluation of the concepts against the criteria mentioned. While CCT helps us to understand the mental processes which occur during learning, it does not emphasise the value of social contributions to learning. For this I turn to Vygotsky's Theory of the ZPD.

Vygotsky's Theory of the Zone of Proximal Development

One of the aspects of this study was to consider how much help learners need when performing critical thinking tasks. Vygotsky's Zone of Proximal Development (ZPD) provides a useful way of describing the mentoring and scaffolding provided by the teacher and more advanced peers. The ZPD is defined as the distance between what the learner would be able to achieve on their own, and what they can do with guidance and support from mentors (Bransford et al., 2000; Vygotsky 1978). Learning is optimal when a learner is operating in their ZPD during situated learning, with their learning scaffolded by mentors (Slavin, 2000) until the learner is able to self-direct their learning (Schunk, 1990). Situated learning means learning that occurs while performing real-life authentic tasks (Alvarez et al., 2000; Anderson & Roth, 1989; Brown et al., 1989). Instructional scaffolding refers to strategies to support a learner while they extend their learning into their ZPD, thus permitting them to perform tasks which would otherwise not be possible (Scunk, 2000). As the learner extends their knowledge and skills, their ZPD shifts.

2.3.2. Effective learning

CCT, IPM and the ZPD are useful in helping to understand how people learn, as well as, to an extent, how they should learn in order for this learning to be effective. To shed further light on the latter, it is first necessary to explore what is meant by effective learning, and then examine its components. I find Schoenfeld’s framework for analysis of problem solving (Schoenfeld, 1985) particularly valuable in doing the latter.

What is effective learning?

It appears to me that the terms learning for understanding, quality learning, effective learning and meaningful learning all refer to learning which involves a two-way evaluation process between new and prior knowledge, resulting in modification of either or both of these and integration of the new information into a conceptual schema, thus making the knowledge usable (Gerace, 1992; Hauslein & Smith, 1995; Kilpatrick, Swaffod, & Findell, 2001; Larkin, 1985; Novak & Gowin, 1984; Stanton, 1990; Stevenson & Palmer, 1994; Willis, 1993). In other words, learning for understanding involves conceptual change. Willis (1993) cites Bowden’s statement that quality learning is about:

> searching for meaning, developing understanding and relating that understanding to the world around. As a consequence, the world is seen differently and student conceptions have undergone change. Quality learning is about conceptual change - seeing the world differently is an essential outcome. (Bowden, cited in Willis, 1993, p. 391)

According to Hewson and Lemberger (2001) “Coming to a deep understanding of a conception ... means grappling with the conditions of intelligibility, plausibility and fruitfulness that define a conception's status." (p. 123). The word grappling suggests an active, effortful process. This could suggest critical thinking, given the effortful nature of such thought (Resnick, 1987). More specifically, the act of making a decision about the need for conceptual change by evaluating an existing concept's characteristics against criteria of intelligibility, plausibility and fruitfulness, is consistent with Lipman's (1991) definition of critical thinking relying on criteria to guide judgement. The view of effective learning, taken by Ertmer & Newby (1996), further encourages a view that critical thinking is an integral component of effective learning. According to this, reflection serves as a link between metacognitive knowledge and self-regulated learning, and so is the key to effective learning. Reflection is an important component of critical thinking since it allows for self-correction, part of Lipman's definition of critical thinking (Lipman, 1991). Therefore critical thought is clearly central to effective learning. However, as Schuster (1992) puts it, "There is a fascinating complexity to thinking, a mixture of chaos and coherence, knowledge and intuition" (p. 160). Consequently, some approach is needed for dissection and analysis of effective thought, and thus effective learning. I have chosen to borrow Schoenfeld's Framework, for this purpose.

Schoenfeld's Framework

Woods (1988) equates problem solving strategies with learning strategies due to their mutual employment of critical thinking to make sense of unknown situations, and Lavoie (1995) and Wheatley (1995) refer to learning as a problem solving activity. Consequently, I consider it reasonable to analyse learning using a framework for understanding problem solving behaviour and have chosen to structure my discussion on effective learning using Schoenfeld's Framework. According to this, problem solving behaviour is determined by the individual's resources, heuristics, control and belief system.

Resources. Mental resources refer to the availability and organisation of knowledge, and of the skills needed to utilise this in a meaningful way. The value of the presence and organisation of resources is highlighted by a study of the difference in performance of expert and novice problem solvers. This difference lies in the nature, structure and utilisation of their stored knowledge. Experts have extensive and highly organised knowledge structures which they draw heavily on during qualitative analysis of problem situations (Bransford et al., 2000; Gerace, 1992; Hauslein & Smith, 1995; Leonard, Dufresne, & Mestre, 1996; Snyder, 2000; Willson, 1995). The relationships between, and organisation of, elements are seen as particularly important, with experts showing a high degree of clustering and linking around big ideas, and hierarchical activation of knowledge. Gick and Holyoak, and Hasselhorn and Korkel, cited in Lipman (1991), suggest that the majority of school children and undergraduate students generally fail to deliberately use prior knowledge when confronted with a new situation. This suggests the importance of not only possessing appropriate prior conceptual and procedural knowledge, but also owning and using strategies necessary for utilisation of this knowledge. Stevenson and Palmer (1994) and Willis (1993) maintain that learning for understanding generates intrinsic motivation because new knowledge becomes meaningfully integrated into cognitive schemas, providing a satisfaction which the fragmentary storage involved in rote learning does not. This suggests that the extent to which prior knowledge can be used affects the belief system of the learner. This discussion shows that it is generally accepted that resources are vital in learning, the mental organisation of these resources affect their usefulness, and their usefulness is further affected by and affects the other components of learning.

Heuristics, Learning strategies. Schoenfeld (1985) classifies automated strategies as resources and those which require conscious thought as heuristics. This shows correspondence with Garner’s (1988) definition of learning strategies as sequences of activities, largely under the deliberate, conscious control of the learner, which are selected from alternative activities in order to attain a learning goal. Research shows that knowledge of and ability to use a strategy is insufficient to ensure that it will be applied where appropriate. Chi (1985) found that there is a complex interaction between the use of a strategy and the amount and structure of the content knowledge (resources) to which the strategy is to be applied. Reynolds and Shirey

(1988) and Schoenfeld (1985) highlight the importance of metacognitive strategies (control), while Palmer and Goetz (1988) point to the importance of motivation (belief system) in selection and use of appropriate learning strategies. This discussion shows that learning strategies are very important for effective learning, but they are insufficient on their own due to their interaction with the other components of learning.

Control. By control, Schoenfeld (1985) refers to self-regulation of activity through selection and implementation of resources and strategies. It involves planning, monitoring and assessment, decision-making and conscious metacognitive acts. In reference to the important role control plays in problem solving, Schoenfeld states: "The issue for students is often not how efficiently they will use the relevant resources potentially at their disposal. It is whether they will allow themselves access to those resources at all" (p. 13). Resnick (1987), referring to the need for control in learning, says "many individuals primarily lack good judgment regarding when strategies should be applied" (p. 26).

In reference to the components of an ability to control learning, McCombs (1988), identifies metacognitive skills as being important: "The self-controlled and self-motivated learner is one who can plan, regulate, and evaluate his or her own skills and strategies" (p.142). A number of authors (e.g. Forrest-Pressley and Gillies, cited in Garner, 1988; Lipman, 1991; Stevenson and Palmer, 1994, Williams et al. 2004) refer to the importance of metacognition in learning. Bandura and Schunk, cited in McCombs (1988) assert that the metacognitive act of self-evaluation against internal standards allows learners to create self-incentives which, when fulfilled, result in satisfaction, which causes interest and an enhancement in self-efficacy. As already mentioned, common to the various definitions of critical thinking is allusion to metacognition. This partially explains critical thinking's central role in effective learning.

Thomas, cited in McCombs (1988), relates control in learning to the learner's beliefs about learning:

> It seems reasonable to assert that the spontaneous use of learning strategies is a matter of disposition: the disposition to perceive a learning task as controllable, to feel responsible for the outcome, and to search actively for ideas for solving the problem posed by the task. (p. 144)

Carver and Schuer, cited in Butler & Winne (1995), also refer to the interaction between the control learners exert in their learning and their beliefs about learning, saying that self-regulated learning occurs when learners stumble on obstacles which they consider themselves able to surmount. Moodley (2000) says self-regulated learning occurs when a learner escapes from the pedagogical cycle propelled by extrinsic motivation from the teacher, to undergo learning propelled by the learner's intrinsic motivation.

It appears to me that the views given above are all embedded in self efficacy theory, which has to do with learners' beliefs about their abilities relative to task demands (McCombs, 1988; Moodley, 2000; Palmer and Goertz, 1988). I conclude, therefore, that the control learners exert on their learning determines strategy and resource usage and is significantly influenced by their belief systems, to which I now turn.

Belief system. Schoenfeld (1985) defines a learner's belief system as "the set of (not necessarily conscious) determinants of an individual's behaviour" (p. 15). He states that "problem-solving performance is not simply the product of what the students know; it is also a function of their perceptions of that knowledge, derived from their experiences" (p. 14). In other words, it is a function of their belief systems. Figure 2.2, taken from Moodley (2000), illustrates a relationship between learning performance and learner perceptions, showing the amount of invested mental effort (AIME) learners are prepared to allocate to learning as being optimal when their perceived self efficacy (PSE) or the perceived task demand characteristics (PDC) is neither low nor high. In other words, when learners perceive their capabilities (self efficacy) either to be high or low in relation to the demand of the task, then they will expend less mental effort in the task than if they perceive it to be challenging but within the range of their capabilities. This corresponds to Vygotsky's theory that optimal learning occurs in the individual learner’s ZPD (Lee and Smagorinsky, 2000). Learners’ perceptions of relevance and interest in the material to be learnt determine the perceived value of the learning outcome, an additional factor affecting the amount of mental energy they are prepared to invest in learning (Moodley, 2000).

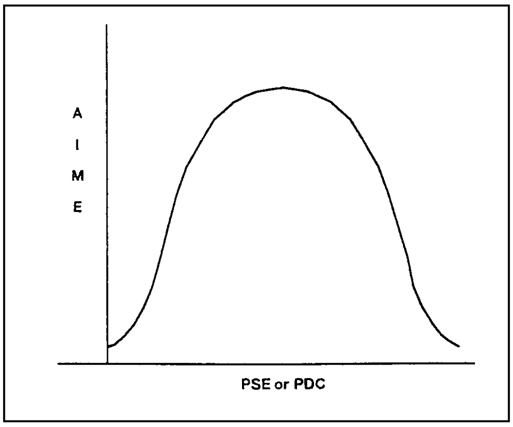

Figure 2.2: Relationship between AIME and PSE or PDC.

(From Moodley, 2000, p.21)

The discussion so far has explained the values of intrinsic and extrinsic motivation in learning in terms of self efficacy theory. Another way of looking at this is that motivation increases the size of the functional mental capacity, which is the portion of the working memory which is utilised (Pascual-Leone, cited in Niaz and Logie, 1993). According to this model, highly motivated learners are able to learn more effectively than less motivated learners because of the greater space motivation makes available for use in the short-term memory.

Various authors stress the role of belief systems on learning and the learning experience on belief systems. Paul & Elder’s reference to *essential intellectual traits* describe a belief system which encourages critical thought, and therefore effective learning (2006d). These traits are confidence in reason, fair-mindedness and intellectual humility, courage, empathy, autonomy, integrity and perseverance. Bailin (2002) refers to a commitment to rational inquiry, listing respect for reasons, an inquiring attitude, open-mindedness and fair-mindedness as examples. She takes the view that teaching of critical thinking should focus on cultivation of the intellectual resources relevant to the particular subject domain, which includes an understanding of the relevant criteria and a disposition to use them. Finally, Dewey points out the influence of educational experiences on learners' belief systems. He emphasises that the learning of a belief system, rather than the content learning through which this is brought across, is often the aspect which most profoundly impacts future learning.

> Perhaps the greatest of all pedagogical fallacies is the notion that a person learns only the particular thing he is studying at the time. Collateral learning in the way of formation of enduring attitudes, of likes and dislikes, may be and often is much more important than the spelling lesson or lesson in geography or history that is learned. For these attitudes are fundamentally what count in the future. The most important attitude that can be formed is that of desire to go on learning. (Dewey, 1938, p. 49 in Carver & Enfield, 2006)

In summary, the learner's belief system is a vital component of learning in that it determines the extent and direction of learning. Further, the nature of educational experiences can influence a learner's belief system. Approaching this research, I expected the planned educational experiences to affect and be affected by learners' belief systems both in their abilities, i.e. self-efficacy (Palmer & Goetz, 1988), and in criteria they consider worthy of evaluating information against, i.e. dispositions (Bailin, 2002). The role of self-efficacy is viewed as particularly important here since critical thinking is expected to be effortful (Resnick, 1981). It seemed likely to me that this requirement of effort should challenge learners' beliefs in their abilities. The role of dispositions towards criteria against which claims should be evaluated, and whether it should be evaluated at all, is viewed as important in directing conceptual choices (Hewson & Lemberger, 2001), and in determining whether they will engage in critical thinking, and if so to what extent and in which contexts this will occur (Bailin, 2002). Additionally, it seemed likely that learners' performance in these tasks should affect their future beliefs about their abilities to think critically, their dispositions towards thinking, and the value of critical thinking in their lives. These aspects were born in mind during the implementation and reflection stages of this study.

Obstacles to effective learning

Having discussed what I understand by effectiveness in learning, above, I now turn to a few obstacles which hinder learning, particularly scientifically sound learning of physical science. I look at the fallacies of knowledge absorption and of conceptual learning through inductive practical discovery, and at gaps in communication. A constructivist view of learning rejects the notion of absorption of information from observations, since observations must be converted to perceptions through interpretation (Cobern, 1995), which is done using prior knowledge, expectation, and imagination (Driver, 1983). As Einstein and Infeld stated:

> Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions. (Einstein and Infeld, cited in Driver, 1983, p. 3)

Driver calls conceptual learning of science through inductive practical discovery “a fallacy” (p. 3). Similarly, Lock (1990) calls for increased teacher control during data interpretation if conceptual understanding is to be the focus of instruction. A consequence of this is that in order for learners to be directed to view observations in the way scientists do, communication is important in learning. However, communication has very real limitations. Figure 2.3, developed by Moodley (2000), is useful for understanding these limitations as well as the role of dialogue in reducing these. It illustrates that the teacher’s instruction lights up certain conceptions in the teacher’s mind and certain conceptions in the learner’s mind. However, only a few of these overlap and therefore meaning is shared only to an extent. The degree by which understanding is not shared describes the degree by which teacher and learner are divided. This can be called the pedagogical gap. This gap can be narrowed by the learner and teacher undergoing a dialogue. The existence and significance of this pedagogical gap explains and is explained by the persistence of students’ intuitive beliefs and the frequent alteration of their conceptions in directions unintended by instruction (Gauld, 1989). This is particularly the case in a traditional classroom where transmission-style lecturing is the sole means of instruction (Leonard, Gerace, & Dufresne, 2002).

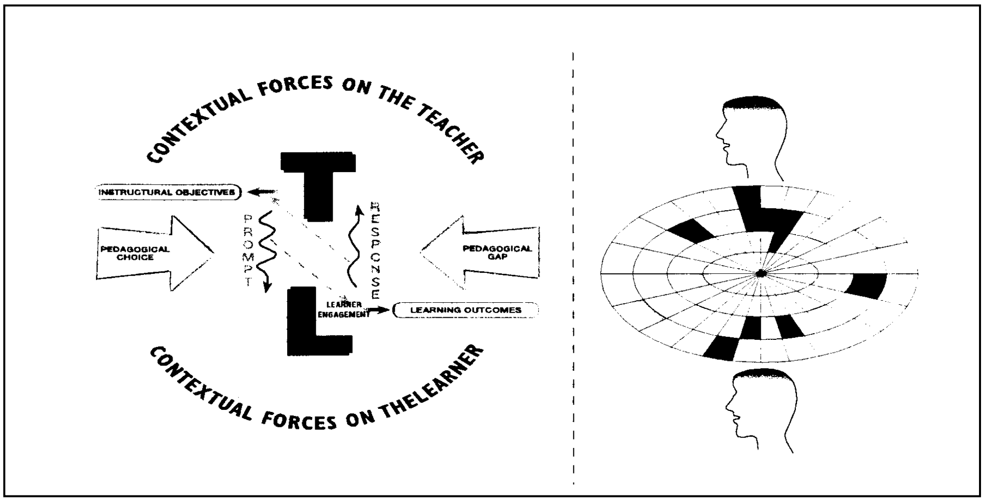

Figure 2.3: Diagrammatic representation of teacher-learner dialogue and the pedagogical gap.
(From Moodley, 2000, p.12)

2.3.3. <u>Summary</u>

I view learning as a process in which knowledge is constructed through the formation of perceptions resulting from the learner's interpretation of information. I consider three factors to be particularly influential in affecting learning outcome, as given by CCT, the IPM and the ZPD respectively. First, learning quality is affected by the effectiveness with which the limited capacity of working memory can be managed. Second, the quality of learners' conceptual learning of science will affect learners' ability to make scientifically sound judgements with regards to a concept's status. Third, learning quality will be affected by whether learners are allowed to operate within their ZPD, and whether appropriate scaffolding is provided until such time as they are able to self-direct their learning.

I view effective learning of physical science to be that which results in possession of a deep understanding. This is brought about by use of resources and learning strategies as learners exert productive control over their learning because of the interest and motivation which arise from a positive belief system towards physical science learning. Effective learning is hindered by the existence of gaps in communication. Communication is a necessary component of learning, given the limited scientifically sound learning that occurs from children's individual practical discovery and the inability of learners to absorb information passively. The understanding of learning, arrived at above, informs conceptions of effective teaching. I turn to this next.

2.4. TEACHING

While the primary objective of teaching is obviously to promote effective learning, how this is to be done is not at all obvious. Neither is it obvious how to promote critical thinking. A myriad of practical decisions have to be taken daily by practitioners as they design and implement tasks and manage classes. Each of these has the potential to promote or inhibit learning in general, and critical thinking in particular, as well as having many other consequences, such as propelling learning through the syllabus at the rate stipulated by the state, engaging learners' interest, including learners of a range of abilities in learning, or failing to do any or all of these. A variety of factors guide practitioners as they make these decisions. One of these is their perception of the curriculum within which they operate. This has already been discussed. Another factor is their perception of what effective teaching entails. I begin this discussion with a look at this, after which I turn to a brief discussion about models and strategies of instruction potentially relevant to attaining this in this particular study. I end with what is known about teaching for the promotion of critical thinking.

2.4.1. Effective teaching

In this section I examine traits of effective classrooms. This serves as a prelude to the discussion on models and strategies of instruction aimed at achieving these traits. These traits are taken from Bransford et al. (2000), who state that an effective classroom should be learner, knowledge, assessment and community centred.

Learner-centred instruction means instruction which is informed by an understanding of the knowledge, skills and attitudes which learners bring to the classroom (Bransford et al., 2000). Unless instruction is sensitive to this, learning is unlikely to be effective. According to conceptual change theory (Hewson & Lemberger, 2001), unless learners realise the need to alter their preconceptions about what is taught in a classroom, they will simply add new conceptions to their existing ones. In contexts which clearly require use of the concept taught in the classroom, learners will use these in the form learnt in the classroom, but in any other context they will revert to the more deeply held conception with which they entered the classroom. Learner-centred instruction recognises this, and so seeks to activate prior knowledge, build on it where appropriate, and challenge it where it is incorrect.

Another aspect of a learner-centred classroom is that the teacher is sensitive to the fact that learners come to the classroom with a variety of skills. The teacher’s response to this variety in learners affects classroom climate, which affects motivation (Pintrich & Schunk, 2002). In a learner-centred environment, the teacher is sensitive to cultural differences related to class participation, and to self-image with regards learning aptitude (Bransford et al., 2000). This can affect learners’ attitude towards intelligence, which, research shows, affects learning effectiveness. Those learners who view intelligence as malleable are more likely to be prepared to struggle with challenging tasks, than those who view intelligence as fixed (Bransford et al., 2000). A learner-centred classroom is one in which the teacher encourages attitudes conducive to effective learning through the choices made, and through taking an active interest in individual learners.

In addition to being learner-centred, effective instruction is also knowledge-centred. Knowledge-centred classrooms support learning for understanding (Bransford et al., 2000). Expert-novice research reveals that for knowledge to be easily accessible and transferable to new contexts, it needs to be highly organised and inter-linked (Prawat, 1992). In other words, it needs to be understood, rather than merely memorised (Willis, 1993).

Prawat (1992) stresses the importance of teachers taking an integrated view of learner- and knowledge- centeredness. By this he means that each of the learner and the content is seen as dynamic. Learners should not be seen as being defined by certain learning styles, and content should not be seen as an infallible and unchangeable body to be learnt without question. Instead, each should be seen as changing over time and affecting one another. He says this requires acceptance of intermediate partial understandings of content to enable accessibility of learning. This requires striking a balance between the purity of the information interacted with and its modification in the light of needing to be appropriate for the particular learners involved, such that content is both accessible to the learner and truthful to certain disciplinary standards. This conception, he claims, is needed for teachers to change their instruction to be more consistent with constructivistic principles. In practise, he sees this as involving the negotiation of meaning, where this means a navigation of learning through the obstacles to effective learning, and the process of reaching consensus of understanding through dialogue.

Finally, effective instruction is assessment and community centred. Assessment-centred classrooms use formative assessment in a manner which makes the learning process visible to both the learner and the teacher, with the purpose of effectively guiding the learning process (Atkin & Black, 2003; Bransford et al., 2000). Community-centred classrooms are appropriately supported by the surrounding community, and themselves form a community with characteristics conducive to engagement in critical discourse by all. For effective learning to occur the community in which the classroom is situated, as well as the community of the classroom, need to value principles conducive to effective learning (Bransford et al., 2000). Effective attitudes include a preparedness to make errors and participate in critical discourse, giving and accepting challenge, during learning. The teacher needs to convert the class into such a community of inquiry (Lipman, 1991).

Informed by the discussion given above, I approached teaching, in this study, with the aim of creating a classroom environment which was learner-, knowledge-, assessment-, and community- centred. How this was practically to be done was informed by an understanding of a variety of models and strategies of instruction, as discussed below. Additionally, as I engaged in the research, I strived to further improve my understanding of this.

2.4.2. <u>Models of instruction</u>

A model of instruction is taken to mean a sequenced series of steps adopted by a teacher to achieve a certain purpose. Gunter, Estes, & Mintz (2007) discuss a variety of instruction models, each of which has strengths and weaknesses and consequent appropriateness for achieving particular outcomes. In this discussion I focus on some such models which appear to be potentially appropriate for promoting critical thinking within a content-rich stipulated curriculum. These are: direct instruction, conceptual learning, problem-centred inquiry, Socratic seminars, Eggen and Kauchak's integrative model and co-operative learning models. These are each discussed briefly below.

Direct instruction

Direct instruction is central to objectivistic, instructivistic pedagogy (Cronjé, 2007). This is a common practise and results in teachers preparing many notes, worksheets and tests to support their instruction. Instruction involves the teacher reviewing previously learned material, stating the objectives for the lesson, presenting new material, guiding practice, assigning independent practice, and periodically reviewing and providing corrective feedback where necessary (Gunter et al., 2007). It is what many of us have experienced particularly in South African schools and could be called a traditional instructional strategy.

Direct instruction has its foundations in behavioural psychology, social learning theory and cognitive learning theory (Gunter et al., 2007). According to behaviourists, learning behaviour can best be conditioned by providing clear targets, a systematic and incremental provision of information and testing of learning, coupled by positive reinforcement. According to social learning theory, people learn from observing one another, and this does not necessarily result in an observable change in the learner's behaviour. Hence, learners can learn from observing teachers teaching, even if no change in the learner's behaviour is observed at the time of the instruction. Cognitive learning theory, to which the Information Processing Model of learning, belongs, supports the clear, careful, systematic relating of new to background knowledge during direct instruction.

Conceptual learning

Concepts are categories of objects or ideas which share essential attributes (Gunter et al., 2007). Learning involves the creation and modification of conceptual structures (Hewson & Lemberger, 2001), and effective learning involves clarification of conceptual boundaries, and consistent usage of conceptual rules which are consistent with the particular subject domain (Stott, 2002; Stott & Hobden, 2006). Models of instruction focussed on conceptual learning concentrate on the essential attributes which distinguish concepts. This involves the teacher providing positive and negative examples, from which a concept definition is derived, in the concept attainment model. The concept development model is more inductive, with learners grouping items according to their own criteria, which they then make explicit to define the concept they have developed. Learners come to the classroom holding many existing conceptions, some of which are in conflict with scientifically acceptable conceptions. Unless the alternative concepts are challenged, they are likely to be retained, and reverted to in contexts where the scientific concept is not clearly required (Bransford et al., 2000; Hewson & Lemberger, 2001). Hence, models of science instruction founded in conceptual change theory aim at exposing existing conceptions, creating dissatisfaction with them where necessary, and showing that the scientifically acceptable conceptions are more intelligible, fruitful and plausible (Hewson & Lemberger, 2001)

Problem-centred inquiry

Problem-centred inquiry involves anchoring learning in real world situations (Gunter et al., 2007). WebQuests and Problem Based Learning (PBL) are examples of problem-centred inquiry. In WebQuests the teacher selects a problem and relevant websites, after which the learners solve the problem, guided by a WebQuest template and using the selected websites. Thomas (2000) identifies five criteria which must be present in an approach for it to be called PBL. These are centrality, driving question, constructive investigations, autonomy, and realism. The project must be central to the curriculum, must be driven by a question which the learners need to engage with as they investigate the related issues, which should not already be known by them. This should be done with a high degree of learner autonomy, i.e. the teacher should facilitate, but not take control of, the acquisition and manipulation of information. Finally, the project must have the feel of being authentic, with the learners' solutions to the problem being implementable in real life.

PBL has been found to be effective in inciting learner interest, enjoyment and active engagement (Albanese & Mitchell, 1993), particularly in the case of unmotivated, low-achieving learners (Mergendoller, Markham, Ravitz, & Larner, 2006). Further, PBL is believed to lead to deep levels of understanding (Gunter et al., 2007). However, there are indications that PBL often leads to gaps in learners' knowledge base, and students' perception that they are not as well prepared for conventional science examinations as their counterparts who were taught in a more traditional fashion (Albanese & Mitchell, 1993). Research suggests that PBL is difficult to implement and depends largely on the teacher having a strong content and pedagogical knowledge (David, 2008) and being skilled at project management (Mergendoller et al., 2006).

Socratic seminars

During Socratic seminars, students undergo a dialogue with one another in relation to stimulus material. This is aimed at developing critical thinking and respectful, yet critical discourse, during a deep engagement with the subject matter by means of asking essential questions (Gunter et al., 2007; Paul & Elder, 2006b; Tanner & Casado, 1998).

Eggen and Kauchak's integrative model

Eggen and Kauchak's integrative model is an inductive approach to instruction which aims at guiding learners to make sense of complex relationships between concepts. It involves learners searching for patterns in data, explaining this and hypothesising about what would happen under conditions modified from the data (Gunter et al., 2007).

Co-operative learning models

Co-operative learning models involve learners interacting with one another as they engage in subject material. Co-operative learning models claim greater achievement gains, and more learner activity, particularly in the case of more reticent learners, than do traditional teacher-dominated approaches (Gunter et al., 2007). However, research done in South African classrooms suggest that such approaches need to be carefully structured to prevent them from leading to limited learning (Adam, 1999; Ankiewicz, Adam, de Swardt, & Gross, 2001). Various models of how this can be done are proposed. These include the Jigsaw model (Gunter et al., 2007), in which learners work in different groupings at different stages in the learning process, aiding cross-pollination of learning among them.

2.4.3. Strategies of instruction

In contrast to a model of instruction, discussed above, a strategy of instruction, is taken to mean "smaller instructional patterns that can be used across models for a variety of purposes with a variety of content" (Gunter et al., 2007, p. 282). Gunter refers to a variety of instructional strategies. In this discussion I will focus only on those which seem particularly relevant to the promotion of critical thinking in a content-rich stipulated curriculum. These are scaffolding, think, pair, share strategies, summarising, questioning, and argumentation.

Scaffolding

Scaffolding involves breaking a process into parts manageable by the learner, with the purpose of supporting learners while directing them towards self-directed learning (Gunter et al., 2007). It is consistent with the notion of learners needing help as they operate in the ZPD, until they reach self-direction (Lee & Smagorinsky, 2000; Vygotsky, 1978).

Think, pair, share strategies

Think, pair, share strategies are aimed at increasing learner participation due to learners sharing ideas in non-threatening environments. Learners are given an opportunity to think about an issue individually, after which they share this in pairs. They then pool these ideas in a whole-class sharing session (Gunter et al., 2007).

Summarising

Summarising involves learners selecting relevant information, and paraphrasing this in their own words (Gunter et al., 2007). This process helps learners to make sense of and internalise learning, and requires employment of critical thinking to be done well (Paul & Elder, 2001).

Questioning

Question asking and answering is central to the sense-making process of learning (Paul & Elder, 2006a). It seems reasonable, therefore, that the quality of the questions asked and answered, as well as who does the asking and answering, will greatly affect the quality of learning resulting from this. South African research suggests that the most common form of questioning in classrooms is of the IRE (initiation-response-evaluation) form (Hobden, 2000; Jina & Brodie, 2008; Msimanga & Lelliot, 2008; Stoffels, 2005a, 2005b). This involves teachers posing a question, learners responding, and the teacher evaluating the response. This seems particularly consistent with an interactive style of direct instruction. Problem-centred inquiry and Socratic questioning, however, would require learners to additionally participate in the question posing and evaluation, with the evaluation possibly being more complex than a simple judgement of being right or wrong. Questions can be classified in many ways. This is discussed in a later section.

Argumentation

Much research has been done, in recent years, on direct instruction of argumentation, and infusion of argumentation in content learning, as a means of promoting critical thinking (e.g. Braund, Erduran, Simon, Taber, & Tweats, 2004; Braund, Lubben, Scholtz, Sadeck, & Hodges, 2007; Driver, Newton, & Osborne, 2000; Erduran, Ardac, & Yakmaci-Guzel, 2006; Erduran, Simon, & Osborne, 2004; Kuhn, 1992; Msimanga & Lelliot, 2008; Newton, Driver, & Osborne, 1999; Ogunniyi, 2007; Scholtz, Hodges et al., 2006; Simon, Erduran, & Osborne, 2006; Zohar & Nemet, 2002). Most of these approaches to argumentation in the classroom utilise Toulmin's model of argumentation (Toulmin, 1958). According to this, an argument is composed of claims which are supported by data. Warrants link data to claims, and are strengthened by backings. Claims are refuted by rebuttals. The strength of an argument rests on the truth of the data and the validity of the claims being logical outcomes of the data (Aikenhead, 1991; Epstein, 2002).

Armed with the knowledge of models and strategies of instruction discussed above, I sought to understand how to use, or modify, this knowledge, in order to promote critical thinking. Additionally, as I embarked on this endeavour I was informed by the literature currently available on the promotion of critical thinking. This is discussed below.

2.4.4. Teaching to promote critical thinking

I began this study with a literature-based understanding of what was already known about instructional strategies aimed at promoting critical thinking. This literature is characterised by debates on competing views. These debates can be categorised into those dealing with general instructional strategies and those related to effective task characteristics. The latter is discussed in a later section and the former here. As has already been mentioned, development of critical thinking is not an automatic consequence of maturation (Lombard & Grosser, 2004) but can be improved by explicit instruction (Resnick, 1987). Some authorities state that this should be done directly, and others that it should be done inferentially. Some promote infusion of such instruction into other subject disciplines, and others argue that critical thinking should be taught separately. These two debates are explored below.

Direct versus inferential teaching of critical thinking

Some programs encourage direct instruction in critical thinking skills, heuristics, criteria and dispositions, followed by application of these. Others use an inferential approach: providing guidance only as the need arises. For example Wheatley (1995) and Lavoie (1995) caution against teaching heuristics directly since this may result in the heuristic being used as an algorithm. Wheatley (1995) supports this view by appealing to constructivism: “In a classroom where instructional practices are compatible with constructivism, students are presented with tasks before being shown any solution procedures. The intention is that students will construct their own meaningful methods” (Wheatley, 1995 p. 1). Cotton (2001) concludes from a literature review of thinking skill instruction that both direct and inferential methods have been shown to improve critical thinking, and research suggests that a mix of the two might be the most effective.

Critical thinking requires knowledge (Lederman & Niess, 2000), and effective learning of knowledge involves critical thinking (Paul & Elder, 2001). Therefore it is relevant to discuss the direct versus inferential presentation of knowledge here too. Knowledge can be presented directly before the task in which it is required, or arrived at inferentially during the task. Another way of saying this is that a learner can obtain information in an already processed form, or discover the information themselves. Ausubel called these receptive and discovery learning respectively (cited in Duminy, Steyn, Dreyer, Vos, & Dobie, 1996). However, Ausubel’s use of the term receptive, and his reference to learning, rather than instruction when speaking about these two ways to present knowledge to learners, seem to be rather unfortunate since they suggest incompatibility with a constructivist view of learning. Such a view seemed to be prevalent amongst teachers and physical science text book writers I had to do with at the start of this study. This led to the propagation of a misconception that learners should have to discover knowledge inferentially for the learning and teaching to be seen as constructivistic.

To avoid the confusion evident in this impression, it is important to make clear distinctions between theories of learning and theories of teaching and, particularly, constructivism as a theory of learning and constructivism as a theory of teaching. Constructivism as a theory of learning is generally accepted in the education community, while constructivism as a theory of teaching is far less well defined and supported (Prawat, 1992). Sense-making activity can be seen as the central component of a constructistic view of learning (Dirks, 1998). As long as sense-making occurs, this can be consistent with either an instructional strategy in which information is presented to learners directly, or one in which they are expected, possibly with guidance, to induce the information themselves. In the former, the sense-making follows the introduction to the information. In the latter, the sense-making is the process by which the information is derived. One of the interests with which I approached the study was a desire to understand the place each of these strategies should hold in instruction aimed at promoting critical thinking within the stipulations of the SA PS curriculum.

An inferential strategy, while seeming more likely to develop critical thinking, has a number of difficulties associated with it. Inference is an important component of critical thinking (Epstein, 2002). It is also an important component of the thinking process scientists use to generate knowledge (Bruner, 1971). However, Driver (1983) points out that inferential learning is very time consuming, and it is neither possible nor necessary for learners to repeat centuries of scientists' induction to arrive at the generalisations they are required to know. Further, she argues that inferential learning through practical inquiry is more likely to lead to misconceptions than to scientific conceptions.

In this study I sometimes approached the instruction of knowledge, skills, heuristics and criteria directly, and sometimes inferentially. Additionally, I used various positioning of tasks within the teaching sequence. Through the research process I sought to improve my understanding of the effect of these aspects on a task's effectiveness in stimulating critical thinking.

Infused versus separate teaching of critical thinking

Another issue relevant to the teaching of critical thinking is whether it should be infused into subject areas within the curriculum, or be taught separately in a general form. Research shows that transferability of skills and knowledge across domains does not happen automatically, although drawing attention to use of a strategy in different contexts can aid transfer (Perkins & Salomon, 1989). Also, while some strategies are specific to a context, others apply to many contexts (Resnick, 1987). Additionally, there is general agreement that domain-specific knowledge is a necessary, but insufficient, component of critical thinking (Barak & Doppelt, 1999; Lederman & Niess, 2000; Nickerson, 1994; Perkins & Salomon, 1989). Glaser and Ennis, both in Barak & Doppelt (1999), view programs that develop thinking without touching on specific content as insufficiently effective. However, critical thinking will not spontaneously occur just by teaching content (Nickerson, 1994). Therefore it is generally accepted that combining a general programme for thinking within specific knowledge domains is the most effective (Barak & Doppelt, 1999; Cotton, 2001; Perkins & Salomon, 1989). This is the approach which was taken in this research.

2.4.5. <u>Framework for evaluation of effectiveness of instructional approach</u>

It was necessary to approach data analysis for this study with a framework for evaluation. An appropriate framework would need to indicate whether an instructional approach was effective in promoting critical thinking within the context of the SA PS curriculum. I began my quest for such a framework with a literature review of existing frameworks. When this revealed nothing suitable, I designed a framework for the purpose of this study, supported by reference to literature. The discussion below explains my dissatisfaction with existing frameworks, and presents and supports the framework I developed for this study.

Shay & Jowitz (2005) remark that critical thinking is very difficult to measure. This is supported by an examination of some of the frameworks used to determine the effectiveness of intervention programs in terms of critical thinking. For example, in a South African study by Kaminsky (2004) the researcher rated learner responses on a scale of 0 to 10, representative of the degree of critical thinking shown, with no concrete substantiation of how the ratings were derived. Herrington & Oliver (1999) used Resnick's descriptors to develop a framework for deciding whether student talk was higher order or not. Their framework classifies any talk other than social discussion or recall as higher order, and is therefore, in my opinion, inappropriate for identifying critical thinking since the normative aspect of the thinking, which is the hallmark of critical thinking (Bailin, 2002), is absent. A similar problem was found with the framework used by Pudi (1999). This lists learner activities indicative of each of information gathering, organising, analysing, generating and evaluating activities, but with few normative descriptions. When reported according to this framework, learners appeared to be actively involved in critical thinking, however descriptions given elsewhere, and the overall conclusion reached by the researcher, suggest the opposite.

Much research has been done on the development of frameworks for analysis of argumentation (e.g. Braund et al., 2007; Driver et al., 2000; Erduran et al., 2004; Jimenez-Aleixandre et al., 2000; Newton et al., 1999; Ogunniyi, 2007). These are based on Toulmin's Argument Pattern (TAP) (Toulmin, 1958). According to TAP, an argument is composed of claims which are supported by data. Warrants link data to claims, and are strengthened by backings. Claims are refuted by rebuttals. In the framework developed by Erduran et al. (2004) arguments are rated according to the frequency of claims, warrants, backings, counterclaims and rebuttals. While this framework was applied in analysis of written work early in this study, it was found to be unsuitable. This was partly due to its lack of sensitivity to the quality of information used in the argument. Given the importance of the learning I tried to promote in this study being compatible with a content-rich curriculum, this weakness in the TAP framework reduced its effectiveness. Further, while argumentation is generally viewed as a component of critical thinking (Erduran et al., 2006), this study was not limited to this aspect of critical thinking. Another framework commonly used to assess argument quality is the SOLO taxonomy (Killen & Hattingh, 2004). This focuses on the degree of cohesion within an argument. This was also used during early data analysis in this study. However it was also not found to be entirely suitable, with motivations for this view including those mentioned for the TAP framework.

Since no suitable existing framework could be found, I designed one for the purpose of this study. According to this framework, learning is seen to be effective if (a) learners are interested and actively engaged in learning, (b) learners display higher order thinking during the learning, (c) tasks used to promote learning are attainable with effort and (d) the curriculum objectives are met.

Use of these criteria to make judgements on learning effectiveness can be justified by reference to the literature. Extent of learner interest and engagement with learning matter has been shown to be a reliable indicator of learning effectiveness (Bransford et al., 2000). This can be measured by observing learner interactions in class time, as well as getting feedback from them through questionnaires and interviews, on their levels of interest and motivation and times devoted to learning out of school hours. In order for learning to be meaningful and transferable to new contexts, new and prior knowledge need to be linked, conceptual boundaries formed, modified or clarified, and implications of the assimilated conceptual structure explored. All of these require higher order thinking (Cotton, 2001; Nickerson, 1994). This can be recognised when learners show “thinking that is reliant on criteria, self correcting, sensitive to context and conducive to judgment” (Lipman, 1989, p. 8) in written work and verbal interactions. According to motivation and self-efficacy theory, and Vygotsian theory of learning occurring in the ZPD (Lee & Smagorinsky, 2000), effective learning occurs when targets are attainable. However, learning with understanding, which requires critical thinking (Nickerson, 1994), is effortful (Resnick, 1987). It is clearly important, if one is operating within the South African national curriculum, for learning to meet the curriculum’s objectives before it is classed as effective within the system. This can be measured by mapping learning to the curriculum documents and measuring learners' performance in assessment tasks.

2.4.6. Summary

In this section I have looked at teaching in general, and the teaching of critical thinking in particular. I have attempted to convey some of the ideals striven for in teaching, as well as some of the tensions involved in teaching for critical thinking. I have also mentioned some models of instruction and teaching strategies which are considered particularly useful in understanding this study. Finally, I have presented, and supported, a framework for evaluation of instructional strategy in this study. I now turn to a discussion on tasks, in general, and, more specifically, to aspects of tasks which are potentially critical in determining whether they will be effective in promoting critical thinking or not.

2.5. TASKS

An academic task is a goal which learners are required to meet while engaging in certain content presented in a particular form (Blumenfield, Mergendoller, & Swarthout, 1987). This study focuses on instruction and use of tasks likely to promote critical thinking while operating within a content-rich curriculum. Literature on effective characteristics of tasks is characterised by debates on conflicting tensions which require optimisation. This is true for tasks in general, and critical thinking tasks in particular. The discussion below aims at representing some of these tensions. These tensions are compounded by desires to cater for a wide range of learner styles and abilities, and occasionally conflicting advice from research. Consider the following example of conflicting advice. Margolis & McCabe (2003) recommend assigning tasks of different levels to different learners. They refer to instructional, independence and frustration levels. Instructional level is the level of difficulty learners are able to cope with under guidance, corresponding, it seems to me, to the ZPD. Independence level refers to the range of task difficulty suitable for learners to work on independently, and the frustration level is the threshold of difficulty which is counterproductive to learning since it falls beyond the learners' ZPD. These authors suggest that no learner should be assigned tasks at or beyond this point. Given the uniqueness of these levels for each learner, and the range of learners present in a typical classroom, this suggests assignment of different tasks to different learners in a single class. On the other hand, Blumenfield et al. (1987) caution about assigning different levels of tasks to learners of different abilities since this encourages the notion that students should take the easiest way out. I begin this discussion on tasks with a study of characteristics of tasks which are potentially critical to determining success in critical thinking promotion. After this I turn to potentially critical task settings and end with mention of existing systems of task classification.

2.5.1. Potentially critical task characteristics

It is necessary to identify characteristics of tasks which are potentially critical in determining whether the task will be successful in inducing critical thinking or not. In this study these informed task selection and design. Study of the literature suggests the following task characteristics as potentially critical: structure and guidance, context, degree of open-endedness, length, degree of complexity, and language usage. These are discussed in turn.

Structure and guidance

A number of researchers point to the importance of well structured tasks for inducing critical thinking (Adam, 1999; Alvarez et al., 2000; Ankiewicz et al., 2001; Lee, 2003; Milton, 1993). Ankiewitcz et al. (2001) suggested that low levels of teacher guidance were partially responsible for the low critical thinking incident in a South African class studied. It seems reasonable to think that the degree to which a task is structured and guided may affect learners' perceptions of whether the task falls into their ZPD or not. Also, due to the limited space of working memory (Niaz & Logie, 1993), teachers or peers are often needed to temporarily supplement a learner's limited working memory space through exploratory or guiding dialogue (Baron, 1987). However, as Resnick (1987) says, "We do not recognize higher order thinking in an individual when someone else 'calls the plays' at every step” (p.3). Pudi’s (1999) documentation of a task involving assembly of a model is an example of the need for critical thinking being removed by provision of a high degree of guidance. The model guided the learners to a predetermined solution, and led to trial and error approaches rather than problem solving through critical thinking. Therefore, a tension exists between giving enough structure and guidance to ensure that learners do not reject the task as too difficult or unclear, but not so much as to prevent thinking from needing to be critical.

Context

Assessment context affects intrinsic motivation (Palmer & Goetz, 1988). This is enhanced by authentic, meaningful contexts (Mehlinger, 1995), while contexts which are not meaningful to the learner encourage a low engagement in school work and inhibit the transfer of learning to new contexts (Newmann, Secada, & Wehlage, 1995). Dewey was a strong advocator of the use of authentic contexts:

> From the standpoint of the child, the great waste in school comes from his inability to utilize the experience he gets outside while on the other hand he is unable to apply in daily life what he is learning in school. That is the isolation of the school--its isolation from life. (Dewey, 1916, in Bransford et al., 2000, p. 147)

Additionally, research suggests that using real-life learning contexts improves the likelihood that learners will engage in critical thinking (Alvarez et al., 2000; Fraker, 1995; Sparapani, 1998). This can be explained by the greater intrinsic motivation the purposefulness and interest inherent to real-life contexts must surely give the learner. Explicitly pointing out other real-life contexts to which a type of critical thinking applies, and using real-life contexts to indicate the consequences of critical and uncritical thinking, can be effective in enabling transfer of thinking between contexts, in developing a disposition to habitually think critically (Mc Carthy, 1992), and in developing a desire to want to think critically (Bailin, 2002). Bailin further points out that critical thinking always arises in particular contexts, and therefore an approach which seeks to promote critical thinking should focus on using the kinds of contexts which would do this. She suggests that these are “complex, scientifically significant problems” (p.373).

On the other hand, both a rich context and the tension of formal assessment might reduce the working memory space available for performing the task. Further, overly contextualised learning has been found to lead to learners being unable to transfer their learning to contexts other than that in which the learning took place, and so abstraction of knowledge beyond the confines of context is necessary (Bransford et al., 2000). In rebuttal, Prawat (1992) argues that this view results from a misconception, namely an impression that learning is hierarchical. This, he says, is propagated by systems such as Bloom’s taxonomy. This suggests that horizontal transfer, i.e. transfer of knowledge between contexts, can only occur once vertical transfer, i.e. learning on higher cognitive levels, has occurred. He argues, instead, that it is the richness of connectedness of knowledge, i.e. the quality of learning, which determines whether transfer can occur or not. Additionally, he points out the importance of *indexical knowledge* as being valuable. By this he means knowledge which develops out of the use of knowledge. He suggests that connections affecting accessibility of learning include knowledge-knowledge and knowledge-context links. Consequently, he argues that contextualisation, if it aids deep learning, will improve, rather than inhibit, learning transfer. Further, he points out that contextualisation of learning encourages the enculturation of appropriate belief systems, causing more than the learning of knowledge to occur.

Degree of open-endedness

Research has shown that use of open-ended questions increases the likelihood of learners engaging in critical thinking (Milton, 1993; Potts, 1994). Ankiewicz et al. (2001) and Pudi (1999) both named closed-ended questioning as a factor limiting critical thinking in South African classes studied. Gott & Duggan (1987) classify investigative tasks according to whether they are open or closed in each of the aspects: defining the problem, choosing the method, and arriving at solutions. Critical thinking is required to search for and formulate questions (Barak & Doppelt, 1999; Lederman

& Niess, 2000), so it is to be expected that tasks which are open in the defining of the problem may encourage critical thinking. Resnick (1987) says higher order thinking is non-algorithmic, meaning that the methods used are not prescribed, and that such thinking often yields multiple solutions, each with costs and benefits. Therefore it seems that tasks where the method choice is open to the learner, and / or where more than one answer is correct, may encourage critical thinking. On the other hand, these task traits may cause the learner to reject the task as falling outside his / her ZPD, in which case they will probably not encourage critical thinking. Alternatively, they may lack a normative dimension, and therefore not require critical thinking (Bailin, 2002).

Length of time

A number of studies name short time allocation as a limit to effective critical thinking (Fraker, 1995; Sparapani, 1998). The complexity of critical thinking seems to suggest that effective tasks should take a fairly long period of time. However, it seems reasonable to assume that increasing task length may reduce a learner's perception of efficacy. South African research done by Chamberlain, Button, Dison, Granville, & Delmont (2004) claims that short questions can be effective in assessing critical thinking. However, task length may have different effects on critical thinking stimulation than it does on its assessment.

Complexity

Higher order thinking, which includes critical thinking, is complex in that it simultaneously involves substantive and procedural thinking (Lipman, 1991), i.e. it involves thinking about concepts at the same time as using heuristics and exerting metacognition. Further, it may involve use of multiple concepts and multiple criteria, and yield multiple solutions in an attempt to impose order on disorder (Resnick, 1987). Therefore it seems reasonable to expect that simple tasks, i.e. tasks which do not require use of multiple concepts and strategies, may be less effective in inducing critical thinking than more complex tasks. However, given the limited capacity of working memory, and the likelihood that a complex task may decrease a learner's perceived self-efficacy, it seems reasonable to expect that learners may reject very complex tasks.

A task which could be complex under certain conditions might cease to be so under others. One of the ways of reducing a task’s complexity is the introduction of routinisable procedures. These include the use of algorithms. Algorithms are cognitive tools which reduce complexity, thus potentially freeing up working memory space for other thoughts. They are “ways of expediting inquiry that can be misleading when thought to be ways of terminating inquiry” (Lipman, 1991, p. 23). Paul (1995) says that critical thinking is often prevented due to teachers presenting algorithms to learners as short-cut substitutes for independent thought. It seems reasonable to expect that the prominence and timing of presentation of algorithms in tasks may affect the extent to which critical thinking will be engaged in. Further, emphasis on routinisation, such as provided by algorithms, reduces learning flexibility (Lavoie, 1995) and may result in “deadening and banalisation” (Bruner, 1971, p.17) of knowledge, decreasing motivation. On the other hand, since algorithms reduce complexity, which very likely affects perceived self-efficacy, this should also affect learner motivation.

The likelihood of converting a potentially complex task into a simpler one is increased by a natural avoidance of complexity and its associated effort. This view is consistent with findings by South African researchers such as Stoffels (Stoffels, 2005a, 2005b), as well as international researchers, such as Blumenfield et al. (1987):

> For teachers, assignments which are cognitively and procedurally simple allow for more routinization of procedures and may be desirable because they are easier to teach or to manage. For the student, less complex tasks, while boring, may also be preferable because they can readily generate acceptable products. And, faced with a press for explicitness from students, teachers may change the nature of the curriculum itself and, as a result, curricular innovations may fail or, more accurately, be sabotaged from within. To gain co-operation, reduce confusion and facilitate success, teachers may transform comprehension or problem-solving tasks into recall and recognition tasks. But, while this routinization serves to reduce confusion and thus helps students to understand what is expected of them it can have negative long-term consequences on students as 'thinkers' and 'workers'. (Blumenfield et al., 1987, p. 143)

Language usage

The majority of the learners who participated in the study do not speak English as a home language, as is the case for the majority of South Africans, and so the language used in the tasks was potentially limiting. Mashike (2000) and Adam (1999) give inappropriate language as a key feature of the failure of tasks to promote critical thinking in South African classrooms. However, some degree of language complexity is surely necessary to support the complexity of critical thinking and for learners to explain scientific concepts in their own words: a key aspect of a critical approach to scientific thinking according to Paul & Elder (2006c). Adam (1999) suggests that skilful teacher facilitation can mitigate the mismatch between learners' language abilities and the language used in tasks. This suggests an interdependence between factors discussed above, i.e., the relationship between guidance and language usage. This concept of interdependence very likely extends beyond this example.

Resources

A variety of resources may be needed to support critical thinking, and when these are not present, interest in thinking critically can easily wane (Sparapani, 1998). This is particularly a problem in the many poorly resourced South African schools (du Preez, 1998). Internet, library, computer, laboratory, video and photostatting facilities were available to support the tasks used in this study and the necessary resources for each task were determined before its implementation.

2.5.2. Potentially critical task settings

It is not only the characteristics of tasks which determine their potential effectiveness, but also the manner in which they are implemented. The influence of collaboration and the role classroom climate play in determining effectiveness are explored below.

Collaborative learning

Research suggests that learning to think critically happens best within an environment of collaborative learning (Gokhale, 1995; Resnick, 1987; Sparapani, 1998). Sparapani (1998) claims that group work ensures critical thinking, and that this can be further enhanced by the teacher expecting critical thinking from the learners. However, Elder (1997) maintains that co-operative learning is a necessary, but insufficient, requirement for learning which involves critical thinking. She says that collaboration must continually be measured against intellectual standards such as those named by Paul (1993), i.e. relevance, consistency, accuracy, precision, fairness, logic, depth, breadth and significance, otherwise it will not lead to critical thinking. Research done in a South African classroom (Adam, 1999; Ankiewicz et al., 2001) documented group work which lead to little or no critical thinking. They suggest a number of possible reasons for this. These include the confusion which can result from South Africa’s linguistic diversity, and the apparent misconception that learner-centred education means teacher-passive education. Suggestions for bridging the gap between the theoretical virtues of co-operative learning in fostering critical thinking, and the reality of what was observed in the study are, “careful design of activities, strategic intervention by teachers, and the possession of a basic set of group process skills by the learners” (Ankiewicz et al., 2001, p. 13).

Collaborative learning was focussed on in this study, partly because of its potential strengths, discussed above, and partly to make learners’ thinking explicit for the purpose of data collection. Think-aloud protocols often fail to sense crucial periods of thought as learners often fall silent during periods of intense thought due to the added cognitive load required to express their thinking (Young, 1995, in Herrington & Oliver, 1999). However, in the social setting of collaborative learning the sharing of thoughts is critical for communication, providing a more natural environment for learners to make their thinking explicit, facilitating data collection (von Wright, 1992, in Herrington & Oliver, 1999).

Classroom climate

Factors which affect the willingness of learners to engage in critical thinking include their perception of the risks versus gains involved, which is greatly affected by classroom climate (Cotton, 2001). An environment conducive to promoting critical thinking encourages openness in participating by learners as well as an attitude of being prepared to give and accept challenge (Elder, 1997). The former requires a perception of safety in making mistakes, and the latter requires an attitude of challenge of error. These two seem to be conflicting, except if error is seen to be a normal and beneficial component of the process of learning (Bransford et al., 2000).

I strived to create such an environment during the course of this study. I did this by employing a learner-centred pedagogy, upholding the affective dimensions named by Paul & Elder (2006d) and attempting to transform the class into a community of inquiry (Lipman, 1991). When referring to employment of a learner-centred pedagogy I mean display of a sensitivity to learner needs, as has been discussed earlier. This included establishing friendly but professional relationships with the learners, respecting learners, and being open to learners' views and suggestions (Bransford et al., 2000). The affective dimensions referred to include fair-mindedness, intellectual courage, humility, and perseverance. This included the teacher taking on the role of co-inquirer, and being prepared to be challenged intellectually by learners. One of the aims of this research was to gain a better understanding of the influence of the teaching and learning environment on the promotion of critical thinking.

2.5.3. Question classification

A number of systems of question classification exist. Classification of questions as being open or closed has already been discussed, and reference has been made to Bloom's taxonomy. Bloom's taxonomy is commonly used by teachers to classify questions. According to this, questions are classified as lower, medium or higher order. Lower order questions involve recall of knowledge. Medium order questions may test comprehension or application. Higher order questions probe for analysis, evaluation or synthesis (Bloom, 1956).

Unlike these generic systems of question classification, Hobden (2008) has designed a system customised to the classification of questions used in physical science classes. Consequently, I find this system particularly useful. According to this system, questions are classified according to the type of thinking they require, namely remembering, reproductive thinking or productive thinking. Remembering involves recall of knowledge. Reproductive thinking requires procedural fluency. This includes graph drawing and formula manipulation. Productive thinking involves going beyond given information to generate new knowledge. Hobden provides three subcategories of questions involving productive thinking. These are those involving conceptual understanding, those requiring use of investigation skills, and those involved in problem solving. Finally, questions requiring provision of a point of view is given as an additional question category. This can involve learners engaging in any or all of the identified categories of thinking. Influenced by this classification system, I frequently refer to procedural and conceptual questions. These terms are used in the sense described above.

2.5.4. Summary

In this section I have discussed task characteristics, settings and classification. I have attempted to portray some of the tensions and occasionally conflicting advice concerning task characteristics, given in the literature. This was done with a particular focus on tasks aimed at promoting critical thinking. I have also explored views on the role of collaboration and classroom climate on task effectiveness. Finally, I have given a brief discussion on systems with which tasks can be categorised. The understanding represented in this section informed the design and implementation of tasks used in this study. Further, I sought to understand these issues more fully as a result of the action research process undergone.

2.6. CONCLUSION

In this chapter I have outlined the theoretical framework within which I operated as I approached the research of this study. I have described policies and perceptions of the South African national physical science curriculum, within which this study occurred, theories of learning and of teaching, and characteristics and usage of tasks. A constructivist view of learning is taken, heavily informed by conceptual change theory, Vygotsky's theory of the ZPD, as well as the Information Processing Model's stress of the limitations of working memory capacity. Critical thinking is taken to mean "thinking that is reliant on criteria, self correcting, sensitive to context and conducive to judgment" (Lipman, 1989, p. 8) , with the elements of thought and intellectual standards referred to by Paul and Elder (2006a) considered to be particularly useful for highlighting aspects of critical thought. I have shown that there is both value in and a need for investigating how to promote critical thinking, particularly within the South African context. To do this effectively requires a sound understanding of how learners learn, how teachers should teach, and characteristics tasks should have in order to be effective in promoting critical thinking within a content-rich curriculum.

In discussing each of these issues I have tried to expose a number of tensions which practitioners face as they attempt to promote critical thinking while operating within the demands and unpredictable conditions of real practise. Each pole of these tensions yields costs and benefits which may conflict with one another. Some of these include the tension between employing a traditional versus a constructivistic pedagogy, infused versus separate, direct versus inferential teaching of critical thinking, a focus on concepts versus a focus on procedures, and long versus short, complex versus simple, highly structured versus loosely structured and open versus closed task characteristics. It was within such tensions that I conducted this research on my own practise. In the next chapter I outline my research design, before relating my story of learning in Chapter Four.

CHAPTER 3
RESEARCH DESIGN

In this chapter I describe and justify the research activities I carried out during the course of this study. The knowledge claim position taken in this study is one of a pragmatist (Cresswell, 2003), with a leaning towards realism as far as ontology and epistemology are concerned. The strategy followed was one of action research with a qualitative approach to data collection and analysis, since this was most suited to the research questions and context. Tools used in the research process included observation, interviews, questionnaires, reflective journals, audio and video recordings, and document analysis. The following general question and associated sub-questions guided the collection and analysis of data:

How should learning tasks be designed and used in teaching to promote critical thinking within the South African physical science national curriculum?

a) Which design characteristics affect a task's effectiveness in promoting critical thinking?
b) How does the position in the teaching sequence influence a task's success in promoting critical thinking?
c) What type of learning environment encourages promotion of critical thinking?
d) To what extent do tasks need to be adapted to fit particular students or student groups in order to promote critical thinking?

I begin by motivating the applicability of the research design to answering the questions given above, after which I outline my research activities. This is followed by a description of methods used to ensure validity and reliability.

3.1. FIT OF RESEARCH DESIGN TO RESEARCH QUESTIONS

As shown by the research questions, the aim of this study was an improvement of my practice as I sought to promote critical thinking. This focus on understanding and improving practice from within, rather than controlling and manipulating it from without, is consistent with an action research strategy of inquiry (Mc Niff & Whitehead, 2006). Action research aims at both action and research, and therefore bridges the gap between theory and practise, thus overcoming the persistent failure of research impacting on practise (Somekh, 1995, in Cohen et al., 2000). In action research the search for answers is driven by the question, rather than by antecedent conditions. Consistent with this, a more flexible approach to research design is required. This would allow responsiveness to the action research processes of observation, reflection, action, evaluation, and consequent modifications in direction (Mc Niff & Whitehead, 2006). This flexibility, driven by what is useful, is appropriate for answering questions, such as the ones given above, aimed at improving practise (Mc Niff & Whitehead, 2006), and is consistent with a pragmatic orientation to research (Cresswell, 2003). Further, this flexibility and responsiveness is suitable in complex situations where little is known about the topic (Swepson, 1995), as was the case in this study.

Action research is founded on the epistemological assumption that through critical self-reflection and negotiation with participants, a researcher can create answers useful to effecting self-improvement (Mc Niff & Whitehead, 2006). These answers will not be definitive, but will be useful. These epistemological assumptions reject the positivist notions that a single mind-independent reality is knowable. On the other hand, I also reject the relativism of radical constructivism, with its associated dangers of accepting anything as truth (Feldman, 2007). Therefore, in terms of my views on ontology and epistemology, I lean towards a post-positivist / realist paradigm. This states that a single mind-independent reality exists, but there are multiple perceptions of this. Realism recognizes the plasticity of perceptions, differences between perceptions and reality, and the need for researchers to interact with the social actors to understand their perceptions, and so try to reach a partial understanding of the reality itself (Krauss, 2005).

My choice of action research was aligned with my pragmatic approach to research. From the point of knowledge claims, a pragmatic orientation to research views truth as what works (Cresswell, 2003). The improvement of practice through the process of action research is largely concerned with determining what works. On the other hand, I approached this research with an awareness of the dangers of viewing all pragmatic knowledge as truth, and of the potential for action research to yield narrative of questionable validity, as warned against by Feldman (2007). This increased my awareness of the importance of strategies to ensure rigor and accountability in this study. This is discussed in detail in a later section.

Qualitative data collection, analysis and reporting were focused on since this is more sensitive to complexity than quantitative methods. Qualitative reporting has also been focused on, since this is more easily understandable, and open to alternative interpretation by readers, thus extending its value beyond the researcher's interpretations (Adelman, cited in Bassey, 1999; Cohen et al., 2000; Stake, 1994). The researcher's observation, synthesising, analytical and interpretive activities are central to such a study, allowing the detection of non-verbal aspects to which only a human instrument is sensitive (Bogdan & Biklen, 1992; Merriam, 1988). Long-term observation and triangulation by comparing multiple sources of data and undergoing a number of smaller action-research cycles within larger cycles, were used. This, coupled with an awareness of the meanings evidenced through non-verbal data and of the possibility of interviewees sub-consciously reverting to narrative frames they perceive to be desirable or expected, rather than representing their perceptions accurately (Henning, 2004), was done to increase validity (Merriam, 1988). A variety of types of data was collected. This included open and closed-type questionnaire and interview items, field notes, a reflective diary, transcriptions or reports of audio-recordings, aided, in some cases, by video-recordings, and document analysis.

Taber (2000) says that “studies of a phenomenon as subtle and complex as the learning of science require in-depth examination of individual learners” (p. 469), and Roth (1998) refers to studies which “display examples of learning processes in vivo” as able to “contribute to understandings of physics learning processes” in a manner which is “accessible to the teaching community” (p. 1019). These remarks point to the value of a study such as this one, as well as motivating the in-depth, in vivo approach of observing a few learners’ learning when seeking to answer questions about the effects of aspects of instructional strategy on the learning process.

3.2. DATA COLLECTION PROCEDURES

This action research study took place over the three years from 2006 to 2008, during which time I taught physical science to grade 10, 11 and 12 learners. I taught the same learners as they progressed from grade 10 to 12. The numbers of participants, per year, are given in Table 3.1. These learners served willingly as participants after informed consent had been obtained from them and their parents. This use of the learners within my classes as research participants is consistent with the action research focus on an in vivo, in situ examination of practice (Mc Niff & Whitehead, 2006).

Table 3.1: Participants per year and grade.

	Grade 10	Grade 11	Grade 12
2006	23	18	
2007	16	23	
2008	16	16	23

A number of tasks were prepared during the course of the study, informed by a literature-based understanding of critical thinking and its promotion, as well as the progressing research. They were given to learners at appropriate times in the physical science learning programme. Lawson’s Test of Scientific Reasoning (Lawson, 1978) was also used. Learners were given journals in which they gave remarks on their learning experiences. Questionnaires and interview schedules were constructed to suit the task and the context. Learners' experience was probed, their work examined for evidence of critical thinking, and classroom observations analysed. Tools to aid reflective analysis were summarisation of the essence of video and audio recordings, transcribing of salient sections from these, coding and pattern searching.

The data corpus of this study is summarised in Table 3.2. This gives the year of collection and quantity of each data type gathered. As can be seen from this, a large amount and variety of data was collected, ensuring rigor. A more detailed explanation of aspects of the data corpus, and motivation of the pragmatic choices made concerning data collection, is now given.

Table 3.2: Data corpus: summary of sources of data by year.

	2006	**2007**	**2008**	**Total**
Audio recorded lessons	22	19	4	45
Video recorded lessons		17	4	21
Researcher journal (RJ) entries	120	182	27	329
Learner journal (RJ) entries		740	136	876
Audio recorded interviews	6	33	1	40
Questionnaires (answered by all learners)	12	3		15
Quantitative analysis of tests or written work	8	8	4	20
Analysis of voluntary learner work	5	3		8
Reflective e-mails / reports of validation discussions	8	12	6	26
Analysis of class-time usage	3	4	2	9
Exemplar paper analysis		5		5
Lawson's reasoning test	2	3	2	7

For the first year of data collection (2006), questionnaires, having closed and open response items, were answered by every learner for each of the 12 tasks considered to be potentially useful in developing critical thinking. One of these is given in Appendix A. Additionally, I conducted interviews and transcribed audio-recordings of these, wrote lesson reports, often aided by audio-recordings which I transcribed fully or partially, and kept a researcher diary. At the end of each cycle I analysed the data collected during that cycle by searching for the emergence of meanings, which I then tested in subsequent cycles. Further, at the end of 2006, as was the case at the end of each year, I reanalysed all of the data by categorising and coding it according to themes. During this process I realised that the closed response items from the learners were of limited usefulness. While their answers to open responses were found to be more useful than the closed-responses, they were limited by a preset amount of space offered in the questionnaire, by the fact that they were only answered at the end of the cycle, and therefore might have failed to capture the learners' experiences during the course of the cycle, and by the fact that they were restricted by the question itself.

Consequently, at the start of 2007 I replaced the use of questionnaires with the use of learner journals. I issued each learner with a book and encouraged them to write in it as frequently as possible. I outlined in general what I was interested in, namely how they felt about what we did in science, how much time they spent on science and what they spent this time doing, how they considered that the approach I was taking could be improved, whether they were enjoying science or not, whether they were struggling with science or not, and if they were, whether this was in a manner that made them give up, or that made them rise to the challenge, and whether or not what we did in science made them think deeply, thoroughly and productively. I stressed, though, that I would appreciate any comments they made, even if not specifically about any of the topics I had mentioned. Where possible, during the last few minutes of those lessons which had particularly been aimed at developing critical thinking, I made learners write in their journals. After this I took the journals in, processed them, and returned them to the learners, usually by the following day. Additionally, a number of learners would write in their journals even when not specifically given time to do this in class, and would voluntarily hand their journals in at various times. This use of learner journals aided the development of my understanding of what was happening during the course of each cycle. At the end of each cycle I would state my understanding of the learners' views, based on their journal feedback, to the whole class, and ask them to comment either in their journal, or verbally in an interview, on whether they considered my representation to be valid, and to add to or correct my understanding if they thought that it was incomplete or incorrect.

In 2006 I conducted a few long interviews. Each extended over an hour in length, largely due to the learners appearing not to want to leave until they had thrashed issues we discussed out in full. In contrast, in 2007 interviewing was mainly done through small groups of learners chatting to me informally, often at break-time, in response to the issues I had raised in class based on the journal evidence. This change in interviewing style resulted from a focusing of the research with time as answers to my research questions became apparent. This shifted the emphasis of the interviewing style from a looser brainstorming approach taken in 2006, to a more targeted one in 2007. Interviews were audio recorded and transcribed, or used as a reference for report-writing. At the start of 2007 I obtained a video camera, which I used to video those lessons directly related to the critical thinking tasks used. These, together with simultaneously made audio-recordings, were referred to as I wrote my report of the relevant lesson. However, even when lessons were not audio or video recorded, I generally wrote a report on each lesson in 2007, with some lapses in the daily routine due to time pressure.

The approach to data collection taken in 2008 was similar to that in 2007, although its scale was reduced. This was because little alteration was made to the teaching approach in 2008 relative to 2007, and so confirmatory evidence, rather than detailed exploratory data, was gathered at this stage. My focus could consequently turn to more formal data analysis, using the software program NVivo, and reporting, as I worked on this dissertation. This process further targeted data collection as specific questions emerged from the analysis and reporting process.

Throughout the data collection period I was careful to encourage learners to be honest in what they told me. I did this by reassuring them that there would be no adverse consequences for them to tell me the truth as they saw it, but rather the opposite, since by letting me see their perspective they were empowering me to improve the situation for their benefit. I followed this verbal reassurance up with action in that I never disciplined a learner based on what they told me in the data, for example confessions to not doing homework. Also, I took time to write comments back to learners to show them that I was interested in and appreciated their views.

Additionally, I made explicit mention of cases where learners' advice to me during the data collection process was being put into practise, to point out the value of their participation in the process. Occasionally I asked learners for greater clarity, and used the journal as a dialogue space as I tried to understand or confirm understanding of what they were saying. This use of the journals was also valuable in motivating and forming positive relationships with the learners.

Records of learners work were always kept, as stipulated by the school's assessment policy. Where these records appeared capable of clarifying whether an impression which emerged from the other data forms was valid or not, they were analysed. Additionally, in some cases written work was analysed to an extent beyond the requirements of school assessment policies. This was done in response to needs for this arising out of the data analysis. Since learner portfolios were kept at the end of each year, learners' work could be revisited and reanalysed in cases where the usefulness of this became clear long after the production of the work. Other written material used as data included questions and reflections learners voluntarily gave me for comment. One of these, including responses I gave, is given in Appendix B.

Rigor permeated the research process in this study. The data collection process was performed extensively, meticulously and thoroughly, as was the transformation of this data, as illustrated below. These traits elicit confidence in the study's trustworthiness, as discussed in a later section.

3.3. RESEARCH CYCLES AND DATA TRANSFORMATION

Each section of work stipulated by the curriculum served as an action research cycle. Twenty such cycles occurred through the three-year duration of the study. These are summarised in Appendix C. For easier communication, I have called these section cycles, and refer to them as sections. I have grouped these into four, each of which exposed a certain principle. I have called these Theme Cycles. This is explained more fully in Chapter Four. Each of these action-research cycles informed the next cycle's practice and was used to reflect on the validity of previous cycles' findings.

I used various methods to help me manage and analyse the data. These included coding and sorting manually as well as by using NVivo (software designed for analysis of qualitative data), and frequent summarisation and reflective writing. To aid analysis of the data I developed a set of criteria for evaluation of effectiveness, as suggested by McNiff et al. (2003). These are given, together with their method of recognition, and motivation for selection, in Table 3.3 (p. 80). This has also been discussed in greater detail earlier. These activities were performed throughout the time in which data was collected, and particularly in between each cycle of action research as prior action was contemplated on in order to direct future action.

Use of NVivo for data transformation was done with the rigor characteristic of this study. Data were captured electronically and then meticulously coded. This coding was subjected to the scrutiny of the critical friends and validation group used in the study, as discussed in a later section. Use of the NVivo software enhanced the efficiency and effectiveness with which data could be manipulated, displayed and retrieved, and thus enhanced pattern searching and the resulting emergence of understanding (Wolcott, 1994). An example of a query, run for one of the twenty sections, is given in Appendix D.

The research is grounded in its data since it was not approached with a hypothesis for testing, as is the case in experimental studies. Rather, understanding emerged through an internal dialogue resulting from cycles of data collection, analysis and literature review (Bogdan and Biklen, 1982; Taber, 2000). This is consistent with the process of action research (Mc Niff & Whitehead, 2006) and the overall emphasis on the qualitative, interpretive research approach which was used. Continual engagement with data analysis throughout the course of the study, with an intensification of this process once all the data was in, is consistent with advice given by authorities on qualitative research and data transformation, such as Bogdan and Biklen (1992) and Merriam (1988).

Table 3.3: Criteria for evaluation of a task's effectiveness.

Criterion	**How will this be seen?**	**Justification for using this criterion as an indicator of effectiveness**
Learners are interested and actively engaged, both in and out of Science class time.	Learners (and possibly family members) report interest and active engagement in and out of class. Learners are observed during (and possibly outside) class time discussing their own thoughts about the task with one another. Learners voluntarily engage in optional activities or activities of their own making, relating to the task.	Theories of self-efficacy and use of working memory, according to the information processing model of learning (Niaz & Logie, 1993), stress the importance of interest in learning (Bandura & Schunk, cited in McCombs, 1988). Active engagement, especially if voluntary, suggests motivation, a key component of effective learning (Cotton, 2001; Schoenfeld, 1985).
Learners use critical thinking during performance of the task.	Learners are observed, during class observations and / or in their written work, to show critical thinking traits, such as: sensitivity to context, reliance on criteria, self correction, objective judgement substantiated by reasons which consider both merits and faults, attention to relevance, consistency, accuracy, precision, fairness, logic, depth, breadth, significance, and display intellectual humility, intellectual courage, intellectual empathy, intellectual integrity, intellectual perseverance and fairmindedness.	These characteristics are derived from literature (e.g.Lipman, 1989; Paul & Elder, 2001).
The task is attainable, with effort.	Learners are observed to struggle but eventually to succeed. Learners report on thinking being effortful, but attainable, having experienced confusion, but having emerged from this to clarity. Learners' written work shows successful answering of the task.	Learning should fall into the ZPD (Lee & Smagorinsky, 2000). Higher order thinking is effortful (Resnick, 1987).
Learners gain the knowledge and skills required by the curriculum.	The task requirements can be mapped to the curriculum core knowledge and assessment standards' requirements. After the task has been done, learners are able to answer questions, in test situations, based on the curriculum, such as the examinations released by the examination board. Learners report on the task helping them to learn the knowledge and skills required by the curriculum.	This is inherent to the research question.

3.4. VALIDITY AND RELIABILITY

While the original conceptions of validity and reliability, founded in positivism, are not relevant to a study such as this, modern understandings of these terms extend their applicability to any study. Further, it is imperative that a study meets criteria related to these modern understandings for it to be trusted (Feldman, 2007). Although taking an extreme view of radical constructivism removes any need for consideration about validity and reliability, I reject such an epistemology. Instead, I take Feldman’s view that research, particularly action research, which aims at improving the human condition, has the responsibility of directing change in a beneficial manner, with such an outlook being incompatible with an acceptance of anything passing as truth (Feldman, 2007). Taking a pragmatic realist view, I consider that a mind-independent reality does exist, and while knowing this fully and with certainty is not possible, it can be approximated (Krauss, 2005). Further, certain practices can aid this approximation of reality, thus increasing the truthfulness of the representation. This can be demonstrated by the research meeting various criteria of validity and reliability, with these terms used according to their understanding within the context of qualitative research, as discussed below.

A variety of ways of substituting the concepts of validity and reliability in the context of qualitative studies have been proposed. Seminal work on this concept was produced by Lincoln and Guba in the 1980s. According to this, the concept of trustworthiness should replace that of validity and reliability, in qualitative research. Further, they proposed specific criteria for testing this (Lincoln & Guba, 1985). Heikkinen, Huttunen, & Syrjala (2006) suggest use of the quality of the research as an indicator of its validity, and they name criteria against which this can be measured. In rebuttal, a number of authors argue that since validity and reliability determine the worth of research, to avoid use of these terms when referring to qualitative studies is to demean their worth as research (Cohen et al., 2000; Henning, 2004; Morse, Barrett, Mayan, Olson, & Spiers, 2002). Further, some authors, such as Feldman (2007) and

Morse et al. (2002) criticise the use of the criteria mentioned above as reliable indicators of validity and reliability.

Based on the discussion above, the terms validity and reliability will be used, although not in the positivist sense. Instead, the following definition of validity, which encompasses both quantitative and qualitative methods of data collection, will be used:

> An account is valid or true if it represents accurately those features of the phenomena that it is intended to describe, explain, or theorise. (Hammersley, 1992, p. 69, in Feldman, 2007, p. 23)

Similarly, a qualitative equivalent of reliability is required. This is referred to, by Lincoln and Guba (1985), as dependability and consistency of data. Walker (cited in Merriam, 1988) says this involves "presentation of material in forms where it is open to multiple interpretations" (p. 44).

Action research aims to describe, explain and theorise about the effect that certain action has in a localised context (Mc Niff & Whitehead, 2006). This is consistent with notions of internal validity, but not with those on external validity (Cohen et al., 2000). The latter, which refers to the degree to which findings can be generalised beyond the study, is not applicable to action research (Mc Niff & Whitehead, 2006). This, as well as the value of naturalistic generalisations formed by readers of qualitative studies, has already been discussed. Since only so called internal, and not external, validity is applicable to action research, my reference to validity from this point refers only to the former. A number of suggestions have been made concerning evaluation of an action research study's validity. Some of these refer to the data collection process, and others to the analysis, interpretation and communication of findings. Some of these suggestions are discussed below, together with explanations of how I sought to meet each criterion.

Lincoln and Guba's (1985) criteria of credibility, confirmability and dependability appear to refer to validity. Credibility, the degree to which we can believe what is being said, is attained, they suggest, through prolonged and persistent engagement in the field, triangulation, peer debriefing, negative case analysis, in-process and terminal member-checks and referential adequacy. Techniques to demonstrate dependability and confirmability, they suggest, involve a dependability and confirmability audit.

Morse et al. (2002) argue, though, that although explicit audit trails do document decisions taken the research process, they do not ensure that these are valid. Further, they point out that in some cases member checks could inhibit the emergence of quality synthesis by researchers as they strive to retain a low enough level of generality to allow members to recognise themselves within the discussion they produce. Despite this criticism, an attempt has been made to make the audit trail explicit in this report, as given by references to data sources in chapters 4 and 5. The audit trail was also subjected to dependability checks by critical friends and a validation group, as documented in Appendix E. Member checks were performed in the manner described earlier in this chapter. Checking of the final dissertation by the research participants, however, was not practically possible. In the light of Morse et al.'s (2002) dismissal of the value of member checks, this is not seen as a limitation to this study.

Merriam (1988) and Cohen et al. (2000) join Lincoln and Guba in referring to the importance of long-term observation and triangulation. Consistent with this, data for this study was collected over three years while undergoing numerous cycles within larger cycles of action and research. The condition for referential adequacy is considered to have been met. Not only is the extent of the data that was collected very large, as indicated in Table 3.2 on p. 75, but signs of data saturation were evident as data collection drew to a close. Further, triangulation of methods was obtained by comparing multiple sources of data, as represented in this table, and triangulation of sources by gathering data from as many learners as possible. Although triangulation of investigators was not possible, since this study was performed individually, active engagement in a reflexive dialectic with knowledgeable and competent peers and superiors, as discussed below, is considered to have reduced the limitation this offered.

Critical evaluation is a vital element of validity, and was engaged in rigorously in this study. This appears to correspond to Lincoln and Guba's (1985) naming of peer debriefing and negative case analysis as techniques to satisfy the criterion of credibility. It also seems to correspond to other authors' reference to the use of a dialectic which seeks disconfirming evidence in cases of agreement, and explanation in the cases of disagreement (Cohen et al., 2000; Dick, 1999; Feldman, 2007; Heikkinen et al., 2006; Morse et al., 2002; Zuber-Skerritt, 2001). Mc Niff, Lomax and Whitehead (2003) suggest that such critical evaluation can be enhanced by engaging in discussions with critical friends and a validation group. This increases accountability, helps the researcher to sharpen up the processes of observation, analysis and deduction, prevents personal biases or false perceptions from leading the researcher to invalid conclusions, and lends credibility to the research. The methods by which I went about this are discussed below.

Critical reflection was aided by frequent interaction with two critical friends. These people, both my colleagues, are both experienced teachers and deep and thorough thinkers. The kind of relationship required between critical friends already existed between myself and each of these. These traits include the freedom to accept and give challenge, an interest in improvement of education, and a mutual striving for attainment of deeper understandings of how to do this through examining the rigor, reliability and honesty of information and its analysis. I frequently discussed emerging ideas with these two, telling them how I had arrived at these in terms of the data. I also discussed issues I was grappling with. This was done informally on approximately a weekly basis, but less frequently for extended periods in a more formal setting, in which case the discussion was summed up by a report. These periods are documented in Appendix E.

Appendix E also shows interaction with a larger validation group. As in the case of the critical friends, one of the purposes served by the validation group was to ensure that the reflective dialectic I underwent while interacting with the data was done in a critical and accountable manner. The validation group included the critical friends, my physical science subject head, my principal, and three lecturers from a nearby college of education. The latter-mentioned members each held PhD degrees. I engaged in formal meetings with available members of the validation group, on only two occasions since meeting with the members was difficult, given their busy schedules. Consequently, I found it more useful to distribute electronic presentations, included videos I produced, of the evolving research, to the members at regular intervals in the research process. These presentations were then commented on verbally or by e-mail by the members of the validation group. E-mail discussion was engaged in on a number of occasions. The start of the first validation group meeting's minutes is given in Appendix F. The final validation group meeting, held on 11/11/08, after completion of the data transformation process, involved a rigorous evaluation of validity. At the start of this session I presented members with the criteria for evaluation of validity in qualitative research which I had extracted from writings by a number of authors. This is reproduced in Appendix G. I then justified the validity of my work by evaluating it against these criteria, thus subjecting the work to the scrutiny of the members. Although no major concerns were raised, minor suggestions were given, and modifications were made in accordance with these. At the end of this meeting, the members signed a declaration that they had evaluated my work, and agreed to it meeting the listed criteria. One of these signed documents is given in Appendix G.

Besides the processes described above, I have subjected my work to the scrutiny of other peers and superiors on a number of occasions, as outlined in Appendix E. This included publishing a paper on a section of the work, participating in three poster displays, and performing two verbal presentations of aspects of the research. The critical dialogue undergone with practitioners, academics and researchers during these events enhanced the quality of my engagement with the study. Additionally, I have striven to represent the reflection I underwent during the course of this study in this dissertation. This is especially shown in chapter 4, where I have tried to represent the process of the development of the thoughts which emerged in this study. In this way I hope to demonstrate that the assertions made are indeed grounded in the data (Zuber-Skerritt, 2001). I have also tried to represent the use of a dialectic which searches out disconfirming evidence, mentioning counterclaims and attempting to represent and compare the plurality of perspectives (Feldman, 2007).

Besides pointing to the importance of undergoing a reflexive dialectic, Feldman (2007) argues that to demonstrate validity, an action research study should make explicit how and why data was collected, and the criteria for determination of what counts as data. This has been done earlier in this chapter. Table 3.3 (p. 80) lists the criteria used for evaluation of task success. The motivation for use of these criteria in terms of literature is given on p. 57. These were also presented for critique by the members of my validation group on 01/01/07 and 28/02/07, as well as by academic researchers on 18/06/07 to 22/06/07 and 23/06/08 to 27/06/08. Further, Feldman states that the action researcher should make the process of transformation of data into narrative explicit. This has been done earlier. Finally, Feldman suggests that validity can be enhanced by the explanation of observed phenomena in terms of theory which is useful in situations beyond the study, and open to critique. This is done throughout the discussion given in Chapters Four to Six. In these chapters I have been careful to evaluate understandings which emerged in terms of theories expounded on in existing literature, and, where this seemed inadequate, to propose relevant theories of my own which I support in terms of existing theory.

Morse’ (2002) views on validity were also considered. He argues that validity should be ensured during the process of research, rather than only through an evaluation of the final report at the end of the research, by which time rectification of error is impossible. He suggests various verification strategies to be applied during the course of the research. These are an attention to methodological consistency, appropriate sampling, concurrence of data collection and analysis, theoretical thinking and theory development. These criteria have been met, as the foregoing discussion has already shown.

3.5. LIMITATIONS AND ETHICS IN RESEARCH ACTIVITIES

Action research searches for fuzzy generalisations, rather than universal truths (Stenhouse, cited in Bassey, 1999). The value of such research is readers' extraction of aspects relevant to their localised conditions (Mc Niff & Whitehead, 2006). The likelihood that readers will find aspects of this study useful to their own situations is increased by the presentation of a rich description, given in Chapters Four and Five, by the fact that the participants represented both genders and were of varied socio-economic, cultural and linguistic backgrounds, and by the naturalistic nature of this study (Mc Niff et al., 2006).

Before commencement of data collection, learners and their parents were informed about the research to allow them to decide on whether to give consent to the learners serving as subjects or not. The English version of the letter and form requesting this permission, is given in Appendix H. These were translated into Zulu and the relevant language version was given to learners and parents. These were signed and returned. None of the learners or their parents objected to the learners' participation in this study. The school's principal, on behalf of the governing body, also signed consent for me to conduct this study before commencement of data collection. This is given in Appendix I.

3.6. CONCLUSION

This is an extensive and rigorous action research study. This can be seen by the extensiveness and meticulousness with which data were collected and transformed. Further, careful attention has been paid to criteria of validity, according to an understanding of this concept which is applicable to qualitative research. These traits lend credibility to a reading of the findings of the study, which follow. This study aimed primarily at improving my teaching practise through seeking to better understand how to promote critical thinking in learners while meeting the requirements of the South African national curriculum. However, it is believed to have wider usefulness than just my practise, based on the assertion by a number of authors that the stories told by practitioner researchers are powerful in that they are situated within the complexity of real life, and so can effectively be related to by other practitioners (Atkin & Black, 2003; Hollingsworth, Dadds, & Miller, 1997; Mc Niff & Whitehead, 2006). This is done by abstraction of relevant issues from the rich description supplied (Stake, 1994). Such abstractions can be applied, with necessary modification, to readers' particular cases. A rich description which will enable such abstraction is now given, in Chapter Four. This is followed by my analysis and interpretation, in Chapter Five, using the theoretical framework given in Chapter Two.

CHAPTER 4
DESCRIPTION: MY JOURNEY OF LEARNING

In this chapter I tell the story of my quest to understand promotion of critical thinking in school physical science, operating within the tensions of real practise. I start my recount with information about the learners involved in this study and the school environment in which the study took place. This is followed by an overview of the action research cycles engaged in, coupled with an explanation of some of the terms used. After this, I tell the story of my learning.

4.1. GENERAL CONTEXT

4.1.1. The school

The research took place at the private mission school in a rural area of Kwa Zulu Natal where I have been teaching ever since matriculating in 1990. All my tertiary education has been conducted part-time while teaching here. Currently there are just over 250 learners and approximately 30 staff members. The junior classes are very small since there is no boarding facility for the younger grades, all learners in these grades living within walking or driving distance of the school. A relatively large intake occurs in grade 7, from which age upward boarding is available. Selection for admission is not done on an academic basis, and remediation is provided, where necessary, for bridging from the generally substandard education learners seem to receive from the feeder schools in the surrounding rural public schools. Classes from grades 7 to 12 average about 25 to 30 learners per class, with two classes per grade in some cases. The majority of learners tend to choose Physical Science in the Further Education and Training (FET) phase. Physical Science is chosen against Computer Applications Technology and Business Studies. Physical Science seems to be held in high esteem by the learners, so that most of the learners who perceive themselves as capable of passing it choose to take it. A science laboratory has recently been constructed, but for the period described in this work science lessons occurred in the register classrooms and I carried equipment to the class as I required. This included a data projector which I often used during teaching.

The school has a history of a 100% pass in the national senior certificate examinations at the end of grade 12 for an uninterrupted 20 years, and has produced top learners in these examinations a few times, as well as having a stellar record of achievement in the Expo for Young Scientists on regional, national and international levels. The school environment is conservative, stable, disciplined and, according to an internal survey conducted in 2006, happy. This survey showed very high levels of interest in science amongst learners of all ages, abilities and backgrounds. This is corroborated by personal observation, as well as the fact that the school's science club is one of the most popular of the extramural clubs. This is possibly due to previous learners' high achievement in the Science Expo. There are very high levels of participation in the competition every year. Much, but not all, of this participation is compulsory. The school management is very supportive. The principal takes an active interest in each staff member and is open to innovation, while also being wary of replacing traditional teaching with what she might consider to be an inferior substitute. She and other members of the school governing body have followed the research I have done as closely as their busy schedules have allowed, frequently inputting their views and providing support in practical ways.

4.1.2. The learners

The participants of this research were members of my grade 10, 11 and 12 physical science classes in 2006 to 2008. A summary of the numbers of learners who participated in my research per grade per year was given on Table 3.1 (p. 74). These refer to the numbers of learners present in the class during most of each year, although one or two learners did leave or join the class during the period of study. In the case of the 2006 grade 10 learners I also taught them in 2007 in grade 11 and in 2008 in grade 12. The classes had heterogenous compositions. To illustrate this, I describe some details of the 2006 grade 10 class, which progressed to grade 12 in 2008. Fourteen of the 23 learners were girls. Three are from English homes, two Afrikaans, two German, two Sotho, and the rest Zulu. Six are white, one coloured, and the rest black. The learners come from middle- to lower- class backgrounds, some from urban and others rural areas. Six of these learners lived on the mission station on which the school is situated, four commuted each day to school from surrounding areas within 20km of the school, and the rest boarded at the school. The kinds of learners in the other classes were similar to this cohort.

4.1.3. Overview of cycles of action and research

This study was both extensive and thorough, as an examination of Figure 4.1 reveals. This summarises the cycles of action and research undergone in this study. Each of the 20 learning sections named in this diagram served as an action-research cycle. Some sections of work are composed of more than one topic. For example, the grade 10 mechanics section consists of three topics: motion, gravity and energy. I created and implemented a number of modules throughout the course of the study. Examples include Tsunami and Must he pay?, parts of which appear in Appendixes J and K respectively. Most of these modules corresponded to a single topic, although in some cases a topic was dealt with over the course of a few modules. In some cases I created a number of parallel modules for a particular topic, with some common elements between them. In such cases, each learner only had to perform one of the modules. The term module is used here to refer to an entire learning-teaching strategy for a unit of work dealt with within a particular context. It includes the direct instruction and facilitation done by the teacher, and the classwork, homework, formal and informal assessment performed by the learner. Each of these modules served as mini-cycles of action and research. The individual modules have not been represented in the figure, but rather only the sections to which they belonged. This was done to reduce clutter in the diagram.

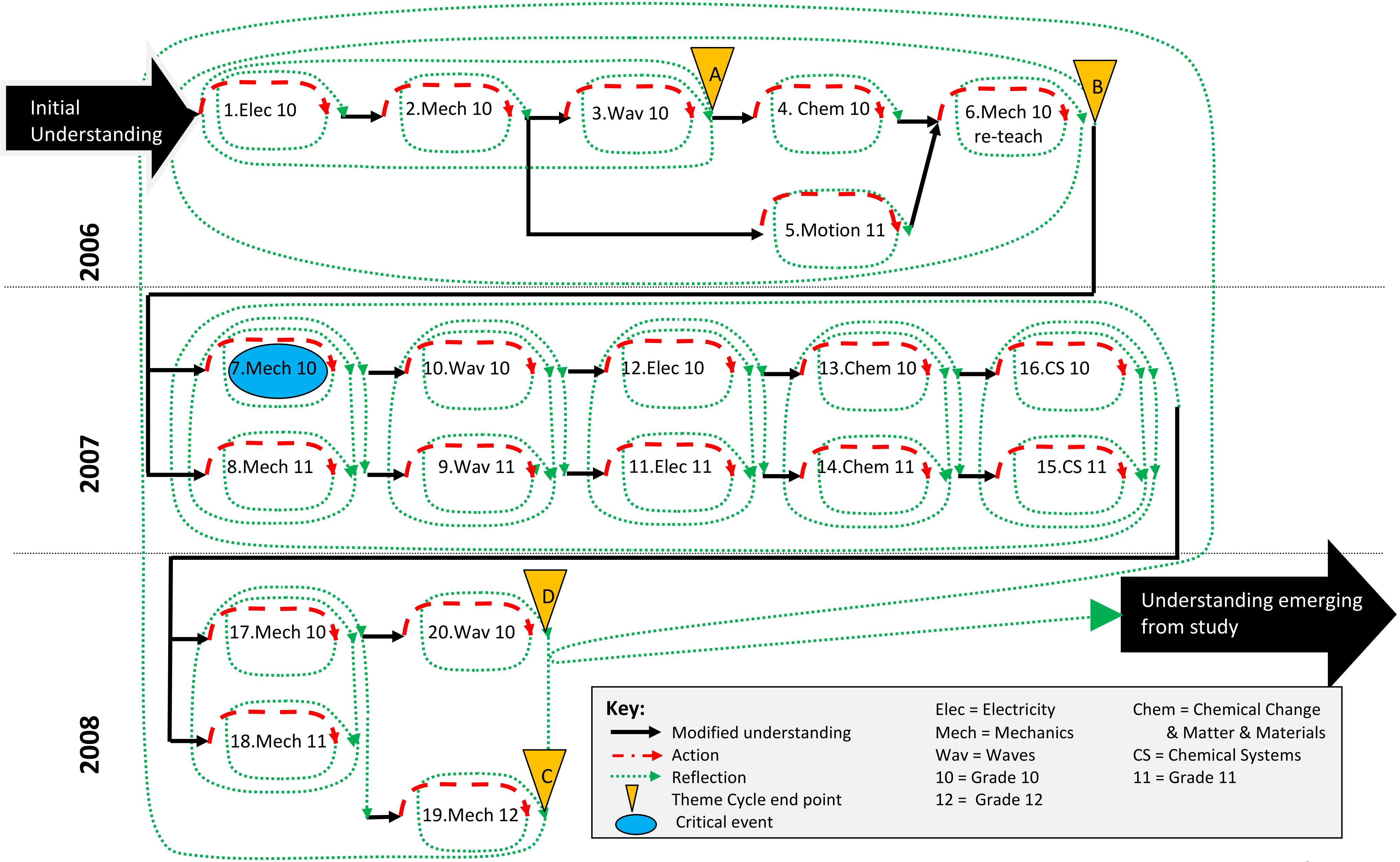

Figure 4.1: Section Cycles of action and research

I approached each section with a particular understanding of best practise at that time in my teaching journey, which I tried to implement. As I did so, I collected data on the effectiveness of this implementation strategy, and reflected on this. At the end of each section I reflected on the action and data as a unit, presented my emerging understanding to the learners, and collected further data on their reactions to my reflections. Further reflection led to modification of my views, which informed the design and implementation of the next section's module(s). At certain points, for example after running parallel strategies with two different classes, and at the end of each year, I reflected on the process undergone in groups of sections.

I have tried to represent this cyclic process in Fig 4.1. As shown by the first large black arrow, I approached the first section, namely grade 10 electricity, in 2006, with an initial understanding of best practise. I tried to implement this in the classroom, as indicated by the broken red arrow. During this time I collected data. I then reflected on the process, sharing my thoughts with the learners and collecting data on their responses to this, as well as on their written performance, and reflecting on these. This process is represented by the dotted green arrows. This resulted in a modified understanding, represented by the black arrow, with which I began the next section.

Within the row allocated for each year, the sections are arranged in chronological order from left to right, with simultaneously occurring sections, implemented with different grades, placed above and below one another. The arrangement, however, is not to scale. For example, in 2006, sections 4 and 5, i.e. grade 10 chemistry and 11 motion, occurred at approximately the same time as one another, although section 5 took less time despite the figure's representation of the two starting and ending together. Additionally, the process was messier than indicated in the diagram. For example, reflection on groups of cycles, represented by dotted green ellipses encompassing more than one cycle, occurred more often than indicated. Reading through data, coding it in various ways, discussing emerging thoughts with the participants, critical friends, the study's validation group, and others, were methods I used to aid my reflection process.

At certain points, represented by the orange triangles in Figure 4.1, this process resulted in the emergence of a conclusion about a certain principle. Four such insights have been identified and labelled A-D. The sections contributing to emergence of each principle have collectively been termed a Theme Cycle. I have named these after the main principle each exposed. These are: A: Context, B: Teaching and Collaborating, C: Concepts and Procedures and D: Scaffolding. These are represented in more detail in later figures. These Theme Cycles do not follow a neat chronology between them. This is because each section lends itself to furthering the understanding of particular themes more than others. Further, data was collected from more than one grade each year. Theme Cycle B incorporates A, since its conclusions emerged as a result of inquiry involving all the sections indicated as being part of Theme Cycles A and B. Theme Cycles C and D occurred simultaneously, with some sections common to both. These two occurred after A and B, which informed them.

Each of these four Theme Cycles will now be discussed in turn, followed by reflection on the process as a whole. Section 7, i.e. 2007 grade 10 mechanics, has been highlighted in the figure. This is seen as a critical event, since the action research cycles which came before and after it suggest that this cycle is the model of best practise emerging from this study. Consequently, it will particularly be emphasised.

During this discussion it is important to bear in mind that I was unable to pursue my goal of promoting critical thinking as a free agent. Instead, this had to be done within the pressures, constraints and expectancies of real practise. As a consequence, I experienced a great deal of tension from interests which often competed with the ideal of critical thinking promotion. These tensions include the requirement that a content-rich syllabus be completed in a limited and interrupted timeframe, and that I prepare learners for a high-stakes final examination which is externally set in some cases. Besides these, the everyday pressures of practise, such as weather conditions, absenteeism and learners joining classes part-way through the year, added further complexity to the process. Consequently, this is the story of my search for optimisation and balance within the often-conflicting tensions of real practise.

4.2. CONTEXT; TEACHING AND COLLABORATING

I launched into this study under the impression that I should focus my efforts on facilitating group discussions revolving around carefully prepared tasks, and keep direct instruction to a minimum. However, later in the year, having fallen drastically behind schedule, I reverted to a traditional strategy to save time and limit confusion. An evaluation of the strengths and merits of each of the experiences during this time convinced me of the importance of prominent usage of both direct instruction and learner collaboration. On the path to this decision I was also alerted to the value of contextual intrigue to a strategy's success.

4.2.1. Initial ideas: using facilitated discussion to promote critical thinking

I began 2006 feeling that I was fairly well equipped to teach the new curriculum. I interpreted this as differing from the old mainly in that I was expected to adopt a strategy which required learners to think critically, and to cultivate a community of inquiry within the classroom. I thought this meant that I should, as far as possible, avoid presenting science as an indisputable body of knowledge to be learnt without question (Watts & Bentley, 1984). Rather, the processes of doing science, such as questioning, analysing, evaluating, arguing, and reasoning through induction and deduction to lead to generalisation and concept development, should be stressed (Bruner, 1996, in Atkin & Black, 2003).

I had understood this from numerous in-service teacher-training courses which the Department of Education (DoE) had presented to teachers during the country's transition to outcomes based education in the Senior Phase, i.e. grades 7 to 9. Further, I understood this to be consistent with recent findings from educational research into development of critical thinking, particularly through argumentation (Erduran et al., 2004) and inquiry (Lipman, 1989), and learning from a constructivist perspective (Slavin, 2000). Additionally, I interpreted the published outcomes of the physical science South African national curriculum statement (DoE, 2003) as supporting this conception. The outcomes and assessment standards of the curriculum seemed consistent with the view that "the style of thought of a particular discipline is necessary as a background for learning the working meaning of general concepts"

(Bruner, 1996, p. 28, in Atkin & Black, 2003). This style of thought is what I was aiming at developing.

Part of the initial understanding I worked from involved use of tasks which should guide learners to derive equations, and formulate concepts themselves. This would be done as they engaged in argumentation and inquiry and underwent abstraction and generalisation. In other words, these tasks would, hopefully, cause learners to undergo the process which scientists undergo while generating knowledge. The teacher's role would mainly be facilitative of the learners' engagement with the guiding questions while collaborating in groups. The teacher would then consolidate this learning during direct instruction. Experiences while co-authoring a grade 10 physical science text book for the new curriculum had given me the impression that such a strategy should be used. During this process I had continually been admonished to take a constructivist approach. This was done in a manner which implied use of an inductive approach with much opportunity provided for learners to infer concepts from making sense of experience or data.

This strategy bears resemblance to Eggen and Kauchak's integrative model of instruction discussed earlier(Gunter et al., 2007). However, since it was implemented with less teacher control than their strategy suggests, I will rather refer to the strategy as *inductive facilitated group discussion.* This approach was used to a large extent for the first part of 2006, during the grade 10 electricity, mechanics, and waves, sections. The teaching of these modules is represented in Figure 4.2. The inductiveness of the strategy used is indicated, in this figure, by placement of the group discussion icon before the teaching icon for part of the electricity and waves, and all of the mechanics, sections. The relative sizes of the teaching and group discussion icons indicate that group discussion, rather than direct instruction, was focussed on.

Facilitated group discussion can also be performed deductively, and this formed another part of my initial understanding of how the curriculum should be implemented. In this, direct instruction is followed by a group discussion about some related issue. The latter is guided by a task designed to encourage the learners to make sense of what they have been taught so as to be able to apply this deductively to solve

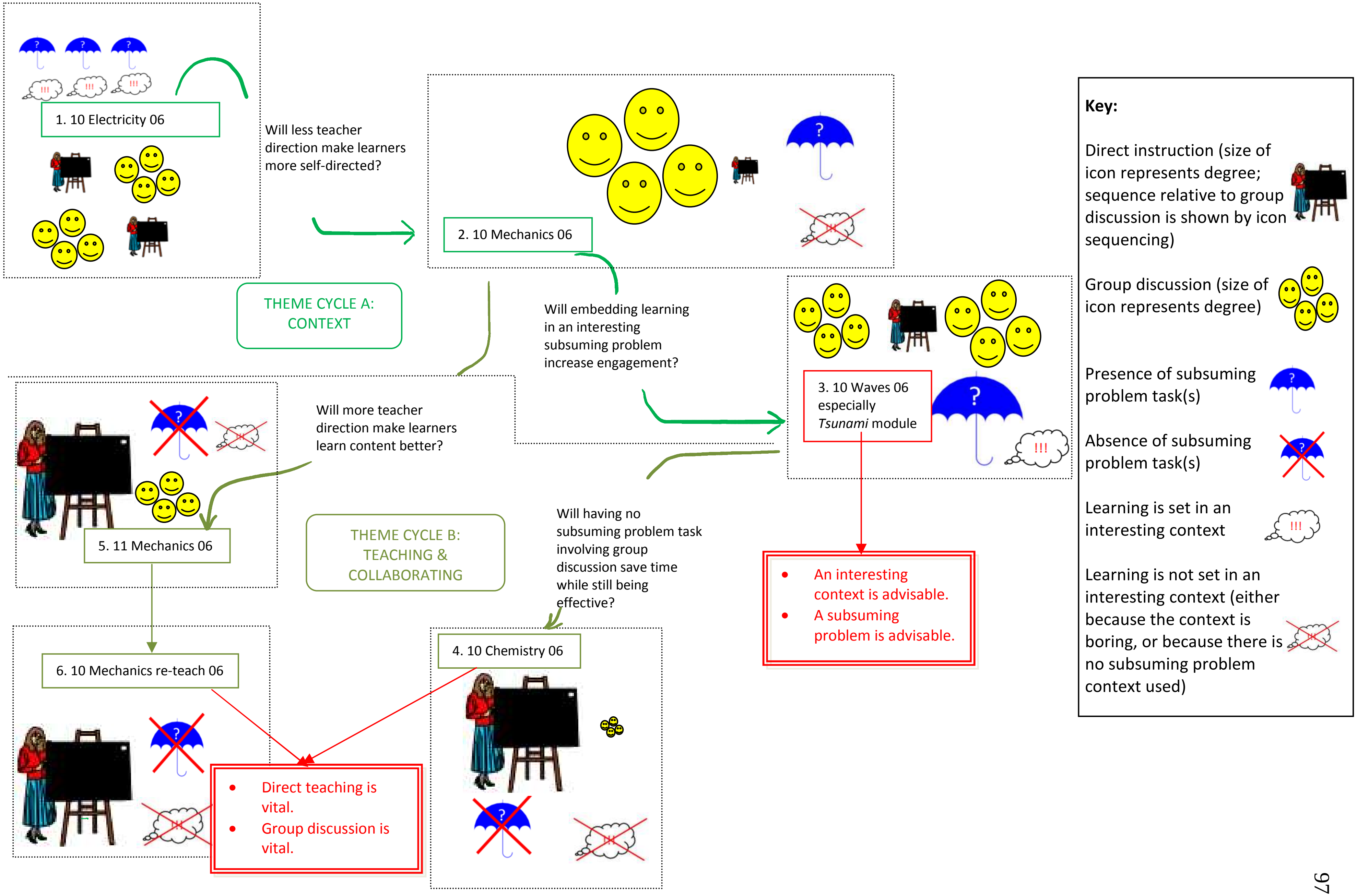

Figure 4.2: Theme Cycles A and B

a problem. This was done during parts of cycles 1 and 3, as shown in Figure 4.2 by the teaching icon being placed before the group discussion icon for part of the representation of each of these.

4.2.2. Does group discussion work?

Action

I focussed on argumentation in deductive and inductive group discussions in the grade 10 electricity section in 2006. I taught aspects of good and poor arguments explicitly. This section consists of three topics: electrostatics, circuits, and magnetism. For all of these I used short tasks designed to improve skills in detecting and improving poor arguments, and in developing good arguments. Each of these tasks had an individual and a collaborative component. Greater detail of how this general strategy was implemented in each of the topics is now given.

I implemented a few modules within the electrostatics topic. Facilitated group discussion was sometimes used inductively and sometimes deductively in these. Short, interesting subsuming contexts were used. These included evaluation of beliefs about lightning and reasoning through the implications of data from electrostatics demonstrations. I provided learners with a good deal of support and guidance and introduced concepts individually within the guiding tasks. For the circuits topic I used direct teaching to a greater extent. This was always done in a highly interactive manner, and was interspersed by sense-making and reinforcement tasks. An inductive group discussion strategy was used in the section on magnetism. However, in this case I could not facilitate learning during class discussions since the learners' engagement with the module's task coincided with a week of teacher-training which I attended. I situated the electricity learning for all three topics in a fair amount of hands-on practical work, although in the case of electrostatics none of the experiments showed what was intended, due to high humidity levels.

Observation

The following extract is fairly typical of what occurred during this cycle. At the start of this 30-minute discussion lesson the class had, using prior experience, listed some materials which were able to attract pieces of paper when rubbed, and others which were not. They then discussed hypotheses of why some materials, when rubbed, are able to pick up pieces of paper, and others not, as well as suggesting ways of testing these hypotheses.

> Helen told me she thought it had to do with the heat released during friction, and the fact that some materials retain heat or heat up better than other materials. I asked her how she could test if this was so. She thought for quite a while, then said something quite illogical and irrelevant. I repeated my question. After a while, she suggested that two pieces of the same material be used at different temperatures, and if heat is not the cause of the ability to pick up material, then they should behave in the same way at both temperatures. Just after this, Silindile, in a different group to Helen, suggested heat as the reason too. I sent Helen to her to repeat the discussion the two of us had had.
>
> Sonja and Jennifer said perhaps it had to do with the degree of smoothness, and then answered themselves saying that if so, then the metal, plastic and glass, all very smooth, should behave the same, which they do not. Marike wondered about electrical conduction. She suggested that conductors could let electrons “run away”. Sonja and Jennifer, independent of Marike and in a different group, also started speaking about conduction. But they were puzzled by wood, and asked “Isn’t wood an insulator?” I told them it can conduct electricity, especially when wet. They then remarked to one another that that was the reason. I asked them to explain why being a conductor or not should cause the difference. They could not answer. I left them to think.
>
> I went to a group of boys. Again the heat theory came in, and then electrical conduction was referred to. Here, as well, they were puzzled by wood. Eventually, amongst themselves, and in response to my prompting, some of them seemed to come to an explanation, although it seemed like only a few followed this, and none of them spoke very clearly. A few learners suggested that rubbing transferred “something” between the cloth and the plastic. Marike used the word “electrons”.
>
> I then got the class’ attention, asked Marike to explain what she had come up with, after which I repeated her explanation with slightly different wording, saying electrons are transferred during rubbing, but conducted away in the case of electrical conductors, therefore charge is not retained. (RJ: 23/01/06)

The extract given above, typical of the section in general, is considered to show that effective learning was occurring, according to the criteria given earlier (p. 80). On the day of this extract, and throughout this section, learners were generally positive, displaying and reporting fairly high levels of interest and enjoyment in their learning. All learners participated actively and productively in the group discussions, although some to a greater extent than others. I also found evidence of critical thinking in learners' discussions. For example, I observed cases where learners challenged their own or one another's statements, and evaluated these against criteria. An example is given in the extract above, where Sonja and Jennifer evaluated their own statement that smoothness differentiates materials which can attract pieces of paper from those which cannot. This they evaluated against the criterion of their observations being consistent with the predictions resulting from this hypothesis. As a consequence they made a judgement, i.e., a rejection of their hypothesis. During this section it was evident that learners engaged in an effortful intellectual struggle. This is visible in this extract in the process the learners underwent to reason their way to an answer. Further, the instructional strategy used in this section is considered to have been compatible with the curriculum in that learners seemed to learn what they were intended to learn. For example, the scientifically acceptable explanation was reached, in the extract, at least by a significant number of learners, within the 30-minute lesson. Further, learners performed well on a test on this section: 15 of the 23 scoring over 70% and only two learners under 50%.

However, the strategy was time-consuming. It took 26 hours, instead of the 14 hours stipulated by the curriculum, to complete the electricity section. Further, learners were heavily dependent on my guidance during discussions, as can be seen by the key role I played in the discussion given in the extract above. It was usual, when I joined learners in discussions during this section, for me to have to prompt learners in a sentence-by-sentence manner. Since this was a slow process, I often could not get to every group during the course of a lesson. The learners' high dependence on me also meant that each group needed me with them for much of the discussing time, which was obviously not possible. Learners complained that this sometimes meant that their discussion drifted off-topic as they waited for direction from me. Additionally, I found the struggle and communication difficulties very tiring, frustrating and slow. This was particularly the case since I was continually required to provide patient guidance and prompting through dialogue customised to each group's need. Also tiring and frustrating were the noise and confusion associated with a classroom in which a number of learners are speaking at once.

Reflection

Reflection on the strengths and weaknesses of the strategy used in the electricity section strengthened my impression that facilitated group discussion could promote critical thinking. On the other hand, it raised concerns that the process, as I had implemented it during the relevant modules in this section, was too time-consuming to be compatible with the curriculum. Additionally, it did not seem effective in getting learners to be self-directed. I thought that perhaps assigning more of the tasks to homework would help with this. I also wondered whether using a higher proportion of inductive tasks involving a number of concepts simultaneously could reduce the need for direct teaching, saving time. Further, I considered the possibility that withdrawing my help to some extent might force learners to become more self-directed. I designed the strategy I implemented in the next section, namely grade 10 mechanics in 2006, with these thoughts in mind.

4.2.3. Does induction work?

Action

I focussed on logic during the instructional strategy I used for the grade 10 mechanics section in 2006. I explicitly taught rules of logic, and logic notation to the learners, and infused their application into many of the tasks of this section. I used one task from the Ideas, Evidence, and Argument in Science (IEAS) resource (Braund et al., 2004), and was informed by strategies used in this resource as well as those taken by Aikenhead (1991) as I designed the other tasks.

In an attempt to overcome the shortcomings of the previous cycle, I assigned a number of tasks to be done for homework, designed tasks in such a way that they dealt with a few concepts at once, and tried to withdraw my support to an extent. I embedded a number of the tasks in the context of a falling stone which I considered to be very simple and uninteresting, but very instructive. This absence of an interesting context is indicated by the relevant icon in Figure 4.2 (p.97).

Observation

The following extract illustrates the kind of interaction typical in this cycle. It refers to an activity from the IEAS material (Braund et al., 2004). This task was meant to lead learners to see that objects of different mass will fall to the ground together if air resistance is negligible. This was done by learners having to make a series of choices between pairs of conflicting claims. The relevant concepts had not been taught before the task was engaged in. Learners had completed the task individually for homework the night before, and had spent about half an hour discussing their answers in groups by the time of the extract. The 23 learners were divided into five groups. The following interaction occurred between myself and one of these groups just after I had realised an error in one of the options in the guiding worksheet, namely that size, rather than mass, had been referred to:

Teacher	Imagine two rocks: a boulder here and a pebble there. Now they’re on a slope, and we’re going to push them to get them started… no, let’s make them on a flat surface, I’m going to push each of them and make them accelerate. Now we push each of them equally – equal force. Are they going to accelerate equally – the boulder and the little pebble?
General	No.
Teacher	Why not?
Jabu	Not the same weight.
Teacher	Which is going to accelerate at the greater rate?
Sonja	Boulder.
Marike	The one you pushed the hardest.
Teacher	No, you’re pushing equally.
[Noise]	
Busi	Pebble.
Teacher	It’s going to accelerate faster initially.
Marike	But the pebble can go and sit on something and the bolder will just go over it.
Teacher	If you have a smooth surface.
Helen	But it’s different if you drop it.
Teacher	The principle is the same, but it’s easier to think of pushing the boulders to start with. Now my point is that the question refers to how big it is, but I could change my question: what if we have a big piece of Styrofoam and a small bit of gold… and then you push them equally, equal force on a smooth surface, which will accelerate greater?
Thandiwe	Styrofoam.
Teacher	Styrofoam.
Helen	Huh?

As can be seen from the extract above, as well as its continuation, to follow, the discussion was messy and confusing. For example, Helen's frequent protests about falling and interjections like "huh?" suggest confusion. I, unwittingly, added to the confusion, such as saying acceleration of the lighter object would be higher initially, unintentionally implying that its acceleration would be lower than that of the heavier object later on. I also forgot that real-life observations, which would be all learners could draw on in the absence of formal teaching, are done in the absence of variable control. For example, I said a Styrofoam block would accelerate at a higher rate than a block of gold of the same size, when the same force is applied. In doing this, I was forgetting that in the presence of air resistance, and therefore in common experience, this would not necessarily be so. The extract continues below:

Teacher	So it's not really the size – it's the mass.
Marike	But the gold is heavier than the...
Teacher	Yes, and the one with a lower mass, when you push it with a certain force, will accelerate at a greater rate – pick up speed faster.
Helen	No.
Teacher	Just think of the bolder and the pebble: if you push them equally, which one is going to pick up speed faster?
Helen	Okay the stone is going to initially, but if its dropped…
Teacher	For now don't think of dropping. If I've got a very heavy bolder and a stone and I push them, which one's going to be easier to get moving?
[Noise]	
General	Stone.
Teacher	If I push them with the same force, which one's going to accelerate faster? – the lower mass.
Helen	But it's different when it's falling.
Teacher	Why should it be different that way than that way? [showing vertical and horizontal with hands.]
Helen	Gravitational pull.
Teacher	Gravity's the pull. Here you were the push, here gravity's the pull. What's the difference?
Helen	But… [unclear]
Teacher	But don't worry about that now, you must decide if it's true that a 1kg object will speed up more than 2kg if the same force is applied. So if you've got a heavy one or a light one, which will speed up faster?
Helen	The small one.

Helen's reference, above, and Marike's, below, to size, rather than mass, suggest that my attempt to show that mass, rather than size, was the significant variable in affecting acceleration, was ineffective. On the other hand, this extract does suggest that the learners were engaging in an intellectual struggle which involved critical thinking. For example, Helen's frequent protests suggest that she is undergoing an intellectual struggle. Further, Helen and Marike's frequent rebuttals to my explanation, such as "but it's different if you drop it", "but the gold is heavier", "but the pebble can go and sit on something", suggest that they were undergoing critical thinking. The learners' lack of self-direction, as shown by their heavy dependence on me, as well as the vagueness of their remarks, however, were concerning. This is shown, further, in the continuation of this extract:

Teacher	The light one – just like that: if you push with the same force the light one speeds up faster. But are they pulled with the same force?
Sonja	No.
Teacher	Which one's pulled with a greater force?
General	The heavier one.
Teacher	How many times?
Helen	Two times.
Teacher	As many times as it is heavier.
Jabu	So that's true.
Teacher	What?
[unclear]	
Teacher	Which one will go faster?
Sonja	The light one.
Teacher	The light one, but…
Marike	The gravity on the bigger one is greater – but if its 1kg and 5kg, then 5kg isn't twice 1.
Teacher	Then it's 5x.
Sonja	The ratio is the same.
Teacher	Exactly. The two effects cancel out so that they fall together.
Busi	Oh.
Teacher	If what?
Kim	If the surface area is the same.
Teacher	Why should that matter?
Jennifer	Air resistance.
Teacher	That's the point: if there were no air resistance, surface area wouldn't matter. So you remember I wrote "if it's heavier then it falls faster". How will you fix that up?
Kim	There is no air resistance.
Teacher	If it's heavier and there's not air resistance it will fall faster?
Jennifer	No – the same.

(Audio transcript: 20/04/06)

Notice the learners' fragmented and vague responses, such as Kim's reply "there is no air resistance" and Sonja's answer "the ratio is the same". This, and the heavy teacher dependence evident here, were usual characteristics of discussions during this section. The reason I took this teacher-dominated strategy here was because learners had not made sufficient progress to manage to explain the argument without this sentence-by-sentence prompting. This was despite the fact that learners had worked on the task for homework and approximately half an hour before this extract.

This extract gives the interaction I underwent with only one of the five groups. Discussions with the other four were similar. I found the teacher-dependent, slow, confusing and repetitive prompting, the noise, intellectual and communication messiness, and confusion, frustrating. Further, it appeared that most learners did not learn the desired concept effectively. Even though over an hour was spent discussing this concept, and it was taught directly the following day, and revised each day for a few consecutive days after this, in the June examination only six learners out of the 23 could give this argument correctly. While this does not necessarily imply that another method of instruction would have been more effective, it does suggest that this method was of limited effectiveness in getting learners to understand the required concepts.

I received the impression that the learners developed an intense dislike for mechanics as a result of this cycle. I received numerous complaints from the learners about this section. I surmised this dislike arose from the learners not developing strong conceptual understandings, and that this was because their poor generalisation and pattern-searching skills caused them not to be able to derive these during the inductive facilitated discussion they were engaging in. This was despite much effort and intense activity and participation on the learners' parts, as well as evidence that critical thinking was occurring. This poor conceptual learning meant that the large numbers of concepts learners were required to understand and link became overwhelming.

The strategy was riddled with other problems too. A number of learners reported to not seeing the use of studying the section because it seemed to have no interesting or useful link to their lives. Additionally, a number of learners confessed to guessing during homework activities. They said they did this since they found the tasks overwhelming when performed alone. Also, they confessed, guessing was encouraged by the fact that they did not have to justify answer selection when answering the multiple-choice homework questions. Further, the strategy was even more time-consuming than the electricity section had been. I spent 30 hours, rather than the stipulated 14, on this section and another 5 hours at the end of the year, re-teaching the section. This was done by means of traditional direct-teaching in response to learners' request to be helped out of the confusion that had resulted from my initial strategy.

Reflection

The discussion above suggests that the inductive facilitated discussion strategy, taken to a great extent in this section, and exemplified by the extract, was not effective in that it did not promote strong conceptual learning. On the other hand, 58% of the 57 learners who participated in this study in 2006 and 2007, responded, in a questionnaire, that they did find this inductive strategy effective, and 61% indicated that they enjoyed it. Test performance evidence is less conclusive concerning the effectiveness of the strategy. For a test which focussed on this section, seven of the 23 grade 10 learners in 2006 scored below 50%, and another seven scored above 70%.

The learners' dislike for the context of a falling stone was very obvious. They complained that it was boring and pointless. They had clearly not enjoyed the section, and part of the reason for this seemed to be the absence of an interesting context. This made me realise the importance of situating the next module's learning within a context which the learners would find interesting. Further, the learners' confusion and need for a more structured provision of information and support during the sense-making process, was clear. On realising the confusion I had contributed to by my unintended communication errors, I wished I had rather introduced the concepts during delivery of a pre-planned lesson. I was convinced that in this way I would have been able to explain the concepts in a more helpful way. Learners would have then have had a chance to make sense of the explanations during the discussions. Further, I realised that inductive discussion does not reduce time through short-circuiting the need for direct teaching. Instead, it requires more time than a more deductive strategy does. Further, expecting a removal of support to induce self-direction is clearly not reasonable in the case of learners whose skills and content knowledge are still poorly developed. Finally, this section suggested to me that critical thinking tasks in which answering can be done by guessing should not be assigned for homework. This is particularly the case if there has been no prior class engagement in the task. Evolving from these reflections, I developed a strategy to be used in the grade 10 section which followed mechanics. This is described next.

4.2.4. How can I capture interest?

Action

The waves section consisted of two topics, namely longitudinal waves and geometric optics. I designed a module for each of these. The first module, *Tsunami*, will be stressed here, since it was re-used in both 2007 and 2008. The second module consisted of a number of tasks related to cell-phones, but in subsequent years this module was discontinued due to time pressure. In the Tsunami module the learners role-play a professor and a sailor. They use knowledge of wave properties and behaviour to give advice on various proposed mitigating measures to protect South Africa from an expected tsunami and to explain how to take measurements of various aspects of waves and from this diagnose whether a wave is a tsunami or not. This task is included in its final 2008 version in Appendix J. The 2006 version did not have the scaffolding worksheets included

I presented the problem and then allowed for initial learner exploration of the task's implications for learning. I then approached the relevant concepts with the following combination of strategies. I tried to induce the learners to derive concepts through guided learner discussions. I used direct teaching in the interactive way previously described, and I expected learners to make sense of directly-taught concepts as they strove to apply these to the subsuming problem task. I periodically demonstrated aspects of waves to the learners and guided their observation and analysis of these. This I sometimes did using a ripple tank and sometimes by means of computer simulations of wave behaviour displayed using a computer and data projector. Using this strategy is consistent with findings that exposure to empirical evidence aids sound concept formation (Gauld, 1989). Further, I made frequent reference to Paul & Elder's elements of thought and intellectual standards during the teaching (Paul & Elder, 2006a), and I frequently called on learners to relate these to particular aspects of the target task.

Additionally, I encouraged learners to submit voluntary written drafts of their understanding of the work and their attempt at answering the target problem. This practice is consistent with the view that getting learners to write about their learning aids critical thinking and, consequently, learning with understanding (Paul & Elder, 2001). It is also consistent with Black's assertion that formative assessment enhances learning effectiveness (Atkin & Black, 2003). I responded, in writing, to each draft. Additionally, I gave verbal feedback to the whole class where I became aware of common misconceptions. By misconceptions I refer to views which are not consistent with commonly accepted scientific thought (Stanton, 1990). The responses I gave to the class included corrections, explanations and questions designed to prompt the learners to think more deeply, express themselves more logically or precisely, provide backing to claims, or explaining the relevance of a claim to the overall argument they were making. I also allowed learners to read one another's work, with my accompanying remarks, if they wished, although prohibited copying. This strategy was intended to empower the learners to be able to complete the target task satisfactorily by the time the end of the teaching period for the section had been reached.

Observation

I found an intense interest and enjoyment, and very high levels of learner engagement both in and out of school hours during this section. For this period my journal features almost daily notes about the learners appearing to be interested. Similarly, almost every entry shows signs of the learners being intensely active in and out of class time. For example, on 25/07/06 I wrote, "a group of girls voluntarily stayed after school to continue discussing what this had to do with the task". Fourteen cases of learners giving me voluntary notes or drafts for checking, further testifies to the learners' engagement beyond the minimum task requirements. During an interview with six learners on 18/08/06, eight exclamations of interest in this task were made within the first ten minutes of the interview, with all participants unanimous about this.

However, as the task progressed, I realised that it was more complex than I had initially thought. This was disconcerting for both the learners and me. Learners would sometimes ask me questions about the task which I could not answer satisfactorily, causing feelings of insecurity for both of us. Learners reported insecurity from the fact that the text-book dealt superficially with the concepts and was therefore a poor resource to support them in the answering of the task. I, likewise, often felt insecure, as suggested by this remark:

> I am not myself sure of exactly what I want from the learners. So in general I get a feeling of interest and enjoyment of the task, but uncertainty of how exactly to go about answering it due to its complexity and open-endedness. (RJ: 01/08/06)

I found, in general, a high standard of work in the final submission, which was marked with a rubric which credited argument relevance, significance and logic, correctness and thoroughness of content. The class obtained an average mark of 68%, with 11 of the 23 learners scoring above 70%. Two of the learners, however, were awarded below 40%. This written work, as well as the dialogues observed amongst learners and between learners and myself, suggested that learners were undergoing critical thinking. This included instances of learners rebutting one another with references to essential criteria, considering multiple options with costs and benefits of each, within a given context, voluntarily asking essential questions, as well as a general atmosphere of self-direction. The generally high standard of work, as well as remarks made in learner interviews, suggested that most of the learners had developed fairly strong understandings of the concepts stipulated by the curriculum. On the other hand, the poor performance of two of the learners was concerning.

The process, however, was slow, taking 26 hours of class time instead of the 14 suggested by the curriculum programme guidelines (DoE, 2003). Further, some learners complained about the high language focus of the task. They also reported needing greater guidance. Five of the six learners interviewed on 18/08/06 remarked that they liked the open-endedness and ambiguity of the target task since they said this encouraged them to think deeply and independently. However, all said this aspect also made them feel insecure. I formed the impression, from what they said, that sometimes this prevented them from engaging with the task as deeply as they might otherwise have. Further, only five of the 23 learners produced drafts for the final task, suggesting poor time management amongst the rest of the learners.

Reflection

The positive outcome of this module convinced me of the advisability of the use of an interesting open-ended subsuming problem into which most or all of a topic's learning is embedded. This conclusion is considered to mark the end of Theme Cycle A, as indicated in Figures 4.1. and 4.2. Other aspects I reflected on were the role of procedural exercises, the need for greater structure and guidance, and the time-consumption of the process I had used here.

I considered the high language focus associated with use of a context-rich subsuming problem to be inherent to critical thinking. I felt that I was supported in this by literature, for example by Paul & Elder's inclusion of the ability to express scientific concepts in every-day language in their list of essential components of a critical approach to science (2006c). On the other hand, I was concerned that the focus on conceptual understanding would prevent learners from developing the necessary competency in answering the numerical questions which might dominate the end of year examinations. However, in the final examination, the learners obtained an average of 68% for those questions involving computation with regards to waves, with only three of the learners obtaining lower than 50% for these questions. This suggests that the learners had learnt the basic computation relevant to this section, although this may have been thanks to my focus on these kinds of questions during revision for the final examination.

The Tsunami module suggested that higher degrees of structure and guidance were needed in the written material provided with the task. This is consistent with findings by numerous researchers that high degrees of structure are necessary for a critical thinking task to be effective (e.g. Adam, 1999; Ankiewicz et al., 2001; Lee, 2003; Milton, 1993). I provided guidance through my verbal interaction with the learners as they underwent group discussion, and in written form on an individual basis for those who submitted drafts of their work for me to check. However, the fact that so few learners made use of the latter service suggested that a different system was needed. Further, I pondered the possibility that allowing the learners to read peers' drafts and comments had masked the weakness of this lack of structure and guidance, to an extent.

At this stage I reflected on how much time each of the modules done so far had taken. I had finished only a third of the curriculum, yet I had used three quarters of the available teaching time. Further, I was disillusioned by the inability of the inductive inquiry strategy to lead learners to sound conceptual understandings. This made me ponder the strengths of a more traditional strategy. Consequently, I decided to try a more teacher-dominated, highly structured strategy when introducing concepts. This would be followed by requiring learners to make sense of the concepts through answering questions based on the preceding teaching. This I did for the remainder of 2006. I convinced myself that this seemed more consistent with a view, taken by the Information Processing Model of Learning (IPM), that the capacity of working memory is the limiting factor in learning (Niaz & Logie, 1993). Consequently, presenting concepts individually, sequentially and incrementally, in a highly structured manner, is more manageable for learners than expecting them to deal with multiple new concepts within a complex problem situation.

At this time I received the Education Department's exemplar examination papers, as well as the revised physical science content document (DoE, 2006). To my dismay I noticed an increased emphasis on content in this new version of the curriculum. I realised from the exemplars that I was not preparing learners well for an externally-set examination. This was partly due to being very far behind in the syllabus. Further, the examination was set in accordance with the revised version of the curriculum content which required coverage of many concepts, whereas I had been teaching according to the original version which allowed for a deeper engagement with fewer concepts.

This reflection led me into a series of cycles during which I reverted to a large extent to a traditional strategy of direct instruction. Together with the sections making up Theme Cycle A, these convinced me of the importance of both direct instruction and facilitated group discussion, which I labelled the outcome of Theme Cycle B. This part of the journey is discussed below.

4.2.5. Reverting to traditional teaching

Action

I employed a highly teacher-controlled, systematic strategy, using PowerPoint presentations, for the next section, chemistry. I did this in an attempt to cover content more rapidly. Additionally, I occasionally performed practical demonstrations for the class. I designed my presentations to be interactive, often posing questions and expecting learners to respond in pairs before I proceeded. I also tried to integrate teaching of aspects of critical thinking, such as the criteria for causation and elements of thought, with teaching of content.

Observation

Due to time constraints, I had to cut the Chemical Systems section out of the grade 10 syllabus. However, I did manage to get through the Matter and Materials and Chemical Change work required by the curriculum in a remarkably short space of time. Four of the five learners interviewed on 03/11/06, however, reported that I had not provided for enough time and reason for them to think critically, except occasionally during class time, during this section. They attributed this to the fast pace taken and the fact that the presentations were not linked to a long, interesting target task. Additionally, I experienced that the pace I took in my teaching was clearly faster than the pace at which learners were able to make sense of and internalise learning. I frequently recorded my frustration resulting from this. The following is an example:

> The lesson was frustrating because the learners were so slow. I realised that I had not provided enough practise with building formulae, although the learners had done all the questions related to this in the text book. Last year's class had done far more and we had worked with lots of equations together, with the old curriculum. So no wonder in comparison these learners seem so slow and dense when asked to write an equation. In the evening I spent three hours adjusting my PowerPoints to make them more incremental and visual. I'm trying to avoid today's frustration. Today it clearly poisoned the class – I felt as if the learners viewed me as an enemy because I was going too fast for them. (RJ: 17/10/06)

Reflection

This experience underlined the fallacy of learning by information transfer from teacher to learner. It highlighted that although the clarity and structure of direct instruction can have the advantages of being time-efficient and less messy than other strategies, it is insufficient as a method of instruction on its own. This seemed to be the case despite the fact that the form of direct instruction which I used was highly interactive, with question-posing and wait-times built into the approach. Some kind of additional sense-making opportunity was needed in addition to direct instruction to promote critical thinking and hence effective learning, and to match instructional pace to learning pace. This is consistent with views in literature that direct instruction is insufficient on its own (e.g. Gunter et al., 2007).

4.2.6. Traditional teaching followed by sense-making

Action

The phasing out of the old curriculum and the implementation of the new resulted in both the grades 10s and 11s studying motion in 2006. In the light of the failure of the largely inductive strategy used with the grade 10s earlier in the year, I decided to take a more structured strategy with the grade 11s to whom I taught motion later in the year. I prepared a series of PowerPoint Presentations in which I developed the concepts incrementally, with frequent short question-posing to promote comprehension and to provide opportunity for sense-making. After introducing the formulae, I worked through examples of their usage, and posed questions to the learners. The answer to each of these questions was voted on by the learners, answered individually in writing, or discussed in pairs, after which I would provide the correct answer, with motivation, or get one of the learners to do this. In this way I made an effort to have the majority of class involved in the questioning. Most of the homework given was of the standard text book, numerical exercises type. At the end of the section I gave the learners two sense-making tasks. These required use of conceptual understanding and critical thinking as well as procedural competence. One of these involved learners performing practical work. Learners did the work for these tasks individually in writing for homework, followed by small-group discussions with frequent alteration of group composition. At the end of the year, I re-taught the mechanics section to the grade 10 class using a highly structured, yet interactive, strategy. This was similar to the one taken with the grade 11s, except that time did not allow for implementation of the final sense-making activities I had used with the grade 11s. This re-teaching process took 5 hours of class time.

Observation

The class time usage for this strategy, together with that for the strategy used with the grade 10s, is shown in Figure 4.3 This shows that the more structured strategy which gave greater prominence to direct instruction, taken with the grade 11s, was far less time-consuming than the inductive strategy taken in grade 10. It should be born in mind, however, that the grade 11 section referred to in the lower graph in Figure 4.3 is a subset, i.e. only the motion topic, of the grade 10 mechanics section shown in the upper graph. The topics of gravity and energy make up the difference. However, these two additional topics are relatively short, being dealt with in only six class hours.

The positive response from the grade 11 learners concerning the motion section was remarkable. In a questionnaire answered by all the learners on 20/10/06, as well as an interview participated in voluntarily by seven of the 18 learners on the same day, there was unanimous agreement that the strategy was better, being clearer and less time-consuming, than the more inductive strategy I had normally used with these learners. Similar positive comments were obtained from the grade 10 learners in an interview on 03/11/06, after I had re-taught the mechanics section to them.

While the stronger grade 11 learners clearly did engage deeply with the topic, which must necessarily involve critical thinking (Nickerson, 1994), the weaker learners were observed to borrow phrases from their academically stronger peers and use these superficially. Additionally, in comparison to the Tsunami module, learners were clearly not engaging deeply and voluntarily in learning after school hours, and were not as interested and excited about the learning process.

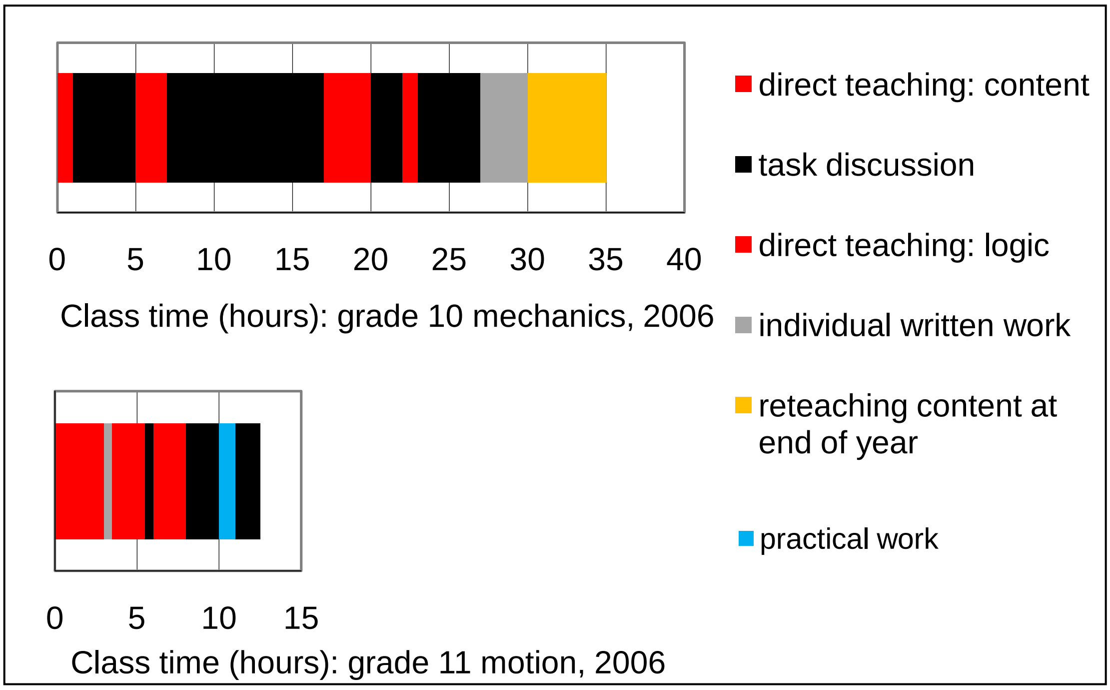

Figure 4.3: Class time usage for grade 10 mechanics and grade 11 motion, 2006.

Reflection

This experience convinced me of the value of well-structured direct, but interactive, teaching, followed by engagement in sense-making activities. However, it also convinced me that even when direct instruction is followed by sense-making activities, learning seems not to be as passionate and exciting as when learners grapple with an interesting sense-making problem throughout the course of a module, as had been the case in Tsunami. I also considered the correlation between the strategy I was taking and literature. I considered that it could be that using direct instruction to a large extent can be less inconsistent with this literature than an initial consideration may suggest. This is particularly so if the teaching is done in an interactive manner which challenges learners, and gives them opportunity to inductively and deductively, inquire and argue. I hoped that if attention was paid to this, the benefits the literature suggested for activities of inquiry, reasoning and argument could be obtained within the closely structured setting of teacher control rather than during loosely structured learner discussion. However, from practical experience as well as literature I was aware of the limitations of direct instruction in exposing learner misconceptions and promoting active learning (Leonard et al., 2002). Also, having seen the interest and active engagement learners displayed during the grade 10 electricity and mechanics group discussions, I wanted the next cycle to include both direct instruction and the opportunity for facilitated group discussion. This is consistent with Cronjé's view that integration between content and teacher-centred strategies, which he terms instructivistic, and more learner-centred strategies, which he terms constructivistic, is both possible and advisable (Cronjé, 2007).

4.3. A CRITICAL EVENT

At this stage I was armed with the conclusions that the instructional strategy to be taken should stress both direct instruction and learner collaboration while engaging with an interesting subsuming problem. I was also challenged by the need to streamline this strategy to squeeze it into the narrow time allotment allowed for by the curriculum. While reflecting on this I was exposed to problem-based-learning (PBL). I recognised this as having some similarities to the strategy which was emerging from my research. PBL uses facilitated group discussions related to an interesting real-life problem, to entice learners to undergo a process of sense-making. This culminates in learners being able to apply their learning to the initially-posed authentic problem. These aspects of PBL corresponded to the understanding of best practise which was emerging from my research. On the other hand, a focus on direct instruction is incompatible with PBL (Thomas, 2000). My research, however, was revealing that it is vital to give direct instruction high prominence in any instruction strategy required to cover large amounts of content and prepare learners for high stakes examinations with many numerical problems to solve. An aspect of my engagement with PBL which particularly influenced my work from this point onwards was its stress on scaffolding tools. These are designed to aid learners in the learning process, and seemed potentially powerful in solving the problems of insecurity and poor time-management I had experienced in the Tsunami module. I was resolved, therefore, to use these in the next modules I created.

Evolving from this reflection, I developed a new strategy towards grade 10 mechanics to replace the 2006 tasks I had evaluated to be unsuccessful. This set of modules, which formed section 7, is viewed as having been critical in this study. Although it occurred at the start of each of Theme Cycles C and D, to which it was common, the sections following it confirmed it as the model of best practise emerging from this study. This section consists of three topics: motion, gravity and energy, with the last two making up very little of the curriculum in comparison to the first. The modules designed for the motion topic were long. They are focussed on in the description which follows. In contrast, the gravity and energy modules were short, together taking a week and a half to complete, but modelled, on a small scale, roughly on the same lines as those focused on in the description below.

4.3.1. Initial planning

I designed three modules for use in the motion topic. While periods of direct instruction were common to all three, the subsuming problem task differed between them. Each learner only had to engage in one of these, but the possibility existed for learners to do more than one for bonus marks, and learners were required to interact with those learners who did the same task as them, as well as those who did different tasks. This was done partly to provide the possibility for performing extra work for enrichment and partly in an attempt to increase the likelihood of learners being able to transfer their knowledge to new contexts According to Perkins & Salomon (1989), this can be aided by explicitly pointing out the application of the knowledge within various contexts. A form of the Jigsaw Model of cooperative learning was used in that learners belonged to and worked with expert groups composed of all the learners assigned to a particular module, but also collaborated in learning groups, where each member was engaging in a different module (Gunter et al., 2007).

One of the tasks is given in Appendix K. This was titled *Must he pay?* In this task learners role-play a judge. They have to decide, on the basis of the partial data from a taxi’s motion, the truth likelihood of a claim that the taxi had bumped a woman standing at a certain spot on the road. They are required to justify their decision.

Before beginning the section, I paid careful attention to preparing the instructional strategy I would take and the support documents I would use. My strategy was as follows concerning the issue of conceptual versus procedural balance.

I would teach the learners how to perform certain procedures, such as using the equations of motion, I would assign class and homework tasks to practise these, and I would also integrate the need to use these into the subsuming mainly-conceptual problem task. I feared that learners might avoid reasoning conceptually in this task due to the presence of the procedural short-cut. I tried to prevent this by designing the scaffolding worksheets in a manner that was meant to force conceptual engagement. I set up a system of scaffolding worksheets during the planning stage of this section in correspondence with my teaching strategy. These were of three types: a KWL (know, wonder, learn) chart, interim reports, and a presentation template. I also created a series of PowerPoint presentations to guide my direct instruction, and a time-schedule planning the sequence of teaching and learning events. I will now describe the strategy taken during this section by referring to use of direct instruction, facilitated group discussion, homework and interaction with scaffolding worksheets.

4.3.2. Direct Instruction

The manner in which I engaged in direct instruction is exemplified by an extract from my Researcher's Journal (RJ), below. This interactive style of teaching is what is referred to when I use the term direct instruction in this dissertation. Some of the PowerPoint slides used to support the teaching of this section are shown in Appendix L Some of the discussion which follows refers to the extract, and some to the greater level of detail evident in the appendix.

> I show the learners a newspaper clipping about a taxi accident, in which terms such as position, distance, displacement, speed, velocity and acceleration are used. I ask the learners to tell one another what they understand by each of these terms, and then we discuss this as a whole class.
>
> Then I teach the concepts of distance and displacement. To make learners realise a need for two separate concepts related to *how far*, I make two learners walk across the room: one straight across and the other along a crooked path. I ask the learners to compare how far the two had gone. The ensuing class discussion reveals that in one way this was the same for the two, and in another way it was different. I then apply the terms distance and displacement to each of these two ways of referring to *how far*.
>
> I show learners the definitions, symbols and units of measurement of each concept. I get learners to use the terms to compare the motion of each of the learners in our simulation. I give learners an equation for calculating displacement for motion in one dimension. I also give the learners practise in applying the concepts of distance and displacement and the equation for calculating displacement in one dimension, to questions I pose. (RJ: 23/01/08)

The teaching style used is interpreted to be consistent with both traditional, and more modern ways of teaching, which Cronjé refers to as instructivistic and constructivistic principles (Cronjé, 2007). It exposes prior knowledge, for example by getting learners to speak about their understanding of various terms in relation to a newspaper article and a demonstration of two learners' motion. Where necessary, a teacher-guided discussion aimed at developing dissatisfaction with current knowledge and a need for further learning follows this. It also tries to support the process of concept construction. It does this by introducing each concept in relation to a need emerging from the discussion, such as a need for two ways in which to differently refer to *how far*. The discussion above is consistent with constructivistic pedagogy. On the other hand, the teaching strategy described in the extract is highly teacher-controlled and structured, consistent with instructivist, or traditional, pedagogy.

Questions aimed at inducing learners to generate concepts and procedures were used in the teaching. An example of a concept-generating question is "How can we define *how far* in two different ways corresponding to the two different meanings we have seen are needed?" An example of a procedure-generating question is "Represent these two understandings of *how fast* in two formulae". These were answered individually in writing or by pair discussion during a short pause within the teaching. Concept application questions were also used during the teaching. This was done to encourage conceptual sense-making and to reinforce learning. An example is "Is it possible for Joyce's displacement to be more than the distance she covers for a certain motion?" Procedural application questions were also used to reinforce learning. For example, "Calculate the distance and displacement Joyce undergoes".

4.3.3. Homework

Procedural-focused homework was generally assigned after direct instruction, with some exceptions. For example, following the teaching of distance and displacement the learners answered numerical questions about distance and displacement for homework. This is shown in Table 4.1. This table lists activities performed in class and for homework for the duration of the motion topic. In addition to the homework which aimed at developing procedural fluency, engagement with scaffolding tools related to the subsuming problem task was required. This involved learners answering these worksheets individually in writing. These worksheets are discussed in detail below.

4.3.4. Scaffolding worksheets

The scaffolding worksheets for this section were designed with the intent of making learners use both conceptual and procedural knowledge to solve the module's subsuming problem task. These worksheets were a *K-W-L chart*, three *Interim Reports*, and a *presentation template*. They were answered partly in class-time and partly for homework. They were engaged in individually in writing after which they formed the focal point of group discussions.

I designed the scaffolding worksheets such that learners would be required to engage in an initial conceptual analysis of the subsuming problem task, followed by procedural performance and then conceptual reflection on this. I did this to try to prevent learners from avoiding conceptual thinking by application of procedures alone. This can be seen in Appendix K as well as in Table 4.1. The K-W-L chart and Interim Report 1 are almost only conceptual in focus. Interim Report 2 and 3 have a procedural focus: graphical for report 2 and equation-based for report 3.

The purposes of the K-W-L chart and Interim Report 1 is to initiate a conceptual engagement in the problem situation. In the K-W-L chart, learners write what they already know, what they wonder about the section, and what they will need to learn to be able to find answers to this. This was done immediately after introduction to the subsuming problem tasks. Interim Report 1 was answered after I had taught the meanings of the basic concepts of motion, and required learners to reproduce the basic facts about these concepts, to link these concepts to aspects of the problem task, and to search for and describe patterns in the provided data. This is illustrated in Interim Report 1 of *Must he Pay?*, given in Appendix K. I found the learners' engagement with these initial scaffolding tools superficial and slow. For example one group spent 20 minutes, on 30/01/07 trying to figure out what photograph number tells about the motion in Must he Pay*?* The learners made

Table 4.1: Time schedule for grade 10 motion, 2007.

Key:

Conceptual focus	Procedural focus	Equal conceptual and procedural focus

Date	What was done during the 1 hour lesson	Homework
19/01	I introduced the motion tasks (*Pay*, *Plunge*, *Car*) and the basic strategy I will be using. Learners wrote in the KWL chart, and shared this with one another.	*Cars* activity 2
23/01	Went through homework; I taught (revision from last year) distance and displacement using PowerPoint.	*Cars* activities 3-5
24/01	Went through homework; I taught speed and velocity using PowerPoint.	*Cars* activities 6,9,10
25/01 (½)	Went through homework.	
25/01 (½)	Learners did Ferrari and Cheetah task.	
26/01	I taught different types of motion and the difference between average and instantaneous velocity and how to find instantaneous velocity. Used PowerPoint.	Interim Report 1
30/01	Learners discussed Interim Report 1 in groups and submitted these to me for marking.	
31/01	I taught graphical representation, using PowerPoint.	Graphical representation worksheet
01/02	Learners discussed Interim Report 2 in groups while I taught new learners what they had missed.	
02/02	I taught frames of reference, revision of graphs, introduction to equations of motion. Used PowerPoint.	Interim Report 2
06/02 (½)	Learners discussed and improved Interim Report 2.	
06/02 (½)	I taught equations of motion using PowerPoint.	
07/02	I taught equations of motion using PowerPoint.	Equations of motion worksheet
08/02	Went through homework.	Interim Report 3
09/02	Learners discussed Interim Report 3 and final presentation. Submitted Interim Report 3 at end.	
13/02	Went through common problems.	
14/02	Went through common problems.	Final presentation
15/02	Learners discussed their answers with learners who had done the same task and with learners who had done different tasks.	Finalise final presentation

statements such as, “The camera takes a photo always after the taxi has moved a certain distance and it tells us the speed of the taxi”, with the whole group agreeing with this for a while. Another example of this superficiality is given by the following comment from my journal:

> On marking the learners’ written work (Interim Report 1), I find that except in *Which car to be in*, there seems to have been little productive and deep thought on the task, and much error. In many cases mistakes are made even in the basic concepts. There is clearly a good deal of copying from one member of the group by the other members evident. I get the impression that the learners are very dependent on me and on one another for progress. (RJ: 31/01/07)

Engagement with Interim Report 1 was followed by direct teaching about graphical representation of motion, as shown in Table 4.1. Learners then answered a worksheet on this for homework, we went through their answers in class, and then the learners engaged with Interim Report 2. This required them to represent the situation graphically, describe conceptually what this showed, and evaluate the implication of this to the solution of the problem task. The following extract illustrates some of the struggle learners underwent while engaging with this. It also suggests a deep engagement with the concepts, and evidence of an emergence of understanding:

> Later in the day, while batting for an absent teacher, Musa comes to me with Interim Report 2. At first I feel we will never get anywhere. He seems not to realise the most basic aspects of the task. For example, he cannot see that change in position between any two consecutive photographs, divided by the time duration between the photographs, would give the average velocity for the interval between those two photographs. However, later I am amazed at how much he actually can see into the task. When I ask him to speak about patterns in the data he gives changes in position per time interval and comments on a steady increase. He links this to the increase in velocity. Later he points out the period of constant velocity and remarks, as he uses his calculator, that the distance increase per half second is now constant. He makes similar remarks about the period of deceleration. I advise him to continue the pattern he had previously noticed. I probe to see if he has realised how this could be significant to the task as a whole, and get the impression he does understand this. He had previously started drawing the graph and asks if this is correct. I tell him to plot per half second, starting with 0s as the first point, but otherwise he has the right idea. (RJ: 01/02/08)

After learners had written answered Interim Report 2 for homework, they were allowed an opportunity to discuss their answers in class time. This is referred to in the extract below. As mentioned here, I found the amount of input I had to input into learner discussions manageable. This can be contrasted to the greater dependence of learners on teacher prompting for progress which was observed when a more inductive strategy had been used, as was described earlier. This extract also suggests that the effortful learning process is beginning to yield results.

> For the first half hour the learners discuss the answers they had written for homework for Interim Report 2. Except for the three new learners, pleasing progress seems to be occurring and understanding seems to be developing well. Some feedback is necessary, from me, concerning Interim Report 2, but not to an extent which suggests learners are very dependent on me. The learners are actively engaged and show interest and application of learning to the task. They seem to be coping well with the task. This is confirmed by the learners' journal entries, which show evidence of struggle, but also progress. Three examples, representative of six others, are given:
> Petrus: I loved today's lesson because I learnt of a new way to work out a problem.
> Musa: I really was struggling to find where he stopped but after I went to Johan and he explained to me then I was confident and I understood.
> Mandla: I have an idea of what's going on with What's in the Plunge, but I often get confused in the process. (RJ: 06/02/07)

The discussion referred to above was followed by direct teaching into use of the equations of motion. This was followed by learners answering exercises to practise the usage of these equations. Then the learners answered the final interim report. This was done partly in class on a day I was absent, and partly for homework. This worksheet required learners to represent the problem diagrammatically, after which they had to solve the problem using relevant equations of motion. They were then required to give a conceptual evaluation of this in light of the problem task. The following extracts from my journal refer to this:

> In the afternoon I mark the learners' Interim Report 3 submissions. I find this discouraging. Almost none of the learners have applied the equations of motion to the problem. Further, a large number did not complete all the work I left for them while I was away on Thursday and Friday. These observations give me the impression that it is important that I am present, especially when the learners are working on a critical thinking task. On the other hand, Sofia and Tanya have each given excellent voluntary drafts of the entire target problem's answer. I give written feedback to each learner. (RJ: 13/02/07)

> I return Interim Report 3 to the learners. They read my comments. I allow learners to discuss common problems in groups and help one another fix their errors and improve their answers, and then work on their final submission. The latter, at least in rough, has to be completed by tomorrow. Two learners write in their journals that they work on this until very late at night. (RJ: 14/02/07)

These extracts suggest the important role the teacher plays in managing learning. This is shown by the reflection that the learners seemed to have suffered due to my absence while they were engaging in Interim Report 3. Further, these extracts suggest that my checking of the learners' work was necessary since it exposed errors and gave me the opportunity to guide learners to correct understandings.

At this stage, with all the interim reports completed, the learners produced a rough draft of the final solution to the problem task. This was guided by a presentation template. An example of such a template is given in Appendix K. The following day, in class, learners gave verbal presentations of their solution to the problem to one another: first to peers who had performed the same task as themselves, and then to those who had performed a different task. In general this appears to have been effective, although for some learners the struggle they had been undergoing over the past weeks did not seem to have led them to clarity on the related issues. This is suggested by the following remarks concerning learners' responses at this stage:

> The discussion is very animated. Ten learners write journal entries today. Eight suggest confidence in their own task. For example, Musa says, "Today it was nice and I was really sure that I understand my task". Two say they are still not managing. For example, Mandla says, "Plunge is very confusing, but I need to put my mind to it. The lesson was nice although The Plunge seems to need a lot of focus". Five make remarks suggesting that they have benefited from hearing about tasks other than their own. For example, Menzi says, "I had a broader view of other guys' tasks so it's good that we got tasks and also look at others to get more view." (RJ: 15/02/07)

The learners then wrote their final answer out in neat, which they submitted the next day for marking by me. As indicated in the extract below, this long language-rich task was found to require learners to spend many hours out of school time on writing the final submission. In some cases this was a consequence of learners working beyond the minimum requirements, as pointed out below.

> Today the learners hand in their final submissions. I also get feedback from them about how they feel about the strategy taken for this section. The general response is that they had struggled through the task, but found that it had made them think deeply, and that they had enjoyed it. They have had to work very hard, and have found there to be a lot of writing required. A number remark that it was nice to see how the various methods, such as explanation, pattern completion, and reasoning, graphs and equations, all corresponded with one another to give the same answer. Five of the 15 learners submitted additional tasks for extension, despite this costing them work into the early hours of the morning, according to comments made by four of them in their journals today. (RJ: 16/02/07)

While this active engagement suggests task effectiveness (Cotton, 2001; Schoenfeld, 1985), it is possible that the extent of the engagement may be seen as unreasonable or have negative effects, such as tiredness in class. For example, Petrus remarked, the following day, that he found concentration in class difficult due to lack of sleep as a result of having answered the motion task into the early hours of the morning.

4.3.5. Facilitated group discussions

Most of the facilitated group discussions in this section revolved around the scaffolding tools, and involved sense-making of information I had taught during direct instruction. The following description, however, refers to a half-hour facilitated discussion which was not related to a scaffolding worksheet or even to the subsuming problem task. It was a half-hour discussion, performed on 25/01, after the basic concepts of motion had been taught, but the equations of motion had not yet been introduced. Learners were asked to work out how far and how fast each of a Ferrari and a cheetah would be after 4 seconds of acceleration of each from rest, given their acceleration rates. In the absence of knowledge of the equations of motion, they would need to reason the answer out conceptually. This was an attempt to force learners to reason with the concepts without having the tools to short-circuit the critical thinking required for such a discussion by converting the task, instead, into a procedural exercise (Paul, 1995). The discussion which followed, described here, is considered to be fairly typical of the strategy I took in management of such discussions, and the general observation of how the learners responded to such discussions, during this section.

The task has the potential to induce learners to derive the equations $\Delta v=at$ and $s=\bar{v}t$. Development of the former is illustrated for one learner, Tanya, in the extract below. The introduction of the latter equation highlights a danger in this type of question. As shown in the extract below, I guided one of the learners, Johan, towards this equation, after which he repeated it, without the conceptual guidance I had given, to his friends. This in effect converted this part of the question to a procedural exercise for these learners. The inability of these learners to explain this equation, suggests that this was not effective in developing understanding or critical thinking. The latter argument rests on the premise that an ability to explain issues qualitatively is a hallmark of both understanding and critical thought (Nickerson, 1994; Paul & Elder, 2001).

> *Individual work*: After posing the problem to the learners, I tell them to work on it individually for a few minutes. Tanya almost immediately puts up her hand and asks if it is alright if she starts by seeing how the conversion between km/h/s and m/s/s works. I say yes. Johan quickly (within the first minute of individual work) has all the answers. Speeds are correct, but distances not since he has calculated these as if the object has been travelling at the final speed for the entire second. I explain this, and ask him what the average speeds are per second. He gives strange answers: 0,6 and 4. I ask him what the average of all the numbers between and including 0 and 6 are. He does something with his calculator and again he gives strange answers (3,5 and 0,5). I then say "What's the average of 0+1+2+3+4+5+6". He comments about dividing by 6 or by 7. He then gets it, and then gets all the answers. During the discussions later he shares his method with others. I wonder, though, whether they see why this method should work.
>
> All learners are apparently intent on work. Sofia is looking in the appendix of the *Cars* module. I wonder if she is revising previously done work so as to apply this here. Tanya calls me again. She is grappling with the meaning of acceleration. She has converted km/h into m/s and is confused about whether to multiply or divide this by the time to get the acceleration. She says "27,7 m/s in 4,6s, so it must be 27,7 x 4,6". I tell her *in* or *per* or *for every* means divide . . .

Johan, who is a strong learner, initially gave unreasonable answers to the seemingly simple question of calculating average velocity. Further, the interaction between him and the teacher was clearly necessary in helping him progress. These observations illustrate that error is a normal component of learning, even for strong learners, and therefore a secure environment which allows for errors to be made and challenged, is important for effectiveness. Tanya, also a strong learner, similarly, needed the freedom and support to struggle with concepts and ask for help. I tried to give this help in a manner supportive of understanding, by linking language and mathematical procedure, rather than merely supplying a rote operation. On the other hand, my reply that *in* means divide, could have lead Tanya to form a misconception, since this is not always true.

> . . . *Group work*: I divide the class up into groups and tell them to discuss the task with one another. Tanya asks me whether multiplying acceleration (6m/s/s) by time (4s) will give final velocity. I ask why that should be so, and she answers that there is a 6m/s change each second, so (6x4)m/s change for a total of 4 seconds . . .

By questioning Tanya on why she thinks that the algorithm she has generated, i.e., v_f=at, is correct, rather than just giving affirmation, I was trying to ensure that she applied conceptual understanding to generate the equation. However, it would probably have been better to have extended this questioning to contexts in which the initial velocity was not zero for the interval of acceleration. This might have led the learner to the generic algorithm $\Delta v=at$.

> . . . I move between the two groups. I find a general disregard for precision between the use of the units m, m/s and m/s/s, and a general tendency to refer to *what it goes per second*. I explain to each group that the racers' speeds are changing throughout the duration of a second, and so it is not possible to give one speed that *it goes* for the entire second. I point out the need to distinguish between the change in speed during a second and the actual speed at a moment within time, e.g. at the end of a certain second. I do this primarily by asking learners questions in response to their statements.
>
> In some cases, e.g. with Wiseman's group, this causes the learners to rethink their statements, asking me to come back later. In other cases, e.g. Petrus' group, it prompts members who had already understood the concepts to correct the faulty statement, this sometimes being their own, and explain this to the rest of the group. In some cases, e.g. with Hlonipha, my questioning does not seem to help. I ask him the difference between 6m and 6m/s. He says there is no difference. Sofia tries to explain the difference to him. It does not seem to me that he understands. I see that Jack, in Johan's group, is quite lost.
>
> There is a lot of struggle and grappling with words, and a fair amount of confusion on some learners' faces, but after a while most groups have the correct answers for the racers' speeds at certain moments in time.
>
> I split the groups and recombine them in different arrangements. I try to identify those learners who cannot explain how to get the answers. I assign learners who are able to do this to help them.
>
> Now the groups are working on finding the distances covered by each racer in the given time. Wiseman says he has calculated the distances using the average speeds, as Johan had explained to them. However, he is clearly using this method as a recipe, rather than with understanding. He, Arthur and Petrus ask why the Ferrari does not travel 6m in the first second despite its speed at the end of the second being 6m/s. I explain that it was not travelling at 6m/s for the whole second. Petrus says "oh – so then you'd have to break the second into segments." I build on this to try to explain why using the average velocity for the interval could be useful to find the distance covered. Petrus comments on how to find the average velocity. These comments suggest that he understands this concept.
>
> *Journal feedback:* Seven learners make comments saying that they enjoyed the challenge, and found group discussion helpful. For example, Wiseman writes "Very excited facing challenges. I've really enjoyed especially because when you discuss in groups you seem to get so much more". One learner says the task "disturbed" him. (RJ: 25/01/07)

This extract illustrates some of the process and benefits of facilitated group discussion, as was implemented in this section. Aspects of the process used includes guidance given by the teacher, and the practise of splitting and recombining groups with different member arrangements part-way through the discussion. The latter is referred to as jig-sawing from this point onward. It also illustrates benefits of this strategy to learning. Active learning is evident as learners grapple with the concepts.

Further, this seems to contribute to effective learning. For example, Wiseman claims that group discussion helped him to “get so much more”.

4.3.6. Reflection

According to my criteria, an effective strategy is characterised by learners being actively engaged and interested in their learning of science, both in and out of class time, the learning involving effort and critical thinking, while also being attainable and compatible with the curriculum. In terms of these criteria, the overall instructional model, with its component strategies, used in section 7, is interpreted to have been effective. This is justified below, with particular reference to the long motion modules of this section. After this, I look at difficulties experienced in these modules. I present the alternation of use of long modules such as these with shorter ones, such as those used for the gravity and energy topics in this section, as a partial solution to these difficulties.

Effectiveness

Active engagement and interest. The data collected for the motion modules was overwhelmingly positive with regards evidence of productive engagement, interest and struggle, with a fairly high degree of attainability. High levels of interest and active engagement were observed relating to the subsuming problem task for the described module. Sixty-four comments, from learner journals, interviews and observations, were counted with regards to learners being active, and 72 to them being interested and enjoying the strategy. In contrast, only 21 comments were counted related to learners not being interested, active, or enjoying the section. Four of the latter were related to initial revision of work which had been done in grade 9, rather than the problem task itself. Examples of learners’ remarks concerning interest and active engagement include the following, by Sofia:

> I like being sort of thrown into the deep end. When you gave me *The Plunge* I thought, mmm, like how am I going to do this? But then as soon as you start discussing it with people then it’s very nice. That’s why I like discussion: if you don’t know what it’s like and then you discuss. (Sofia: Interview: 27/02/07)

Critical thinking and effort. There is evidence that critical thinking did occur during the cycle. This includes the fact that the majority of the learners were able to perform well in the task, which demanded critical thinking for successful completion. Further, critical thinking was observed as learners engaged in the group discussions. Finally, abundant evidence of struggle for this section suggests that learners did engage in the effortful process of critical thinking.

Curriculum compatibility and attainability. Almost all learners did appear to acquire the necessary knowledge and skills stipulated by the curriculum for this section. As shown in Figure 4.4, 12 of the 15 learners achieved over 60% for the final submission to the subsuming problem task, with nine of these scoring A's. Additionally, five learners voluntarily engaged in more than one of the modules for bonus marks, although these are not reflected in the graphs. The learners' performance in the mechanics section of the externally set final examination also seemed to confirm that the desired competencies had been developed successfully in the majority, although not all, of the learners. This section was out of 40 marks, with 30 of these assigned to procedural questions and 10 to conceptual. The 14 learners to whom I had taught this section and who wrote the examination scored an average of 67% for this section. Eleven scored over 60%, five of these achieving over 80%. However, two of the learners achieved 39% or lower. This is represented graphically in Figure 4.5.

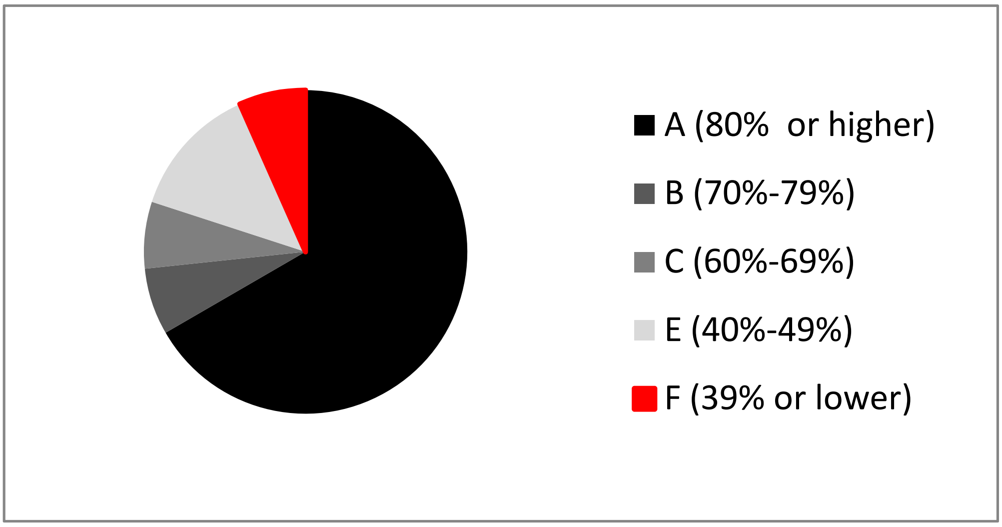

Figure 4.4: Mark distribution for the grade 10 motion task in 2007.

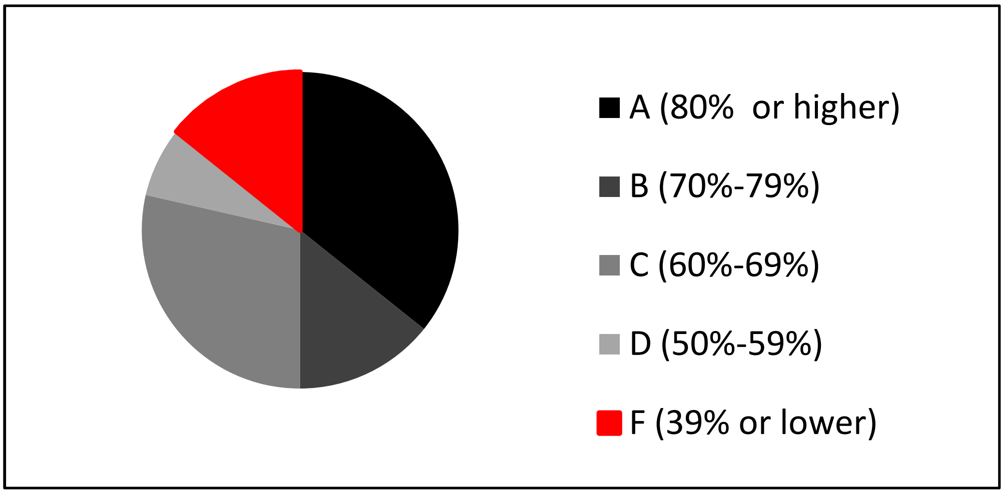

Figure 4.5: Mark distribution for the mechanics section of the final IEB examination, grade 10, 2007.

This performance also seems to suggest that the strategy of integrating procedural requirements into the subsuming, mainly-conceptual problem, was effective for most learners. Learners' comments, such as the following, also suggested a sense of satisfaction in seeing the integration of various strategies to problem solution:

> The task really got me critically thinking because all that we learned in the science lesson and put it into practise. It was very enjoyable to see one getting the right answers, to all the equations. Also that the equations' answers corresponded to the graphs. It was time taking to write it then all in neat. (Elizabeth: LJ: 16/02/07)

Difficulties

Despite this evidence, in general, of the success of the instructional strategy used in this section, it was not without its faults. One of these was that this success did not extend to all the learners. Three of the learners had not engaged deeply with the problem, one ascribing this to the conception that only a procedural treatment was required. Clearly, for these learners even the scaffolding worksheets had been insufficient to guide their learning in an effective manner. Another aspect which could be viewed as problematic was the lengthiness of the writing process required for the final submission. Additionally, I found it difficult to apply the rubric repeatably during marking of the final work. This was because much subjective judgement was required. Further, the marking was very time-consuming. Additionally, I was still unable to complete the work within the time required by the curriculum, although this effect was significantly reduced relative to the previous year. The curriculum stipulated that approximately 14 hours of class time be spent on mechanics. In 2006 I had spent 35 hours on this section for grade 10, i.e. 150% more than I should have. In 2007 I spent 21 hours on the same section, i.e. a relatively small 75% more than I should have. All of these difficulties seemed to me to be unavoidable consequences of the highly conceptual focus and the length of the problem task. However, it seemed possible to mitigate their effects somewhat by interspersing engagement with long tasks with shorter ones. Examination of the shorter tasks used for the gravity and energy topics of this section suggested this to me.

Shorter tasks

The discussion above has focussed on the long modules of the motion topic. Data collected concerning the shorter gravity and energy topics suggested that most of the learners who had coped with the longer module found it more effective in promoting deep engagement and critical thinking, but those who had found the longer module unattainable preferred the shorter ones. Even some of those learners who said they found the longer motion module more effective at promoting critical thought, remarked that they preferred the shorter modules because the final write-up of the motion task had been long and tedious. A few of the remarks made by learners in their journals are given below. These show extended periods of time spent on this final submission, as well as giving a sense of the struggle and achievement which many of the learners reported to for this task:

> Tanya: In the beginning of my task I didn't understand everything at once but now that I have finished it, everything is crystal clear. Last night I sat for about 3 hours rewriting my task. It took a lot of time.
> Musa: The project *Must He Pay?* was very interesting. I got to really like it when I understood the concepts. I really enjoyed the assignment, although it was a lot of work. (LJs: 16/02/07)

Reflection on all of the above reinforced the views I had developed during Theme Cycles A and B. In addition, it suggested that long subsuming problem tasks should be alternated with shorter ones. Further, it suggested the potential effectiveness of an integration of procedural and conceptual requirements in the direct teaching, scaffolding worksheets and requirements of the subsuming problem task. On the other hand, it highlighted the danger that the presence of procedural elements in such a task may subvert conceptual engagement. The latter finding was the reason why I continued my quest for an optimum conceptual-procedural balance, i.e. continued working within Theme Cycle C. This process is described below.

4.4. CONCEPTS AND PROCEDURES

While I was at school I formed an impression of physical science as a process of subjecting an arbitrary collection of equations to banal and mundane manipulation for little purpose other than finding an answer. In contrast, my later exposure to the fascination of scientific concepts created an impression of physical science as an intriguing, powerful, dynamic and exciting investigation. As a physical science teacher, I wished to pass the latter outlook on to my learners. My initial understanding of the new curriculum seemed to suggest to me that it supported me in this. However, as described in this section, I was soon confronted with the paradox that although I was able to achieve my vision of inspiring passion in learning of science, this threatened to brand me as a bad teacher. This was because, I found, a conceptual emphasis failed to prepare learners to answer exemplar examination papers. Below is a description of my quest to both prepare learners for exams and develop a deep understanding of and love for science concepts. This yielded no quick-fix solution. However, the strategy of integrating conceptual and procedural foci, as was used in the critical cycle (7), emerged as optimal.

4.4.1. <u>Stressing conceptual explanation</u>

Action

The main difference in strategy between sections 8 and 7, was the approach to integration versus separation of conceptual and procedural tasks. In 8, i.e. grade 11 mechanics, 2007, these two aspects were not integrated. This is indicated in Figure 4.6. by the relevant icons being separated from one another. I used this design to

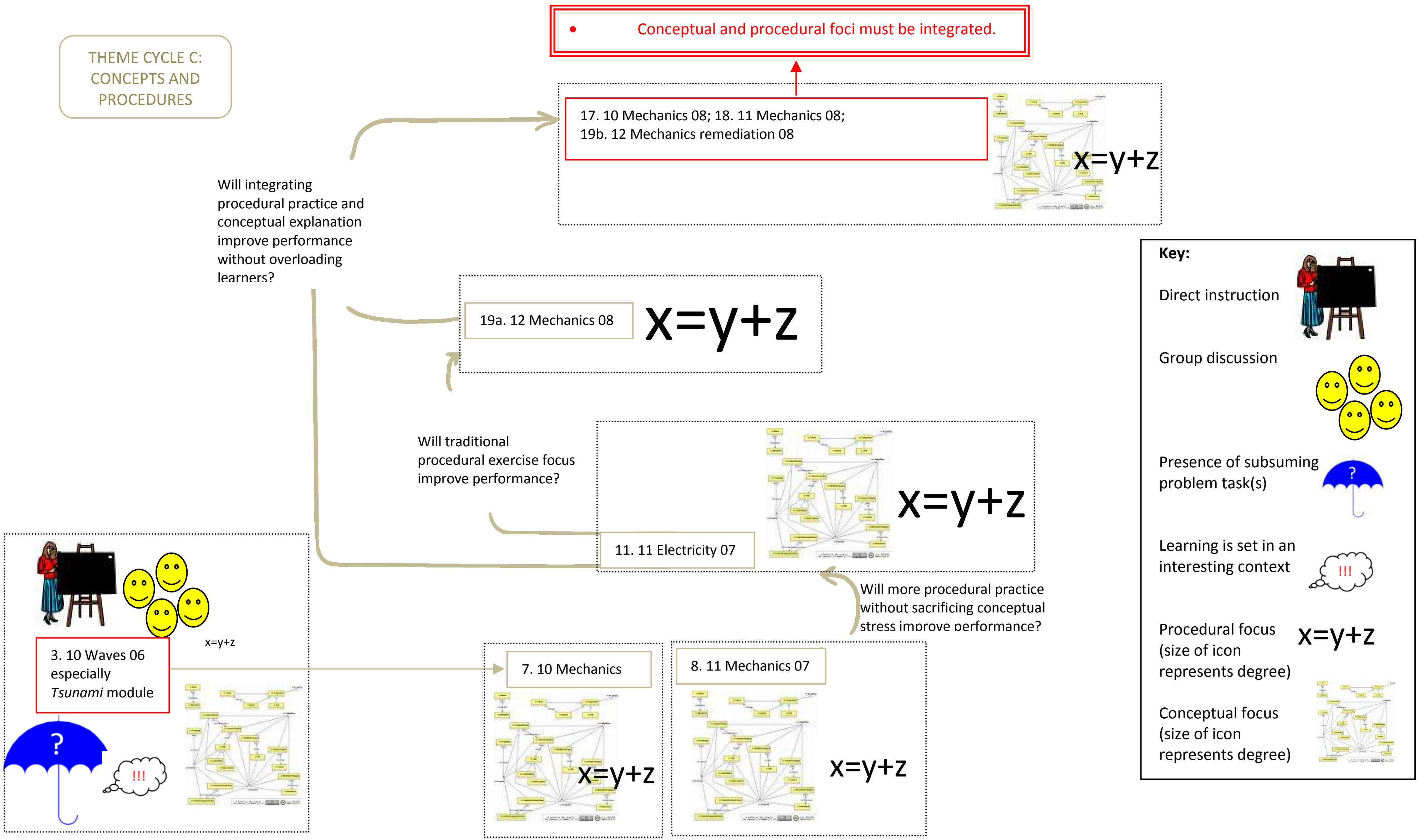

Figure 4.6: Theme Cycle C: Concepts and Procedures.

prevent the short-circuiting of conceptual thinking as a result of procedural performance (Paul, 1995). On the other hand, I feared that learners might not develop procedural competence as a result of this strategy. I tried to prevent this by expecting the learners to do a fair number of procedural exercises for homework.

Observation

Learners' remarks concerning interest, enjoyment, engagement in active, productive learning, and struggle with eventual attainability, were overwhelming. On the negative side, my fears concerning procedural competence were realised. I received criticism from learners and colleagues concerning the under-emphasis of routine procedural exercises. Further, after the learners had worked through the IEB exemplar, and, later, written the externally set IEB examination at the end of the year, 15 comments were made by the 23 learners that they had not been sufficiently well prepared to answer numerically-based questions. An example is given below:

> I think we did too little numerical. During the year it did not seem so because we were writing your exams, but now, all this manipulation of formulae, substituting unknowns by some other formulae derived from changing the subject of the formula etc. (Kim: LJ: 01/11/07)

The class scored an average 50% for the final IEB physics examination. Their average score for the mechanics section of this paper was 46%, with them scoring an average of 41% for those questions involving calculations, 55% for those involving explanation, and 57% for those involving recall or representation. These statistics do seem to confirm the learners' views that they were not well equipped to answer numerical questions in this section. Statistics for the physics examination as a whole, given in Figure 4.7 show a 33% average obtained for calculation-type questions, supporting the view that learners had not developed the required competence in this area.

Reflection

Reflection on this section revealed the paradox that a strategy which seemed highly effective in promoting critical thinking seemed incompatible with the South African physical science (SA PS) curriculum. The strategy taken here had

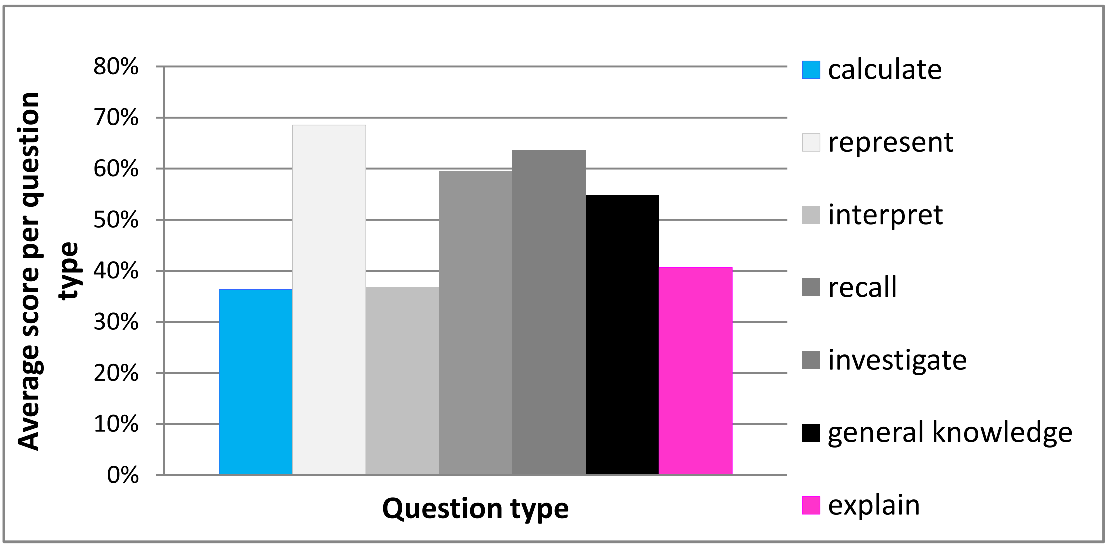

Figure 4.7: 2007 grade 11 performance in the IEB physics November examination, per question type.

clearly excited learner interest and induced intense, productive and persistent engagement in deep learning and critical thinking, despite requiring significant effort on the parts of the learners. However, it had not sufficiently developed the learners' procedural competence, which had disadvantaged them in the final externally set IEB examination where this had been stressed in the mechanics section. Clearly, a greater stress on procedural exercises was needed. However, I was unwilling to reach this by sacrificing the advantages of the strongly conceptual strategy I had taken here in exchange for the lifeless procedural drilling of the traditional physical science classroom (Hobden, 2005). Consequently, my options appeared to be increasing the amount of homework learners were required to do and / or integrating procedural performance into the subsuming conceptual problem task, as I had done in cycle 7.

Besides the issues raised above, the fact that I had done no practical work during the mechanics modules meant that the instructional strategy used in cycles 7 and 8 could not serve as a prototype for learning throughout the year. According to the assessment requirements stipulated by the national curriculum statement (NCS) subject assessment guidelines (SAG) for physical science (DoE, 2005), two practical investigations have to be assessed formally per year.

4.4.2. Stressing both conceptual explanation and procedural fluency

Action

In an attempt to better align my instructional strategy to the curriculum requirements, I developed a set of modules for the grade 11 electricity section which incorporated all the principles learnt so far as well as providing for practical work and more numerical drill questions to be done. I listed the curriculum requirements and where each part of my strategy was linked to it, and provided printed and video support to learners so that if they fell behind in class they would be able to catch up after school. Preparation of this took 75 hours of my Easter holiday, and demanded extreme organisation and discipline to enforce, since class and homework time were tightly prescribed in order to squeeze everything in. Unfortunately syllabus pressure compromised some of the critical thinking tasks. It also excluded almost any addressing of difficulties learners experienced during homework tasks, with negative consequences of these being noted.

Figure 4.8 compares the class time usage and estimated homework time, for the grade 11 mechanics and electricity modules. These show that similar amounts of time (17 to 18 hours) were devoted in total to conceptual explanation for each, but much more time was spent on answering procedural exercises in the electricity module (12 hours against 6 hours), and that this extra work was done for homework.

Observation

This strategy did seem to be effective to a large degree. High levels of learner activity were evident in the video and audio data of class activities. The class average for the final submission was 85%. This task was marked using a rubric which rewarded accuracy and relevance in self-design of circuits required to perform particular functions, and precision and logic in the learners' written conceptual explanations of why these would operate as required. The learners seemed to feel more confident with numerical practise questions, according to a group of six grade 11 learners interview on 05/06/07. Despite journal entries suffering due to the increased work-load pressure, learners still found time to express their interest and enjoyment in the conceptual explanation aspect of the section. Evaluation of whether the increased amount of numerical homework improved learner test performance is difficult, though. Performance in the test on electricity was similar to that of mechanics, with very high scores attained in familiar types of questions and low in those requiring transfer and higher order thinking: both for numerical and explanatory questions.

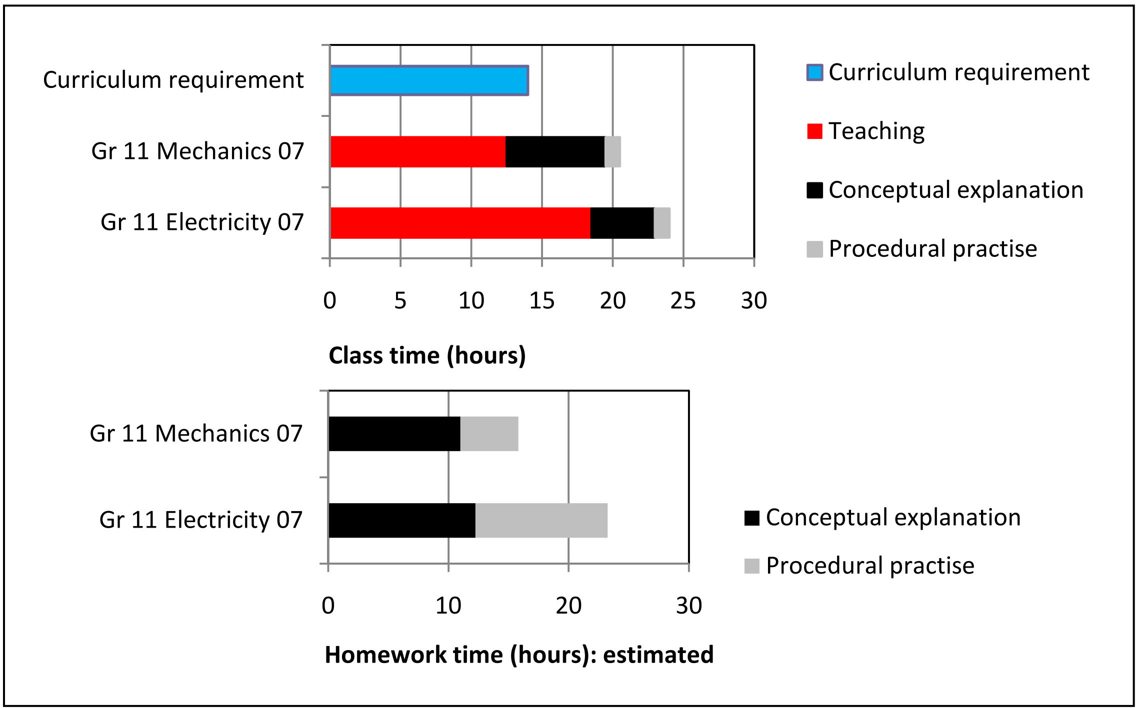

Figure 4.8: Class and homework time usage for 2007 Grade 11 Mechanics and Electricity.

Reflection

On considering the amount of homework I had been loading learners with in order to stress both conceptual explanation and procedural exercise, and on hearing rumours of younger learners being frightened of science due to the enormous workloads involved, I wanted to find a different solution to the one taken in this cycle. I considered whether an integration of procedural requirements into the subsuming conceptual problem wasn't a more appropriate strategy to use. On one hand it did seem to have the potential weakness of encouraging learners to take a procedural short-cut to avoid reasoning conceptually. On the other hand, its alternatives: either sacrificing one of the competencies for the other or overloading the learners with homework, seemed worse. Further, this strategy is consistent with work done by Dufresne, Leonard, & Gerace (1992). This work showed that expecting learners to precede numerical problem solving with conceptual consideration encourages learners to engage with the numerical aspects of a problem in a way that makes sense, rather than just exercising mindless *plugging and chugging*. This strategy was also found to improve problem-solving performance. These reflections caused me to alter my strategy to grade 11 mechanics in 2008, as discussed below.

4.4.3. Will integration develop proficiency in an appropriate time?

Action

At the start of 2008 I modified the grade 11 mechanics modules used in 2007 to be more like the strategy used in the critical section, 7. I did this by integrating procedural requirements into the subsuming conceptual problem task. This required learners to invent data and manipulate it using the relevant equations, to illustrate the concepts they explained. Further, I set aside more time for explaining problem questions on the board than I had in the previous year, cutting down somewhat on teaching time to make way for this. This is shown by a comparison between the class time usage for each of these modules respectively, given in Figure 4.9. While no time is indicated for correcting procedural homework questions during class time in 2007, this is not an entirely accurate representation. No entire lessons had specifically been devoted to this in 2007. Instead, model answers had been handed out for marking either at the start of the lesson or for homework. However, common problems had occasionally been discussed during teaching time.

Unfortunately, due to time constraints, I did not take in and check the interim report in which learners had to apply procedural knowledge to the subsuming conceptual problem. I did, however, allow learners to discuss this interim report in groups during class time. Possibly as a result of this lack of teacher control, seven of the 16 learners dealt superficially with this section of the final submission. To try to salvage the strategy, I required, and monitored, thorough corrections on this section of the task by those learners who had performed poorly in this section.

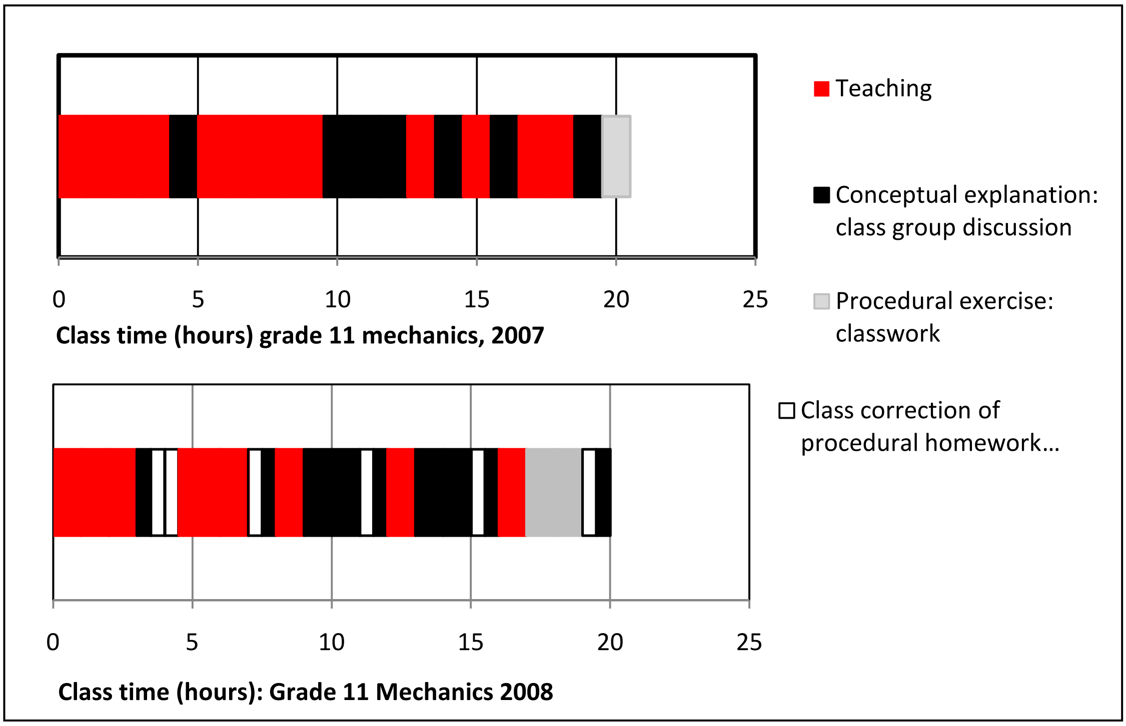

Figure 4.9: Class time usage: Grade 11 mechanics 2007 and 2008

Observation

I attempted to determine whether this procedural-conceptual integration was effective in developing procedural confidence. Five of the 16 2008 grade 11 learners commented that they felt confident with procedural questions and four that they were not confident and needed more procedural practise. Two remarked that having been forced to invent data had made them more proficient problem-solvers, two said they did not think it had made any difference to them, and three that they had found this requirement too difficult. The 2008 learners scored slightly higher than the 2007 learners had in two numerically-focussed momentum questions answered by both classes under controlled conditions. Their average for these questions was 53% opposed to 49,5% for the 2007 class. However, this small difference might well be insignificant, particularly due to the small sample sizes and obvious lack of variable control between the classes.

Reflection

Whether the strategy of integrating procedural requirements into the conceptual problem task, and paying more attention to the marking of homework exercises improved learners' competence in solving procedural problems is unclear. Possibly paying more attention to enforcing the scaffolding worksheet dealing with this integration would have improved meaningful engagement with the procedural aspects of the subsuming task, and so improved procedural competence.

4.4.4. Does drill improve procedural competence?

Action

In 2008 I was afraid to depart from a traditional instructional strategy with the grade 12s for the mechanics section. This was because I had formed the impression that the mechanics section would be examined mainly from a procedural angle. I had developed this impression from the 2007 grade 11 exemplar examination for which 67% of the mechanics section's marks were allocated to calculations. Speaking informally to examiners on 23/02/08 had confirmed this impression. Consequently, I approached the section with a strong focus on numerical practise

By this time the grade 12 IEB assessment syllabus (IEB, 2008) had been cut down to include little more than a revision of grades 10 and 11 mechanics. For a week I allowed the learners to revise basic concepts and discuss scenarios conceptually from multiple angles, working in groups and individually. After this, I devoted the next three weeks to working through numerous numerical questions. I occasionally used direct teaching, but much of the time I modelled the answering of problem questions on request by learners in a style consistent with traditional practise (Hobden (2000). Learners were expected to answer and self-mark questions for half an hour of homework each school day.

Observation

At the end of this period, the learners wrote a test in which 60% of the questions involved calculation. The result was disastrous. The class average was 40%, whereas for their previous test it had been 66%. No-one scored above 70%, and a third of the class failed.

Reflection

This suggested to me that my hypothesis that a traditional strategy is effective at preparing learners for highly numerical tests might have been faulty. Over the next month, I tried to improve the learners' ability to answer numerical questions in a manner more consistent with the findings which had emerged from this study, and with work done by Dufresne et al. (1992). According to this, forcing learners to analyse problem situations conceptually before allowing them to find suitable equations for substitution and solution, is effective in improving problem-solving capability.

Action

I did this by devoting the first ten minutes of most of the lessons between the 28/04/08 test and the June examination, to engagement with numerical mechanics questions. I first provided the stimulus situation without the associated numerical questions and required learners to make sense of the situation conceptually, after which this was discussed in groups. This was followed by the learners answering the situation numerically. I monitored this process by taking learners' books in on three occasions

Observation

I found little evidence of success of this process, with only two learners being able to solve the problem. Instead of providing the learners with the final numerical solution, I gave them a written conceptual explanation of the problem situation and asked them to try to improve on their solution. I got the impression that this did not seem to help much. I then verbally explained the problem situation, and got learners to explain this to one another, after which learners were asked to reattempt the solution. This process was repeated with another problem, with learner performance improving relative to the first attempt, according to my journal entries. Performance in the mechanics questions of the next tests, suggested improvement. In a mechanics test written in October, for example, the learners achieved a class average of 71%, with only two learners achieving below 50%, one of these failing.

Reflection

It is unclear how much the intervention of getting learners to precede formulaic manipulation with conceptual reasoning was to thank for this improvement, though. The questions used in the later tests did seem to be easier than those in the earlier April test. Further, one would expect enhanced performance in the later tests, thanks to learner maturation and additional practise time.

Reflection on all of the sections comprising Theme Cycle C developed an awareness of the difficulty of achieving a balance between conceptual and procedural foci which will promote critical thinking as well as meeting the requirements of the curriculum. This difficulty is compounded by syllabus pressure, particularly in grade 11, where this is intense. It appears to me at this time that the most promising strategy involves integration of procedural requirements into the subsuming conceptual problem task. For such a strategy to work optimally it seems to be important to monitor learner engagement with the scaffolding worksheets. As this implies, these findings cannot be divorced from those of a set of cycles, some of them common to Theme Cycle C, which highlighted the importance of use and management of scaffolding. These are collectively called Theme Cycle D. These occurred concurrently with Cycle C, with some overlap of sections between the two. I now turn to a discussion of those sections contributing to my understanding of the importance of scaffolding on a strategy's success.

4.5. SCAFFOLDING

In my experience of speaking to teachers, there seems to be a general perception that critical thinking tasks, such as research projects, should be left over to learners to be done on their own, with very little structure provided. I had taken this view myself during the 2006 Tsunami task. The insecurity which resulted mostly did not seem helpful, and contributed to the module being very time-consuming. Between completion of the 2006 Tsunami task and the start of 2007, I participated in a course on problem based learning (PBL). This emphasised the importance of worksheet-based scaffolding. This is provided by tools, such as worksheets or templates, designed to empower learners to manage one aspect of the task at a time and, collectively, to succeed in the whole. I saw this as a potential way to reduce Tsunami's weaknesses. I found this to be a powerful tool during the critical section, 7, as has already been described. The rest of my experiences concerning scaffolding are recounted below.

4.5.1. Does loose, voluntary scaffolding help?

Action

The scaffolding I provided for the second implementation of the Tsunami task turned out to be a feeble attempt with little success. I introduced a mostly-empty mind-map, loosely structured around the task issues, to be completed voluntarily by the learners through the course of the section. This was intended to serve as a scaffolding worksheet. However, it differed from those used in the critical event, previously described, in that it did not consist of incremental pieces each required to be answered at a stipulated time after the corresponding teaching. Additionally, completion of this mind-map was voluntary and was not formatively assessed. This was partly due to the impression that although I had realised, from sections 7 and 8, that scaffolding worksheets were important, the *Tsunami* module had seemed effective in 2006, and therefore it did not seem to me so necessary to make much of an adjustment to the strategy I had taken. Also, I did not have the time available to set up as detailed a scaffolding system as I had done for the mechanics modules.

The 2007 implementation of *Tsunami* differed from that in 2006 in that I cut down significantly on group discussions in an attempt to complete the section in the time required by the curriculum. This is evident in Figure 4.10. This figure shows class time usage for the waves section in 2006, 2007 and 2008. Part of the difference stems from the IEB's removal of optics from the assessment syllabus, resulting in less needing to be taught in 2007 and 2008. However, this effect on time was minimal in comparison to the change in strategy.

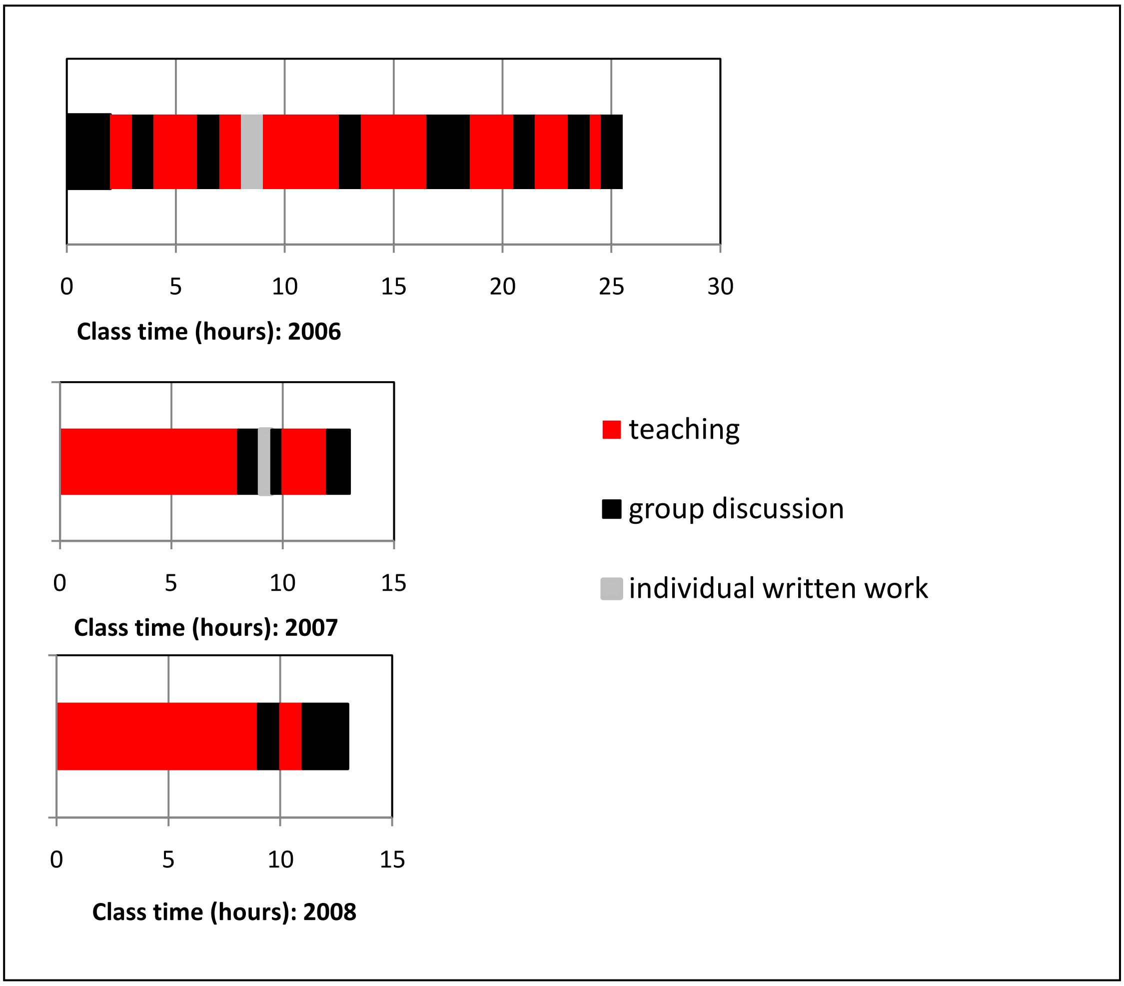

Figure 4.10: Class time usage for grade 10 waves, 2006, 2007 and 2008.

I hoped that use of the scaffolding mind-map, although it was minimal, would compensate for the decrease in time provided for group discussion. I hoped that in this way attainability would not be compromised. I encouraged submission of voluntary drafts of the final work, and wrote detailed comments back to each learner who did this. Eight of the 16 learners submitted drafts, although only two did this for the entire task. The minimal provision of scaffolding for this section (10) is represented, in Figure 4.11, by the scaffolding icon being very small for this section.

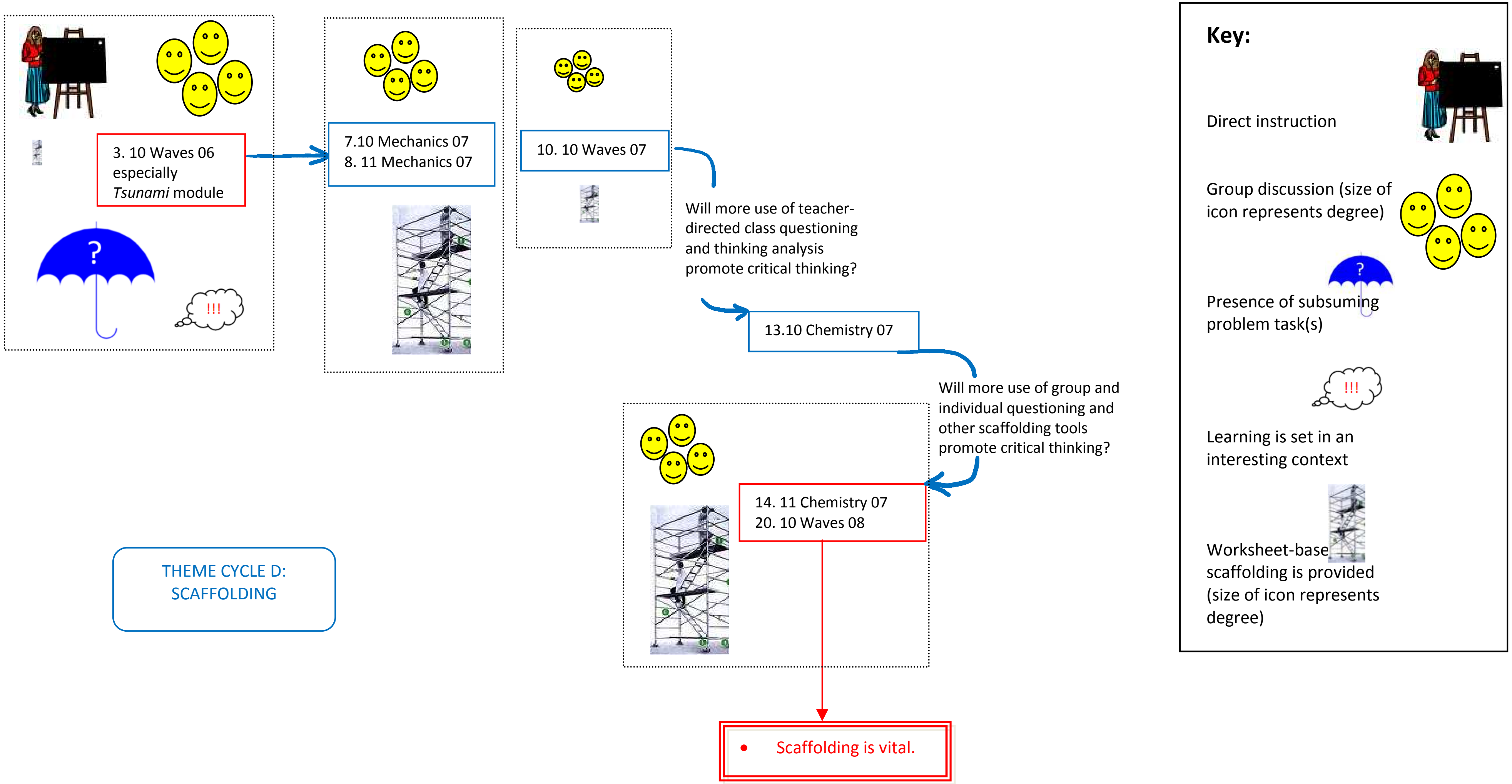

Figure 4.11: Cycle D: Scaffolding

Observation

Figure 4.12 compares the mark distribution for the final submission for the *Tsunami* module across the three years. As can be seen from this, the task seemed to be fairly effective for 12 of the 16 learners, in 2007, but disastrous for the other four. These four scored 22% or lower for this task, with one achieving as low as 5%. All four of these learners had failed to submit complete tasks by the deadline date, giving poor time management and lack of relevant resources and guidance as reasons for this when interviewed. Although I had been prepared to help them by checking drafts of the assignment, they had not managed their time appropriately to be able to produce these for the whole task. As remediation I made these learners repeat the task, making it compulsory for them to submit drafts. I gave detailed feedback on this, referring them to specific pages in their text book for information where necessary.

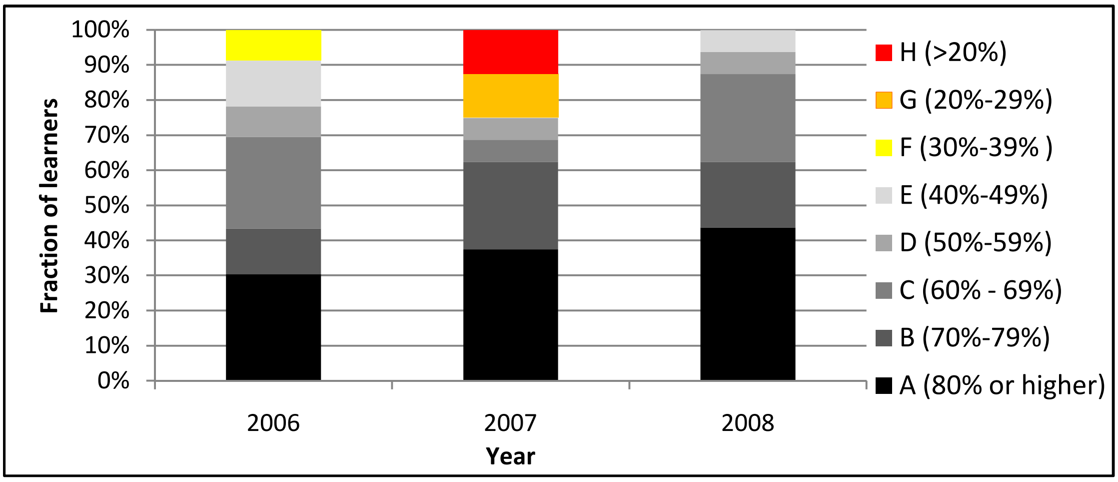

Figure 4.12: Mark distribution for the grade 10 waves task, Tsunami, in 2006, 2007 and 2008.

During interviews or in their journals, a fair number of comments were made by learners saying that they found discussion with others very effective in helping them with this task. Two learners remarked that more discussion time was needed. While the loosely-structured mind-map was referred to by half of the learners as having been helpful, it appeared not to have provided adequate support at least for the four learners for whom the task was a failure.

Reflection

Reflecting on the data convinced me of the importance of well structured and enforced scaffolding worksheets and group discussions revolving around these. Consequently, I resolved to create a set of formal interim report worksheets modelled around the 2007 mechanics units' scaffolding worksheets before re-implementing this task in 2008. This I did. These worksheets can be found in Appendix J.

4.5.2. The value of scaffolding

Action

The 2008 implementation of the Tsunami module revolved around these scaffolding worksheets. These were answered incrementally by the learners after the topic relevant to each report had been taught. After this they were engaged with in small-group and whole-class discussions, modified in the light of these, and then checked by the teacher. Unlike in the previous years, however, drafts of the final task were not accepted and commented on, this being too time-consuming for me to manage.

Observation

All learners were able to meet the task deadline, unlike the previous year, and the task was attainable for all 16 of the learners, as shown in Figure 4.12. Interestingly, the fraction of learners achieving 70% or higher was the same for both the 2007 and 2008 classes, namely 10 out of the total of 16 learners in each case. The main difference Figure 4.12 suggests between the three years is that the task was attainable for more learners in 2008 than in the previous years. This is despite the fact that my general experience of the 2008 grade 10 class was that they are considerably weaker than the other two groups.

Reflection

It seemed to me that the improvement in attainability amongst the learners in the lower end of the academic spectrum in 2008 relative to the previous years could be attributed to the presence of enforced scaffolding worksheets in 2008. Reasons for this success seem to include the fact that the interim reports served to induce learners to engage in the sense-making process necessary to succeed in the task, in an appropriately time-paced manner.

4.5.3. Point of view arguments

Because of the crowdedness of the curriculum, I concentrated most of my efforts at developing critical thinking in contexts which would also propel the learning of content knowledge. In many cases this involved expecting learners to develop explanation-type arguments. However, I have received the impression that the understanding of the majority of educators, of the use of critical thinking, is its application in point of view type arguments (Hobden, 2006), often about controversial ethical issues. In these, multiple correct answers could be considered acceptable, with answer quality being determined by the quality of the motivating argument. I developed these impressions from interaction with teachers, such as at IEB cluster meetings on 23/02/08 and 24/05/08, and from perusal of external examinations and activities. The Chemical Systems section and Learning Outcome 3 lend themselves well to this type of question. Unfortunately, though, syllabus pressure prevented me from touching this section at all in 2006, and allowed only for a short treatment of it in each of grades 10 and 11 in 2007. In much of my previous experience with these kinds of questions, I had found that learners tended to debate illogically, emotionally and egotistically. I wondered whether scaffolding could help prevent this. I designed such tools for two such questions within the 2007 grade 11 chemistry work, and found both effective.

Action

In one, I expected the learners to write a list of criteria, against which each of two opposing views had to be systematically evaluated. In the other strategy, I required the learners to map out their argument using a branching structure, a model of which I provided. This required a classification of claims as supporting or opposing a motion or another claim. Learners also had to provide authority references for each. After learners had completed each of these in writing, they shared their work with others in groups, the compositions of which I changed at approximately 15 minute intervals, and improved on it accordingly. After this, the learners wrote their essays guided by these plans.

Observation and Reflection

Not only did learners report to finding these thinking tools helpful, but their work was generally of a high quality. The tasks were assessed with a rubric which credited correct factual content and its logical and relevant support for claims made. Intellectual fairness, in the form of well supported counterarguments, was also required, as was appropriate referencing. These criteria are consistent with views on the nature of critical thinking (Paul, 1993). Evaluated against these criteria, the learners achieved a class average of 80% for their written work. Nineteen remarks were made by the 23 learners in their journals between 18/10/07 and 22/10/07 saying that the structure provided had been effective in helping them produce quality arguments.

4.5.4. Essential questions

Besides worksheet-based scaffolding, I also explored the use of more informal discussion strategies to be used during general teaching. These can also be viewed as scaffolding tools in that they serve to incrementally help learners towards managing a target goal. Reading work by Paul and Elder (e.g. 2001), and other related resources, I became convinced of the importance of being able to ask essential questions. These promote self-direction, and hence critical thinking and effective learning (Paul & Elder, 2006a). I tried to stimulate learners to ask questions which would be effective in propelling their thoughts in a meaningful and productive direction by using two main strategies. I call these *Journal sharing* and *Question-answer dialoguing* respectively. Besides these two concentrated approaches to questioning, I made it a continual habit to encourage questioning and prompt using and calling for essential questions. This was done throughout all my lessons with all the learners for the entire period of the study.

Action: Journal sharing

I implemented the Journal sharing strategy in the teaching of Chemistry to the 2007 grade 10 class. I expected the learners to keep a journal of essential questions they thought up during the course of our study of the history of man's understanding of the atom. Occasionally I called on learners to read out the questions they had written in this journal. I also encouraged question-asking interspersed within my teaching. I used the learners' questions as spring-boards in my teaching.

Observation

I found this method worked very well for the strongest learners, but dismally for the majority. Some learners reported in their journals to losing concentration during the asking and answering of the stronger learners' complicated questions. Also, the majority of the learners seldom managed to come up with good questions themselves.

Action: Question-answer dialoguing

The question-answer dialoguing strategy was more effective. I used this in the teaching of electricity and the matter and materials section of chemistry to the 2007 grade 11s, and to the 2008 grade 11s. I gave the learners a diagram of a scenario which needed explaining, e.g. the functioning of a solar panel. I expected them to generate a set of questions which, when answered, would help them to explain the scenario. They first did this individually in writing, after which they shared these questions in small groups, answered them and then posed further questions, and so on. To aid those who were unable to self-direct themselves in this way I handed out a partially completed mind-map containing some questions essential to the understanding of the particular topic after about 20 minutes of discussion. After another 20 minutes, I handed out a more complete version. Near the end of the session I got two volunteers to explain the scenario in a question-answer dialogue form. After this I handed out a completed question-answer mind-map to all learners. Learners then produced a written explanation for homework.

Observation

Learners were actively involved and interested during this strategy. After the solar panel discussion, 18 enthusiastic comments were written by learners. An example is given below.:

> The group work was excellent. I had no idea how I would explain it and I had absolutely no idea how it worked. First coming into the group and asking questions didn't help much, but when we moved and I was with Sonja, Anne and Thandi, we tried to answer the questions and this made my brain hum. Then when James came to the group, he had a very straight-forward explanation and we argued and explained (tried to) all the in-between stuff, like diffusion, etc. I understand completely now. It also helps having to explain it to others because it shows what you know and understand and what concepts you have all wrong. It was also fun! (Lauren: LJ: 15/08/07)

Action: Continual modelling and expectation

In addition to the concentrated strategies referred to above, I infused critical thinking into everything done in science throughout the period of the study. This included modelling critical thinking and expecting and prompting for it on a daily basis.

Observation

Some learners reported to finding themselves self-applying the strategies used during science to their learning outside of science classes. An example is given below:

> An interesting thing I found out, when I was studying for maths, I began to ask myself, "why" questions when applying formulae, like we were taught in science. This curiosity helped my understanding and it was more fun than just the usual practise I used to do. I hope the results will also show improvement. (Agnes: LJ: 25/03/07)

Reflection

Reflecting on these experiences and results convinced me of the importance of maintaining a continual expectation of critical thinking in the classroom over a long-term period. This is done through modelling and provision of opportunities for asking essential questions. This does, eventually, at least for some learners, pay off in that learners develop a habit of doing this themselves, as suggested by Agnes's comment, above, and the remarks made by the learners in the extract below:

Me: What is it that has made you become more careful about things like that?
Tim: I guess it's the way Miss Stott teaches us.
Silindile: You ask us why.
[General agreement]
Me: Do you find that that makes you do better?
[General agreement] ...
Agnes: Then you get into the habit of it.
(Interview: 03/11/06)

4.6. CONCLUSION

In this chapter I have described my journey of learning in my quest to promote critical thinking while teaching physical science within the South African national curriculum. This is further represented in Appendix C. Out of this voyage, a theory of best practise, briefly summarised here, and elaborated on in Chapter Six, emerged. Additionally, a number of principles were learnt. These are expounded on in Chapter Five and form the basis of the answers to the research questions of this study. At this time, having completed my study, I am convinced that the instructional model outlined below, can be effective in promoting critical thinking while also managing to comply with the curriculum requirements. This model is exemplified by the critical event (section 7) which has been described in this chapter. While my current views on this model are reasonably stable at this stage of my reflections, I accept that in the future the model will undergo refinement as further action reflection cycles are encountered.

An interesting, subsuming problem task should be introduced at the start of a section. This should preferably integrate both procedural and conceptual foci. The relevant work should then be taught directly, interspersed with individual answering of scaffolding worksheets which link this teaching with the problem task. These tools should serve as group discussion points, and learners' responses to them should be formatively assessed by the teacher. The subsuming problem should infuse the learning experience, and be so captivating to the learners that they are inspired to reflect on the problem on an ongoing basis throughout the duration of the section, not only during times of formal class or homework focus on it. While this focus of classroom activity shifts between direct teaching and engagement with the problem, the influence of each should run parallel to one another throughout the learning experience. These two parallel strategies aimed at promoting critical thinking as well as complying with curricular requirements are linked to one another by references the teacher makes to the problem during instruction, and by engagement with the scaffolding tools. The classroom environment created throughout the learning experience should be such that it supports long-term struggle and a continual use of question-answer dialogues revolving around critical questions, so that critical discourse becomes a normal expectation and habit. In Chapter Six I describe this strategy in greater detail, and name it *The Ladder Approach.*

At the end of the reflective cycles described in this chapter, I am left with the overall feeling that promotion of critical thinking is difficult, yet rewarding. It requires a commitment by both teacher and learner to embark on a long-term, patient, dedicated struggle. The model of instruction I consider having emerged from this study brings with it risks and resulting anxieties, as well as inducing fascination and exciting an eagerness to learn. As a teacher, watching learners become more critical in their thinking is one of the most rewarding experiences there is. This is especially so since it comes at the price of a long and often painful battle.

CHAPTER 5
ANALYSIS AND INTERPRETATION

Having provided a detailed description of my action and reflection cycles in the previous chapter, the purpose of this chapter is to focus more specifically on the research questions and provide some convincing answers. Being the focus of the chapter, the study's research questions are repeated here:

How should learning tasks be designed and used in teaching to promote critical thinking within the South African physical science national curriculum?

a) Which design characteristics affect a task's effectiveness in promoting critical thinking?
b) How does the position in the teaching sequence influence a task's success in promoting critical thinking?
c) What type of learning environment encourages promotion of critical thinking?
d) To what extent do tasks need to be adapted to fit particular students or student groups in order to promote critical thinking?

In this chapter a number of assertions are made in answer to these questions. Each of these assertions is then supported by reference to the study's data. It is important to note that these assertions refer to what emerged from this study, which is no doubt only one manner in which critical thinking can be promoted.

5.1. DESIGN CHARACTERISTICS

Assertion 1: The design characteristics dealing with a task's ability to capture a learner's interest, its complexity, and its focus on conceptual explanation all play an essential role in promoting critical thinking.

5.1.1. <u>Interest</u>

Assertion 1.1: Intriguing tasks that capture learners' interest are more likely to promote critical thinking.

Importance of interest

Literature suggests that capturing learner interest is important for the success of a critical thinking task. One way of explaining this is that interest increases the capacity of working memory (Kirschner & Sweller, 2006; Niaz & Logie, 1993), as well as the motivation to struggle through the discomfit that working memory load provides (Bandura & Schunk, cited in McCombs, 1988). Since critical thinking places particular demands on the limited space of working memory, given the fact that it is effortful (Resnick, 1987), it seems reasonable that interest should be particularly important in securing the success of such tasks.

The findings of this study confirmed this. This is suggested by as many as 206 learner comments in the data mentioning interest as a positive aspect contributing to the success of a tasks intended to promote critical thinking. For example:

Thandiwe:	Yes, otherwise you feel like what's the use of it. Like the cell phone one, I thought you'd just ask questions like this this this this this, but like putting Sipho and John and how cell phones work is like what really makes you interested – like I want to know I want to know... it makes you want to know more. It makes you want to understand and learn …
Agnes:	But now there's more interest driving you...
Thandiwe:	And it really helps us with this thinking thing. And it's like we only started with Physical Science this year, and if you were just to start with the text book, I don't think we would have made it to grade 12, because like the interest will be down.

(Interview: 18/08/06)

In this study I found that novelty, role-playing, puzzle-solving and practical work can provide interest. I propose that this is because these aspects provide intrigue. By intrigue I refer to a sense of mystery and wonder which appeals to both the learner's affective and cognitive facilities.

Novelty

Non-novel work, even if set in real-life, and seemingly interesting contexts, were found ineffective in inspiring intrigue. For example, four remarks concerning boredom, and none suggesting interest, were counted in reference to redoing tasks performed the previous year, for section cycle 7. This was despite the fact that the activities used were set in the real-life, seemingly interesting contexts of cars and the motion of SpaceShipOne. Comments such as Sofia's, below, show that the lack of novelty caused the tasks to be boring for those learners for whom the tasks were not novel. In contrast, the challenge of the novel task, What's in the Plunge?, appeals to her:

> I liked the challenge of What's in the Plunge? At first I didn't know how I'd get the answer, but after jotting down my ideas, things became clearer. Though I'm still in the dark. I really feel bored and tired about the Cars revision. (Sofia: LJ:19/01/07)

Similarly, I had used the context of an electric-current-based lie-detector in a previous year with the 2006 grade 10 learners. Some of the learners pointed out that the consequent lack of novelty of this task caused it to lose its interest (Questionnaires: 16/02/06). This corresponded with my observation of a general atmosphere of lower interest than I had anticipated (RJ: 16/02/06).

In contrast, the contexts in which the subsuming problem tasks were embedded for cycle 7, were clearly interesting to the learners. This is evidenced by many (72) remarks in journals and interviews stating that this subsuming problem was interesting or enjoyable. Video footage of the learners' first exposure to these problems confirms this impression, especially in the case of the task related to the newspaper clipping of a man surviving a 61m fall onto a car. Learners laughed, looked at one another and commented in a manner that suggested interest. In the discussion below I argue that although a number of factors seem to have contributed to learners finding these tasks intriguing, it seems that novelty may have been the imperative quality.

It would appear that learners need to perceive some usefulness in engaging in a task. In an interview with six learners, all remarked that they had found the context of a falling stone, used in grade 10 mechanics in 2006, boring. These learners pointed out that they did not see the point of answering questions about a falling stone, e.g. "Why do we do the calculation – get the displacement, maybe" (Jabulani: Interview: 18/08/06). In the case of some of the modules for which interest was observed, such as Must he pay? and Tsunami, the factor of perceived usefulness could have contributed to interest. However, in the module What's in the Plunge?, learners discuss the motion of a man who survived a 61m fall. This explanation is not useful except in satisfying curiosity.

It could be that this high level of interest in cycle 7's subsuming tasks was partly due to the tasks' links to life experiences. All three of the tasks used in cycle 7 had a link to what happens in life. Nine comments were found in the data in which learners remarked on enjoying a context which related to life. However, a falling stone does also have a link to life, and despite this learners found this context boring. The fact that learners generally did not seem curious about the stone's fall, but did about the man's seems linked to novelty rather than to reality. While stones often fall, people very rarely fall 61 meters and survive. This suggests that novelty, rather than a useful link to life, was the component eliciting intrigue here.

Learners gave a number of comments in which they related interest to novelty. An example is: "Now we are really getting to stuff I don't know, so I'm beginning to enjoy the lessons." (Sofia: Learner's Journal: 26/02/07). It seems that a novel question is intriguing to learners, i.e. it inspires them to wonder, and that this motivates them to engage deeply in the process of seeking a solution.

Role-playing

In an interview in reference to the *Tsunami* module, a group of learners remarked that role-playing had enhanced their interest and enjoyment and made them feel important. Possibly role-playing contributes to interest in that it makes the process of answering the question intriguing, capturing learners' imaginations as they engage in performing an act of simulated usefulness.

Puzzle-solving

Puzzle-solving seems to be another way to capture intrigue. As many as 32 comments referring to interest and enjoyment were counted in semi-structured questionnaire responses concerning a logic-puzzle task in grade 10 gravity in 2006 (12/05/06). In this, the truth of statements written in logic notation had to be determined (Aikenhead, 1991). The subject content of this task, namely data about the weight of an object on various planets, does not seem intriguing. It has no novel or apparently useful link to every-day life, and involves no role-playing.

Possibly the interest came from the challenge involved in the process of debating the truth of the statements in groups. This is suggested by the following extract from a learner referring to a cause effect puzzle task:

> Because you had a statement and you said okay guys it's like this, and others would say, no Thandi, its actually like this, and then you'd say like "why?", and then you'll start debating together. (Thandiwe: Interview: 28/08/06)

On the other hand, having to make judgements about the truth of statements about a falling rock had failed to evoke the same interest (Interview: 18/08/06). This, however, was not done using logic notation. This might have caused learners not to view this task as involving puzzle-solving. Aikenhead (1991)'s extensive experience with learners enjoying the use of logic notation even on a relatively long-term basis, suggests that this enjoyment comes from more than the novelty of the notation. Perhaps the interest I observed in those tasks using logic notation might have stemmed partly from the notation turning the task into a puzzle, i.e. an intriguing question. Further, the successful gravity task was debated by learners in class, whereas the less successful task related to a falling stone was done largely individually for homework. The opportunity to figure this puzzle out through debate, an intriguing process, could further explain the success of the logic puzzle tasks.

Practical work

Teacher- and learner-performed practical demonstrations using real or computer-simulated equipment were used in some of the action-research cycles. The data suggests that each of these activities contributed to interest and active engagement. It appears that the practical work served as an intriguing process. Twelve comments relating practical work to interest were found amongst 15 grade 10 learners' journals after studying waves. Remarks include, "I just enjoyed the lesson so much. I like practical work than theory. It was really interesting" (Patricia: LJ: 28/04/08). This referred to the interest offered by practical demonstrations made by the teacher, using real equipment. Other remarks, such as "the magnets: we could see the magnets and work with the magnets" (Silindile: Interview: 12/05/06) suggested that the concreteness offered by learner hands-on practical work enhanced enjoyment. Additionally, remarks, such as the one below, referred to the benefit of use of computer simulations in learning.

> The clips (on the presentations) about pulses etc. made the work clear. They helped and were great. I like it that we looked at the video clips and then had to write what we see. It was difficult to word what we see, sometimes, but in the whole, it makes you think. (Victoria: LJ: 28/04/08)

This discussion has shown the importance of interest in a critical thinking task, and ways in which this interest can be captured. I have argued that an intriguing question or process can capture interest. By this I refer to a question or process which engages both learners' affective and cognitive faculties. I suggest that this can be done through novelty, role-playing, puzzle-solving and practical work.

5.1.2. Length and complexity

Assertion 1.2: Tasks that have a degree of complexity and require a longer time to solve are more likely to promote critical thinking.

Advantages of long, complex problem tasks

The long, complex motion modules described earlier were effective in promoting critical thinking. Each took one month to complete, making them long tasks. Each involved multiple concepts, namely all the concepts in the grade 10 motion syllabus, as well as added complexities arising from deviation of real from idealised situations, such as the inclusion of air resistance, affected by aspects such as the falling man's body orientation, type of clothing, and wind speed and direction on that particular day. Therefore, the tasks were complex (Paul & Elder, 2006a). The tasks were introduced before the learners had been taught the work, and solved incrementally during the teaching. This meant that when the tasks were introduced they were new to the learners. Further, their solution was not found in the learners' notes. Instead, answering these tasks required learner creativity, reasoning and argumentation. This makes them problem tasks (Hobden, 2006). The effectiveness of these modules to promote critical thinking and be compatible with the South African physical science (SA PS) curriculum has been described in detail earlier (pp.128-130). This included overwhelming interest, enjoyment and active engagement by learners, abundant evidence that learners were undergoing an effortful struggle in which they employed critical thinking, curriculum correspondence, and attainability by most of the learners.

The data suggests that the length and complexity of these and similar problem tasks contributed to their effectiveness. The length and complexity seem to have added interest to the task, goaded learners into thinking critically, and provided opportunity for long-term struggle involving deep engagement. As just mentioned, complexity seems to add interest to a task. Remarks to this effect, found in the data, include “Make it a bit more complex and interesting” (Cole: Questionnaire: 18/02/06). During the motion tasks of cycle 7, eight remarks, volunteered amongst the 16 learners, said that the struggle they were undergoing due to the task’s complexity caused them to be interested. A potential for exploration into a problem task’s complexity seems to goad learners into thinking critically. The following is an excerpt from a report on a group discussion lesson, in which learners exposed further complexities in an already complex task, namely having to explain why a bullet could be stopped by a silk handkerchief. The learners displayed depth of thought, a hallmark of critical thinking (Paul, 1993), clearly as a result of the complexity of the situation.

> The group discussing the bullet task unearthed a number of aspects deeper than the basic questions. This included the effect of the bullet’s heat on the silk and the effect of the distance between the gun and the person who was shot. (RJ: 07/02/07)

All of the learners were observed to undergo a long-term struggle through the duration of engagement with the complex problem task described for cycle 7. Forty-five comments were counted in journals and interviews regarding struggle during this section. An example of a learner’s remark that the long-term struggle and complexity caused them to think deeply and engage actively is given below:

> The big problems are quite thought provoking and I enjoy them. But exercises e.g. Activity 12 – yes, they help to drill the things in you, but they tire me out and they don’t make me think as much as a big problem, little by little working through it. I feel by the end as if I’ve grown. (Sofia: LJ: 16/02/07)

This comment compares long with short questions, with longer questions seeming to be more effective in promoting deep thought and enjoyment. This view seemed to be widely held by those learners for whom long questions were attainable. Fifteen comments were coded in the data from learners’ journals and interviews, for the 2007 mechanics section, to this effect. Examples include:

> The second and third were too short, and there was too little information, so you felt like you must be missing something, but the first task: every day you got to new things, so I got to link it with the task, so I had to work through a lot of information to get to it, but for the 2nd and 3rd tasks I didn’t think much. (Jabu: Interview: 01/03/07)

Disadvantages of long, complex problem tasks

Despite the evidence of the effectiveness of long, complex tasks, given above, they are not without their difficulties. These difficulties include time-consumption and potential tediousness. They also encourage feelings of insecurity, and tend to be less attainable for weaker learners than shorter, less complex tasks. Each of these difficulties is discussed below.

Long, complex problem tasks are time-consuming. This is illustrated by the fact that for most of the modules in which I required learners to engage with a complex problem task, I spent more class time than the curriculum stipulated. This was so even when I followed as disciplined a time-schedule as possible and assigned a great deal of homework (e.g. see Figure 4.8 on p. 137). This is also shown by the time-consumption of guided class discussions where I expected learners to engage with complexity, rather than avoiding the need for this by telling the learners facts for them to learn without question. See, for example, the lengthy discussion (p.102-104) aimed at leading learners to realise that objects of different masses fall together in the absence of air resistance. Further, writing the final answer for these long tasks was intimidating and very time-consuming for learners. Twenty out of the total 38 learners in grades 10 and 11 in 2007 remarked on how time-consuming the final write-up for the motion task had been, at least four working on it until the early hours of the morning. The following comment was made by a learner who obtained full marks for both the short and long tasks for grade 11 motion in 2007.

> The longer tasks get you thinking more, but the first task's writing component, being so big, was daunting, and so I put off doing it, whereas with the shorter tasks I got down to doing it quickly. (Kim: Interview: 01/03/07)

Not only did the learners find the final write-up time-consuming and daunting, but the task tended to get tedious after a while. In the grade 11 mechanics module, eight learners said they had eventually tired of the task because of it being so long. This is illustrated in the following learner's response to whether the long task made her think more or less than the shorter tasks:

> Very much definitely more. I spent many hours after school with Jabu or sometimes alone in my room. Then I got confused, then I did it again, then I got it. I think it was

> fun, I actually enjoyed it very much. At the start I was actually looking forward to it. And then towards the end I was sick and tired, and I was too tired and I just wanted to get it over and done. (Silindile: Interview, 01/03/07)

If a complex task is presented with little structure, the insecurity which results can compromise the task's effectiveness. This is illustrated by the first two implementations of the Tsunami task, described earlier. This task is long and complex, and, in the first two implementations, was loosely structured. My feelings of insecurity during the first implementation are illustrated by 15 journal entries such as the following:

> I also realise that the task is very complex – so I am not myself sure of exactly what I want. So in general I get a feeling of interest and enjoyment of the task, but uncertainty of how to exactly go about answering it due to its complexity and open-endedness. (RJ: 01/08/06)

These feelings were mirrored by learners who remarked on being unsure of what was required (interview: 18/08/06). To prevent this insecurity from sabotaging the task's attainability, large amounts of time were devoted to group discussion during the first implementation (see Figure 4.10, p. 144). The following year, when this was removed, attainability plummeted (see Figure 4.12, p.146). On being interviewed (11/05/07), the learners for which this task had failed remarked that they had not been sure of what they had been expected to do in it.

Even with the provision of structure to reduce insecurity, as given by scaffolding worksheets in sections 7 and 8, complex tasks tend to be less attainable by weaker learners than simpler tasks. Fifteen of the 38 learners involved in these sections scored lower than 50%, with one failing. In contrast, all learners scored over 50% for a shorter, less complex task which followed this. The assessment mark for the first term was obtained from the sum of the marks achieved from the long motion task, and those from two other shorter tasks. In this final mark, the lowest mark achieved was 59%. It was found that the shorter tasks generally raised learners' marks, particularly of those who did poorly in the longer task. This is shown in Figure 5.1. In this graph the learners are arranged along the x-axis in descending order of mark improvement between the long and short tasks. This graph shows that, in general, the greatest mark improvement between the long and short tasks was experienced by those who had performed less well in the long task.

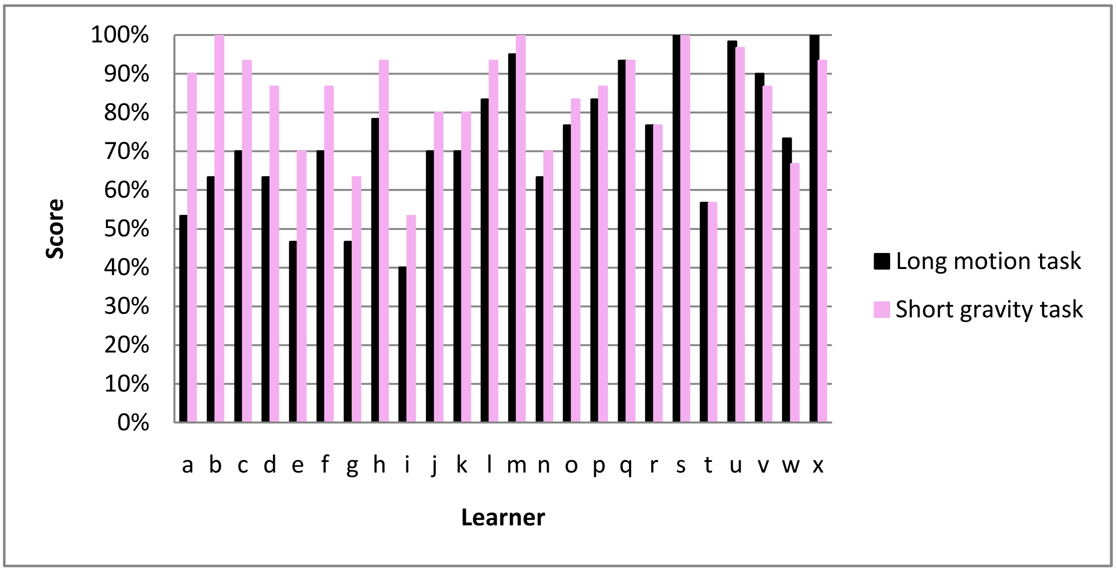

Figure 5.1: Comparison of performance of 2007 grade 11 learners in two mechanics problem tasks: a long motion task and a short task about gravity.

Advantages of shorter, less complex problem tasks

Shorter, less complex problem tasks have a number of advantages over longer tasks, although seem less effective at promoting critical thinking. These shorter tasks were generally viewed as more pleasant than the long complex ones. Learners who made remarks to this effect included those who had performed well in the long complex problem task. Reasons they gave included feeling more secure with the shorter task and not having to write as much. Some learners, however, when asked further about this, admitted that they had actually found the longer task more effective at getting them to think critically (Interviews: 27/02/07).

The discussion above suggests that while complexity does tend to promote critical thinking, it has downsides, so sensitivity is needed in use of complex tasks. These findings correspond with suggestions by Blumenfield et al. (1987) that complex tasks tend to be more interesting to learners than simpler tasks, and to be more effective at promoting thinking skills and work ethic. However, because simpler tasks require less effort they are more likely to be preferred. Blumenfield et al., state that this encourages teachers to simplify tasks to “gain co-operation, reduce confusion and facilitate success”, with “negative long-term consequences on students as ‘thinkers’ and ‘workers’” (p. 143). I suggest that findings of this study provide practical strategies to teachers so that attainability for most learners can be achieved without having to remove the task’s potency. One of these strategies is alternation of long complex tasks with shorter, simpler ones. Others are discussed in other sections of this dissertation.

5.1.3. Conceptual explanation

Assertion 1.3: Subsuming tasks which have a primary focus on conceptual explanation are most effective in promoting critical thinking.

The subsuming problem questions described in cycle 7 can be called concept explanation questions since they required learners to explain an issue conceptually. This required learners to make sense of information. The discussion below suggests that use of a subsuming conceptual explanation problem is more effective in promoting critical thinking than is a more traditional focus on procedural application exercises, although is associated with difficulties. I have argued for this elsewhere (Stott & Hobden, 2008), and provide a condensed version of this argument here.

Advantages of concept explanation tasks

Use of a subsuming concept explanation task was found to be effective in promoting enjoyment of the subject. This is seen by 158 data entries referring to interest and enjoyment for sections 7 and 8, in which subsuming concept explanation tasks were used. These were made amongst 39 learners over a period of a month. Additionally, almost all of these learners were interviewed, and all who were interviewed said they enjoyed a conceptual focus is learning science: “before I wasn’t really interested in science, but now I’m so interested, and even just in normal life I just mention something to do with science.” (Agnes: Interview: 01/03/07). Active engagement was evidenced by 173 remarks, such as reports of voluntary engagement with the concepts after school, for these two sections. In contrast, no remarks concerning enjoyment of numerical practise were found in the learners’ journals throughout the data corpus. An example of evidence for enjoyment of conceptual explanation is given below:

> C came to me during break and said she and N had been discussing why a ball bounces when hitting the ground but a person doesn't, and wondering about whether an egg bounces on grass and about the contribution of the springiness of the grass. (RJ: 23/01/07)

Conceptual explanation tasks were found to promote critical thinking amongst learners. Audio-recorded class discussions were transcribed and analysed in terms of Lipman's (1991) definition of critical thinking, and evidence of critical thinking was found in most group discussions requiring conceptual explanation. Illustrative examples of learners verbalising their thoughts and giving evidence that they are thinking critically has been given on many occasions throughout chapter 4 and 5 (see for example p. 99 and p. 104).

Concept explanation questions seemed to have been effective in developing at least some degree of conceptual understanding in the learners. Of the 57 learners who participated in this research in 2006 and 2007, 90% responded, in a questionnaire, that explaining concepts in words helped them to understand science. In contrast, only 67% said that answering numerical questions helped them understand science. Learning in section cycle 8, i.e. grade 11 mechanics in 2007, can be used as an example to support this. At the end of a month-long process of teaching and learner engagement in sense-making conceptual explanation discussions, learners produced a written answer to the subsuming problem. Nineteen of the 23 learners were awarded a mark higher than 60% for this submission, which was marked using a rubric which credited thoroughness, clarity, precision and depth of understanding suggested by the written explanation. The class average for this task was 77%. This suggests that conceptual learning had occurred to a significant extent. On the other hand, an observation that most learners demonstrated limited transfer to contexts other than those discussed in class does suggest that the depth of conceptual learning was possibly lower than the results given above suggested. This is referred to again in the discussion which follows.

Difficulties with concept explanation tasks

Although conceptual explanation tasks were found to be effective in promoting critical thinking, interest and understanding, they were associated with a number of difficulties. These included them being time-consuming and frustrating, a focus on them tending to cause a neglect of procedural practise in preparation for answering numerically focussed questions, and learners showing limited transfer of the knowledge they gained from these tasks to new contexts. These difficulties are discussed below.

Concept explanation tasks were found to be very time consuming and frustrating. They involved communication messiness, confusion and insecurity. For example, eight learners assigned to explain the deceleration of a taxi to a stop struggled for two hours in class over two lessons, trying to sort out confusions. These confusions included saying that since the taxi has more mass than the road it does more work on the road than what the road does on it (RJ: 01/02/07). I provided input to these two groups during at least half of the discussion time. I found this frustrating since the learners needed prompting for even seemingly simple steps in the explanation, and continual repetition and revisiting of concepts, with much misunderstanding evident in the process (RJ: 25/01/07, 01/02/07). Further, written work submitted for formative assessment immediately after this discussion suggested that only one of the eight learners had managed to understand the situation correctly. On the other hand, by the time the task was submitted for summative assessment (12/02/07), only two of the learners were unable to explain the situation in a way that suggested a considerable level of understanding. This suggests that although the process was frustrating, with persistence, it proved to be successful in the long term.

The discussion above suggests that although the time-consumption and frustration of conceptual explanation questions pose difficulties, in these very difficulties lie part of the power of these types of questions. This includes the potential to induce struggle and critical thinking, and the potential to develop the beneficial trait of persistence. The requirement for effort, evident above, is consistent with Resnick's view that critical thinking is effortful (Resnick, 1987). Zimmerman (1994) names persistence, which was clearly demonstrated by the learners and teacher in the extract above, as a key contributor to general academic success. Unfortunately, though, these beneficial aspects might not proceed from the difficulties mentioned. Instead, they are likely to encourage task avoidance (Blumenfield et al., 1987).

A consequence of the time-consumption of a focus on conceptual explanation was that less time was available for dealing with numerically focussed procedural exercises in class time. Instead, these were mainly relegated to homework. However, this was not found to be ideal since some learners did not take homework seriously and in general learners' mathematical competence was very limited. For example, in the 2007 grade 10 mechanics section interaction with the learners suggested that nine of the 15 learners were unable to perform basic algebra at the start of the mechanics section. Similarly, almost all of the 2008 grade 10 learners were found not to possess the algebraic competence necessary for working with the equations of motion (RJ: 19/02/08). None of the 23 grade 11 learners in 2007 was able to convert cm^2 to m^2 when this was required in the electricity section in 2007 (RJ: 10/05/07). This meant that learners needed the teacher's help in answering even basic numerical questions, as well as suggesting that a good deal of numerical practise was needed. Some 2007 grade 11 learners complained of being confused by the numerous equations used in mechanics (e.g. Interview: 01/03/07). These learners made 15 journal entries suggesting that more attention needed to be paid to numerical questions. For example, "I got most of my answers wrong" and "I didn't understand the corrections" (N and M: LJs: 05/02/07). Since the text-book activities had all been answered through the course of the section, this suggested that supplementary questions were required. Additionally, the school's physical science subject head, and principal, expressed concern that the strategy taken in the teaching of mechanics in 2007 did not equip learners for the potentially highly numerical senior certificate examination (RJ: 28/02/07).

Further, although the grade 11 learners performed well in the final presentations of the subsuming problems of the mechanics section, they performed fairly poorly in a test situation in which explanatory questions were set in a different context. Nineteen of the 23 learners were awarded a mark higher than 60% for the final presentations of the problem tasks, which were marked using a rubric which credited thoroughness, clarity, precision and depth of understanding suggested by the written explanation. The class average for these tasks was 77%. In the test, unfamiliar contexts, e.g. an asteroid's path being altered through an impact, rather than the familiar egg breaking on concrete, were used. The average score for higher order conceptual explanatory questions in these new contexts was only 44%, with 13 of the 23 learners scoring below 50% and none over 70%. In contrast, the learners scored an average of 81% for recall-type questions in the same test. For those numerical questions which were very similar to those done throughout the teaching period, learners scored an average of 77%, whereas for those requiring the learners to be able to perform more than the familiar numerical manipulation, the class average was only 50%. This data suggests that the learners had effectively learnt the basics of the mechanics section, but were generally poor at transferring learning to non-familiar contexts and applying their learning to answering higher order thinking questions in a test situation. This is consistent with findings by numerous researchers that transfer of knowledge to new contexts is generally limited (Bransford et al., 2000).

An attempt to overcome the problems discussed above while still holding on to the advantages referred to, by doubling up on homework time, was impractical. In order to provide for enough learner activity in each type of task, namely procedural and conceptual, for the learners to feel reasonably confident with each, it was necessary to give learners approximately 1hour of homework each week day. Also, in order to accommodate both foci to a satisfactory extent, marking of homework and performance of practical work had to be done after school hours. Additionally, the class time needed was approximately 50% longer than that allowed for by the curriculum statement (Figure 4.8, p. 137).

Integrating procedural application questions into the subsuming conceptual problem seems to show promise as a solution to the need to stress both conceptual and procedural elements while not overloading the learners. This is consistent with work by Dufresne et al (1992) that forcing learners to precede solution of numerical problems with conceptual analysis improves problem-solving ability. However, the difficulties discussed above were not eliminated by this strategy. This is suggested, for example, by two of the 14 grade 10 learners who had participated in the integrated approach described here and who wrote the final examination in 2007, failing the mechanics questions in this examination (see Figure 4.5.,p. 130).

The above discussion suggests that while the shift towards a more conceptual strategy to physical science learning, suggested by the curriculum documents, seems to be advisable in promoting understanding, interest, and critical thinking, it brings with it additional challenges. These are particularly as a result of the intense syllabus pressure of the curriculum, the time consumption and messiness of a conceptual strategy, and the apparent need for learners to practise numerous numerical questions in order to compensate for their poor mathematical skills and low ability to transfer learning to new contexts. The latter raises the possibility that unless formative conceptual explanation tasks are set within the same context as used in the externally set examination, the large amounts of class and homework time which conceptual explanations must, of necessity, due to their messiness, take, might contribute little to examination performance. On the other hand, the possibly more predictable nature of the numerical questions could mean that class and homework time spent on this might show up more in examination results. While the study suggests that integrating some procedural questions into the subsuming problem task is advisable, the difficulties discussed were not found to be eliminated by doing this.

The finding that conceptual explanation questions are effective in promoting critical thinking is consistent with Paul & Elder’s view that being able to explain concepts in words is a vital component of being able to think critically within a discipline (Paul & Elder, 2006c). Further, the findings that this kind of question is associated with difficulties are not surprising. This is to be expected, considering the cognitive load which critical thinking tasks provide to the mind’s limited short term memory (Kirschner & Sweller, 2006; Niaz & Logie, 1993). The disposition for persistence seems to be developed as learners engage in the task despite the discomfort this cognitive load causes. Persistence is viewed as being effective in promoting the development of critical thinking skills (Resnick, 1987), and to be an attitude conducive to academic success (Zimmerman, 1994).

5.2. TEACHING-TASK SEQUENCING

Assertion 2: Under certain conditions both inductive and deductive approaches to developing understanding can promote critical thinking.

5.2.1. Induction

Assertion 2.1: The use of group work at the beginning stages of instruction to generating new conceptual understanding, before direct instruction, should be used with caution.

A use of group discussion to induce generation of conceptual understanding was often found to be ineffective. This is referred to as an inductive strategy, in the discussion below. The difficulties associated with such a strategy include time-consumption, frustration and poor conceptual learning. However, some success with an inductive strategy was found when this was used on a small scale rather than in a subsuming task. These are now discussed in turn.

Difficulties

Using group discussion to induce learning of concepts was found to be very time-consuming, and therefore largely prohibitive under the heavy syllabus pressure of the curriculum. The grade 10 mechanics section was taught in 2006 predominantly using this strategy, and took nine weeks: more than double the four weeks stipulated by the curriculum. In contrast, the following year this strategy was abandoned. Instead, direct instruction, supported by group work in which learners made sense of learning as they sought to apply knowledge deductively to the subsuming problem, was used. The mechanics section took six weeks using this strategy. This is still longer than stipulated by the curriculum, but at least less so.

Using an inductive strategy was found to be a difficult, strength-sapping experience for me. This was due to the noise and stress associated with handling multiple discussing groups simultaneously, the frustration and confusion arising from communication imperfections, and the energy demand of facilitating the slow and messy struggle of multiple groups' simultaneous learning. Further, the loss of control relative to using direct instruction sometimes meant I had to answer questions on issues I had not prepared myself for. This sometimes made me feel insecure and required me to think on my feet as opposed to being able to teach according to a carefully prepared plan. During some of these discussions I inadvertently said things in a way which is likely to have encouraged learners to develop misconceptions, whereas I think this would have occurred to a lesser extent had I been teaching according to a prepared plan. I also faced decisions of how long to prolong learner struggle before providing information, how much input to provide at what times, and what to consider irrelevant discussion. All of these added stress and uncertainty to the teaching experience. Further, these decisions were compounded by pressures from multiple groups requiring my assistance, often even on the most basic level and in a repetitive manner, limited time and classroom noise. This heavy dependence on me encouraged off-task talk while groups waited for my help. For example, as many as six admissions by learners of off-task talk because of not getting my assistance when it was needed, were recorded for a single lesson involving the inductive strategy. One example of these is, “we got into dead ends, most of us were off track” (Tim: Interview: 01/02/07).

Although learners were generally observed to be engaged during an inductive strategy, the data often suggested limited understanding occurring. This suggests that the struggle and frustration present in these cases was of limited value in the context of the SA PS curriculum, despite the potential value of struggle, and even of a degree of frustration, discussed earlier. It appeared that the confusion associated with this inductive strategy was overwhelming, so that few learners emerged from this confusion into clarity. An extract, given earlier (pp. 102-104), illustrates the struggle and confusion typical of this strategy, and the limited conceptual learning resulting from it. This discussion had intended to induce learners to realise that objects falling in a vacuum will fall together regardless of mass, but resulted in only six of the 23 learners being able to demonstrate an understanding of this in an examination. An example of a learner’s comment suggesting that inductive discussions are ineffective in promoting understanding is given below.

> You have to try and apply it now, and you don’t know exactly what this term means, and then you get totally side-tracked, and when eventually you get back to the point

> you've confused yourself. But if you get taught what this means and then you have to apply it into some situation, then you can start to try to think of other ideas and more complex things. (Phil: Interview: 19/10/06)

The poor conceptual learning of the grade 10 mechanics section in 2006 seemed to cultivate a general dislike for the topic. This is testified to by many negative comments recorded in interviews (26), as well as numerous comments I overheard from learners to this effect throughout 2006, and none to the contrary. In contrast, later in the year the section was re-taught in a teacher-controlled manner, with no negative and some positive comments (11) being received in an interview with a voluntary sample of the class. An example of such a comment was:

> I didn't understand it the first time, whereas now I did because it was clearly explained at the start, whereas the first time it was like all thrown at me and I had to take it all in big chunks. (Tim: Interview: 03/09/06)

This dislike for mechanics seems to have resulted from the teaching strategy rather than the topic itself. This is suggested by a high degree of interest and enjoyment (86) reported on for the mechanics section the following year, when a different strategy was employed.

Successful experiences with small-scale inductive strategies

In some cases the evidence suggests that the learners' having to struggle through the stimulus material to derive the concepts themselves did suggest task effectiveness according to the criteria developed to determine this. An example of this is the discussion, reported on earlier, in which learners discussed hypotheses of why some materials, when rubbed, are able to pick up pieces of paper, and others not (p.120). This is considered to illustrate effective learning. This can be seen by the critical thinking the learners displayed, as shown by them making judgements substantiated by reasons, showing sensitivity to context and self-correction through their *if-then* statements. The learning described was attainable with effort. The learners' intellectual struggle is evident in the learners having to reason their way to an answer. The scientifically acceptable explanation was reached, at least by a significant number of learners, within a reasonable time, i.e. a 30-minute lesson. Further, the strategy is compatible with the curriculum, since learners did seem to learn the prescribed concepts of electrostatics derived inductively here and through similar discussions, well. At the end of the electricity section, the learners were given a test, in which 16 of the 23 learners scored over 70% and only two under 50%. Further support for the usage of group work to teach concepts inductively comes from some learners' comments, such as "It's better for us to discuss it because you understand it better if you've found it out by discussing it yourself" (Laura: Interview: 01/02/06). However, such comments were not abundant, with only ten being found through the three-year data corpus.

It is possible that the difference in effectiveness of the mechanics and electrostatics inductive discussions, referred to above, can at least partly be explained by the following. The less effective experience required learners to use numerous abstract concepts they had not yet mastered, such as acceleration, force, weight, mass, size, density and ratios of weight to mass, to derive an argument which did not match common experience, i.e. that a light and a heavy object would fall together in a vacuum. In contrast, the more effective experience required learners to use fewer, and more familiar, concepts, such as electrical conductance, friction, heat and smoothness, to derive an explanation for a phenomenon most of them had observed, i.e. the ability or inability of various substances to pick up pieces of paper when rubbed.

The discussion above suggests that use of group work to induce conceptual learning should only be done in cases where few concepts unfamiliar to the learners are involved. It is also suggested that this only be done on a small scale so that if the process fails to induce effective conceptual learning, which seems fairly likely at least for a significant portion of learners, time will still allow for use of other methods to help learners to understand the section before it is necessary to move on. Also, if teachers choose to use this method they should be prepared for the intellectual messiness of struggle, confusion, noise, having to think on their feet, and insecurity, and should develop strategies to curb off-task learner talk.

The findings that inductive approaches can promote critical thinking is not surprising. Induction is a reasoning process central to knowledge generation in scientific research. Construction of knowledge during learning is characteristic by sense-making (Dirks, 1998), and learning with understanding involves critical thinking (Nickerson, 1994). This suggests that inductive inference, which is a cognitive sense-making tool, should be important for effective learning in physical science, and, more specifically, critical thinking, a view supported by literature (e.g. Epstein, 2002). The finding that inductive approaches can be time-consuming and lead to learning in unintended directions corresponds with Driver's (1993) research showing that knowledge-generation types of activities are time consuming and unlikely lead learners to the formulation of scientifically accepted conceptions.

5.2.2. Deduction

Assertion 2.2: Deductive application, following direct teaching, is effective in promoting sense-making using critical thinking.

The strategy of following direct instruction with sense-making group work aimed at enabling learners to apply learning to solve a problem, is interpreted as having been effective in terms of this study. This is referred to as a deductive strategy in the discussion below. Two cycles are used to illustrate use of this strategy, as well as to support the assertion made above. These cycles are sections 7 and 8, i.e. grade 10 and 11 mechanics in 2007. The strategy used in part of section 7 has been given in Table 4.1 (p. 121), and illustrates the strategy used throughout both of these sections. As can be seen from this table, roughly week-long direct instruction of subsections of the syllabus were followed by hour-long group discussions. In these learners were required to make sense of concepts they had learnt throughout the week in order to use them in explaining a real-life, interesting, phenomenon. These group discussions were guided by scaffolding tools the learners answered, in writing, individually, for homework, during the course of the week. Such a strategy was found to encourage effective critical engagement, increased attainability of curriculum goals, and reduced teacher stress, as discussed below. The strategy was, however, not free from difficulty, as will be explained in this discussion.

Positive aspects

Learners were interested during these two cycles (158). Numerous comments similar to the following testify to this: "I'm really enjoying Science this year"

(Phindile, LJ, 31/01/07). These remarks include Agnes' statement, given earlier, that previously she had not been interested in science, but now she is so interested that she applies it in normal life. This application to life extended to discussions on the sportsfield: "I also spoke about it practically with Gert and Seth when we were playing cricket yesterday (the momentum and when we catch the ball)" (Cole: LJ: 01/02/07). Other evidence of active learning (173) is given by the audio-recorded footage of discussion sessions, and comments given by learners and their parents, e.g. "She would discuss it at the supper table" (Parent: Personal Communication: 22/02/07) and "I would think about it before I went to sleep" (Sofia: Interview: 27/02/07). Learners thought critically during the group discussion times as well as independently and in voluntary groups out of school hours (32). The extract given below, of a group of grade 11 learners discussing why a silk handkerchief can stop a bullet, shows evidence of critical thinking occurring. This can be seen in the learners' judgements, supported by reasons, and their use of questions to self direct learning. Learning throughout the section was characterised by effort (102). The discussion below illustrates this too.

Thandiwe:	When they meet.
Marika:	That makes it slow down.
Thandiwe:	That compression force – does it make it a Newton-3 thingy?
Marika:	No, the same force that the bullet hits the person with, the person pushes back with and this slows the bullet down, I think.
Thandiwe:	Well, yes, it does, because if it didn't, the bullet would have continued through.
Marika:	So it does.
Lauren:	But what I think is: if it's a jersey, how come doesn't it stop the bullet?
[Pause.]	
Lauren:	Because N-3 applies in the case of a jersey too.
Thandiwe:	Doesn't it… friction helps it to…

Learners had been taught about force, Newton's Third Law, friction, momentum, and impulse, before this discussion occurred. The discussion above, and its continuation, below, show the learners and teacher engaging in critical sense-making discourse using these concepts. At this point I explained that friction from a surface only acts parallel to the surface, and so there would need to be a component of the bullet's motion parallel to the surface for friction to play a role in slowing the bullet. Thandiwe's response to this shows that instead of accepting the knowledge I had offered as from an unquestionable authority, she was thinking critically while trying to construct her own understanding of the situation. She said that as the bullet is making an indentation, during its deceleration, its sides rub against the sides of the indentation, so friction would act even if the bullet had hit the person perpendicularly. My response to Thandiwe encouraged this critical attitude, since I acknowledged that I saw that what she said made sense. However, I also continued the critical discourse by pointing out that this still did not answer Lauren's question. Lauren said that silk is more elastic than jersey fabric, so it stretches with the bullet's motion. I asked why the fact that the silk is elastic should mean that it can stop the bullet, whereas the jersey, being less elastic, cannot. The discussion continued as follows:

Thandiwe:	Because it's elastic.
Me:	So?
[Other suggestions were given, but the recording is unclear.]	
Thandiwe:	The silk slows the bullet down.
Me:	The jersey too.
Thandiwe:	More; the time it's going, the silk is more and more.
Me:	And all that time what's it doing?
Thandiwe:	It's losing momentum, decelerating.
Me:	Why?
Lauren:	It's getting tighter and tighter.
Me:	And what's that causing?
Lauren:	Accelerate more, push more.
[The recording is unclear.]	
Me:	Deceleration is caused by force; the silk applies a force for longer.
Marika:	So actually the force would get greater.
Thandiwe:	Because of the tension thing.... because being stretched it wants to go back to its original.
[The recording is unclear.]	
Me:	What does the silk being stretched – and so the force being applied for a longer distance – mean about the silk compared to the jersey?
[Lauren said something about the silk being more likely to be able to stop the bullet than the jersey is.]	
Me:	It's more likely to decelerate it to a stop.

(Audio transcript: 25/01/07)

Had the above discussion been attempted before direct teaching of the concepts, it is unlikely that learners would have been able to engage effectively in critical discourse, since it is unlikely they would have been aware of the necessary knowledge needed to do so. Had the discussion not been held at all, with direct teaching of the concepts being followed by only engaging in procedural practise related to them, it is unlikely that the sense-making and critical thinking which clearly occurred in this discussion, with resultant conceptual learning, would have occurred.

This view is supported by findings that a focus on procedural proficiency does not lead to conceptual understanding (Zoller, Lubezky, Nakhleh, Tessier, & Dori, 1995), potentially implying that it also does not lead to promotion of critical thinking, given the close link between conceptual learning and critical thinking (Paul, 2001).

In contrast, the strategy used here was found to lead to conceptual learning as a result of the learners engaging in critical thinking. For sections 7 and 8 learners provided a written explanation of the phenomenon they had been discussing during the motion section. This was done after three sessions of teaching and discussion, with alteration of group composition at approximately half-hour periods to aid sharing of thoughts amongst learners of mixed abilities. Thirty of the 39 submission implied a deep or reasonably deep understanding of the associated physics. Another eight of the answers were satisfactory, and only one of the learners did not perform acceptably.

Relative to the inductive strategy, the deductive strategy was associated with reduced teacher stress. During periods in which I had used an inductive concept development strategy, I had continually had to prompt and discipline the learners in order to keep them on task. In contrast, during the deductive strategy, learners required my input only occasionally. This was with the exception of two groups in the grade 11 mechanics class, previously referred to, who required almost constant help. This reduced stress on me and is expected to have reduced the effect of learners drifting off-task as they waited for me to finish helping other groups when they needed my help to progress.

In a questionnaire, 86% of the 57 learners in the 2006 and 2007 data sample reported that they enjoyed a deductive strategy, and 68% that they learnt effectively from it. Numerous (106) learner journal entries, following discussions in which groups applied conceptual knowledge to a situation, reported enjoyment and / or effective learning. A typical example is: “Explaining things to people helps to sort out the logic in my mind” (Sofia: LJ: 01/02/07). In contrast, very few entries (6) were recorded in which learners gave some form of negative comment about this strategy. However, since most of these had to do with struggle and effort, they could be viewed to be positive comments in terms of the criteria for determining effectiveness, used in this study. An example is given below:

> I thought the egg doesn't decelerate when it hits the ground... This made it difficult for me to understand most of my group's discussion. By the end of the lesson I had a headache! (Busi: LJ: 25/01/07)

Negative aspects

Although the deductive strategy was found to be effective in terms of this study, as described above, it did also have difficulties associated with it. These include time-consumption and messiness. These negative aspects are common to both the direct and inductive strategies referred to in this study, although their extent differs between the two, being more acute with an inductive approach. Application discussions, like inductive discussions, were found to be time-consuming, although to a lesser extent. As already mentioned, teaching grade 10 mechanics in 2006, with a focus on inductive discussion, took nine weeks. Using direct instruction interspersed with application discussion, in 2007, took six weeks. The curriculum, however, only allows for four weeks for this section.

While not as messy and frustrating as inductive discussions, application discussions are also associated with struggle and communication difficulties, which contribute to time-consumption and possibly to frustration. An example of this can be seen in the discussion where learners made sense of knowledge about motion while engaging in a question about the movement of a Ferrari and a cheetah (pp. 125-128). Another example is given on pp 175 to 176, where learners made sense of Newton's Third Law, force, friction, momentum and impulse in the context of a bullet being stopped by a silk handkerchief. A further example is the reference to two groups' grappling with an explanation about a taxi coming to a stop (p. 166). These discussions are clearly messy. This is certainly more so than the kind of interaction usual in a traditional classroom. I see this messiness, however, as a positive indication of effective learning occurring as long as the learner does emerge from this messiness to understanding, rather than remaining confused by the discussion process. This view arises from a conception that learning is messy, but for it to be helpful it should end in the learner understanding what was learnt (Bransford et al., 2000). In the two examples of application discussions cited here, it appears that a significant number of the learners did emerge from the discussion with an understanding of the work discussed. This is suggested by the high scores achieved on the target explanatory task by the grade 11 learners who underwent discussions such as the one on pp. 175 to 176 (see Figure 5.1 p. 163) and the remarks concerning attainability of this task (p. 177).

As discussed above, general success was observed when direct instruction of concepts was followed by learners engaging in sense-making activities. This sense-making occurred during learners' manipulation of their perceptions of these concepts as they sought to apply them to explain problem situations. Part of this sense-making occurred during group discussions. The success of such an instructional strategy suggests that this kind of activity should be catered for as frequently as syllabus pressure allows. In the long modules of this study the knowledge to be taught was broken up into pieces. Each strategy: direct instruction and engagement in sense-making activities related the instruction to the subsuming problem, was focussed on successively, although the influence of each extended throughout the learning period. A number of learners remarked on the effectiveness of this model. An example is given below:

> What I liked ... was that you first got the task, and then got taught and solved it along the way. (Silindile: Interview: 02/03/07)

The discussion above has suggested that teaching should precede sense-making group discussion. These findings can be understood in terms of existing literature. This literature includes the inclusion by some authors of deduction or application amongst critical or higher order thinking processes (e.g. Bloom, 1956, Epstein, 2002). It also includes views on promotion of conceptual learning, which is seen to require critical thinking, and therefore indicate its occurrence (Paul & Elder, 2006a), Nickerson, 1994). The value of sense-making activities to development of conceptual understanding can be understood in terms of the learners being given an opportunity to construct understanding (Dirks, 1998). During this process learners were able to explore their perceptions of concepts and implications of these, and to challenge and be challenged on these. In other words, this process allowed for critical discourse to be entered into (Dirks, 1998). This discourse serves to narrow the pedagogical gap (Moodley, 2000), encourage conceptual learning (Hewson & Lemberger, 2001), which involves critical thinking (Paul & Elder, 2006a). The effectiveness of setting these in group discussion experiences corresponds to learning occurring in the ZPD, where social interaction enables learners to achieve what would have been impossible in individual endeavour (Bransford et al., 2000). The role of direct teaching in this process is also seen to be consistent with this, being a form of social interaction between the teacher and the learners. Further, it seems likely that the structure and clarity which direct instruction lends itself to contributes to a deductive approach being less cognitively demanding on the limitations imposed by short term memory (Niaz & Logie, 1993).

5.3. TEACHING AND LEARNING ENVIRONMENT

Assertion 3: Critical thinking is encouraged by an environment in which struggle is accepted as normal, and participants are free to accept intellectual challenge.

5.3.1. An open, struggling environment

Assertion 3.1: An environment in which struggle is accepted as normal and beneficial is vital for a critical thinking task's success. This can be encouraged by various strategies.

Struggle was found to be a normal component of the critical thinking activities used in this study. Evidence from this study revealed this process of struggle to be effective in promoting critical thinking. This is supported by literature. From this it follows that learners' struggle should be treated as valuable and so an environment conducive to encouraging it is worthy of striving for. Two strategies effective in doing this were found, namely pair and group discussions and journal use. These were found to encourage learners to feel free to engage in struggle in a safe and supportive environment.

Struggle is a normal component of critical thinking. This is illustrated by the long term struggle undergone during the study's critical event (pp. 116 - 132). This cycle also illustrates the difficulty and confusion experienced by learners as they engaged in critical thinking. Numerous remarks (56) referring to effort and struggle were made by learners throughout cycle 7. Following one learner's journal entries through the duration of the motion module illustrates the general observation that learners underwent a long-term struggle, feeling confused and experiencing difficulties at times, particularly initially. The positive feeling of managing to struggle through a difficult task and conquer the challenge is also illustrated by these entries.

> 19/01/07: Today's lesson was not that interesting because we learnt stuff that we had already learnt in Grade 9. But the first challenge that we got about *Must He Pay?* was a bit challenging. Firstly I didn't grasp understanding about *Must He Pay?* But at the end I understood.
> 23/01/07: Today's lesson was nice and easy because it was stuff we did last year.
> 25/01/07: The work was challenging. I enjoyed working with others.
> 26/01/07: Today I didn't clearly understand most of the stuff we did.
> 30/01/07: It was very tough. I didn't understand some stuff but it became a bit clearer near the end of the lesson
> 31/01/07: Today's lesson was very nice and I could understand everything.
> 01/02/07: Today I didn't understand a thing with Interim Report 2.
> 06/02/07: I really was struggling to find where he stopped but after I went to Johan and he explained to me then I was confident and I understood.
> 15/02/07: Today it was nice and I was really sure that I understand my task.
> 16/02/07: The project *Must He Pay?* was very interesting. I got to really like it when I understood the concepts. I really enjoyed the assignment, although it was a lot of work and I had to sleep at 12 o'clock but it was interesting. (Musa: LJs)

Further evidence of struggle is found in comments made by learners new to the school. They said that they found the instructional strategy I used different and difficult. Five comments to this effect were made by learners new to the school, with the following being typical:

> I'm not used to the way Miss teaches. Now you have to think for yourself. I'm just used to hearing things and then. (Phindile: Interview: 18/08/06)

The learner who made this comment, as well as two others who were also new to the school at the start of the participation period, and who made similar remarks, showed dramatic improvement in reasoning skill, as measured by Lawson's Test of Scientific Reasoning (Lawson, 1978), during the course of the study. Each of these learners more than doubled their score over a two-year period, one improving by 257%. This suggests that the difficulty of having to "think for yourself", mentioned by this learner, was not in vain.

Even those learners not new to the school, when interviewed, indicated that they were not used to being expected to think to the extent required by the instructional strategy used in this study (e.g. Interviews 18/08/06, 28/02/07 RJ 11/02/08). This further supports the notion that struggle is a component which sets an instructional strategy aimed at promoting critical thinking apart from other strategies. This is not surprising. As Resnick (1987) points out, critical thinking involves uncertainty and is effortful. Therefore it is reasonable to expect that an instructional strategy aimed at promoting critical thinking should be characterised by struggle.

With perseverance, this struggle was found to pay off. This is as evidenced by learner successes following engagement with struggle. One example of this is the gains made in the reasoning test scores, previously mentioned. Other evidence of learning success following struggle includes the general attainability of the majority of critical thinking tasks used, as has been referred to a number of times. An additional illustration was given earlier by reference to the majority of learners managing to produce conceptual explanations suggestive of understanding after struggling through a discussion about a taxi decelerating to a stop.

From this it seems to follow that a task which could have been effective at developing critical thinking, with perseverance, might be considered a failure unless teachers and learners are prepared to undergo a long-term struggle. A comparison of two groups during a discussion lesson on 04/05/06 further illustrates the value of an atmosphere of openness to struggle. One group verbalised their confusion, enabling me to direct them to productive learning, while one member of another group claimed their group understood, ending learning despite the fact that later interaction showed that a number of learners in that group had not understood the work (RJ: 04/05/06). This observation points to the need for strategies to encourage an environment of safety to embark on, and openness to verbalise, struggle. Various strategies were found to help create such an environment. These were pair and group discussions, and journal use. These are discussed below.

Pair and group discussions

Expecting learner response within a whole-class setting was found to be non-conducive to creating the climate needed to support struggle. The quote below suggests this:

> Miss it's bad to call us to answer. Please don't point me I'm shy it's better if I put up my hand coz it might happen that I don't know the answer and can't answer right then recognized as a dum person. (Sihle: LJ: 13/02/07)

Additionally, calling for voluntary response was found to tend to offer opportunities only to the few who were bold enough to participate in this way, as illustrated by the following learner journal entry:

> When a question is asked in the class, sometimes I know the answer but it's just that I'm shy, maybe afraid to say it aloud in class. (Faith: LJ: 14/08/07)

In contrast, high levels of active participation were found by all learners when instead of calling for a response in front of the whole class, all learners were instructed to answer a question with their desk partner, the teacher walking amongst the learners during this process. I would then feed individual answers back to the whole class for critique. This would be done anonymously where criticism would be required in a manner which would be likely to embarrass the learner. An example suggesting the effectiveness of such a strategy is given below:

> I enjoy doing science. I just have to force my lazy brain to work and think hard. I like it when a teacher asks questions, I'm quite scared to make a mistake in front of my classmates but I just go against that feeling because I learn from mistakes. I like it when we Miss says, "Tell the one next to you", or, "Close your eyes and put up hands". (Lindiwe: LJ: 15/04/08)

However, such a strategy is not without its difficulties, some related to classroom climate, and others related to other issues. It was found to tend to slow the teaching process down, reducing time for other activities such as group discussion revolving around the task, practical work and going through homework problems. This slowing effect particularly occurred when I listened in to the learners' pair responses and drew some of these into the lesson, rather than simply allowing for what seemed to be an appropriate amount of time for the discussion before supplying the answer (e.g. RJ: 31/07/06). This was especially the case when weaker learners were listened to (e.g. RJ: 23/04/07). Further, I received the impression that sometimes such pair discussions broke the lesson flow (e.g. Lauren: LJ: 06/08/07, 28/08/07, Busi: LJ: 30/08/07). It also occasionally led to off-topic talk (e.g RJ: 16/02/06, 24/04/06, Interview: 18/08/06), and sometimes made some learners lose concentration (see p. 150). Related to classroom climate, group discussion was found sometimes to hinder the development of an open environment, as suggested by the following remark:

> I loved the topic we were talking about, but I couldn't say anything much because there is no use of speaking nonsense just for the sake of it especially if you are not sure what the answers are. When everyone goes on like that I know it they think I'm dumb cause I'm quiet but there wasn't a right moment for me to say something. I felt discouraged today. I lost my touch and no one believes in me anymore. (Helen: LJ: 25/01/07)

The composition of Helen's group could, possibly, have been a factor causing prevention, rather than promotion, of open participation in the struggle of learning. Group composition's effect on openness and critical discourse is complex. The discussion below explores this.

Thembi:	Yesterday – on the discussion topic – I had a problem with task 10. Then I went to Busi, we had a problem, both of us. Then we called Kim. We had a problem. Then we called Cole. And then we all discussed. We're normally not in the same group, all of us. Then we all discussed, and then it was so helpful because we're not in the same groups, plus Cole was just putting more effort because he never discusses, he saw the point.
Me:	Yes, the boys don't usually discuss.
Agnes:	I think it's more "who am I" – ego.
[Commotion]	
Agnes:	I think you should write a list and then rotate the groups.
Thandiwe:	The girls are different from the boys. Now if I take Tim and put him with James, maybe they don't feel comfortable together.
Me:	So maybe the girls can be mixed, but not the boys?
Thandiwe:	But maybe if I put Tim with Bhekani, and maybe they have the same brain, and then they get stuck, then they realise they must ask Miss because we are stuck, but if I were to put him with James, James will like: Oh, this this this this, and he's left behind, because he knows James is going to get impatient, so I think maybe let the boys go together with those they want to and from there they can even make it a secret.
Silindile:	If I'm put with Sonja, Kim and Lauren I feel very small and I just have to listen to them because they just understand.
[Commotion]	

Silindile's remark, above, suggest that learners should be placed in similar-ability groups, since being placed with stronger learners made her feel small and stopped her from participating. Similarly, Jabu's claim, in the continuation of the extract, below, that she works well with Thandi, who is of similar ability to her, might suggest that similar ability groupings are beneficial. In contrast, Agnes challenges this notion, below:

Agnes:	Probably we have the problem of socialising together, now we need to overcome that problem.
Thandiwe:	It's a matter of understanding one another. I've learnt to accept Lauren, so I don't go to her because I know she cannot… I picked it up in maths. She's a very good worker if she's to work alone, because if I get there and I ask like x times x, and she'll like "Thandi, you're so stupid" – she can actually tell you!
[General agreement]	
Thandiwe:	And I'll go back and think I won't go to her, meanwhile if she were to... Like Kim, we can actually talk together. But I think like...
[Commotion]	
Jabu:	Being with Thandi's group helped me a lot. It has increased my science marks because it's got me to express myself.
[Agreement]	

Thandiwe states that "it's a matter of understanding one another". This might refer to academic ability, or it might refer to personality traits. Similarly, Thandiwe's remark that she will ask Kim for help, but not Lauren, suggests that personality, rather than merely academic ability, affect group composition's effectiveness. Both Kim and Lauren are academically strong learners, but Lauren has a more independent and direct personality. Kim's remark about having "confusing" people in her group preventing the group discussion from having been effective (see p.203) might also suggest the effect of personality incompatibility on the effectiveness of group discussion. Jabu raises a further factor, communication skills, in affecting the effectiveness of group discussion, linking this to gender:

Jabu:	I think girls have that communication, because I think with boys... If we get stuck we do like go to Kim, no matter.

As Jabu mentions here, and as was referred to in a few other places in this interview, the boys in this class were found to be hesitant to discuss work with one another. Mixing the genders was proposed as a possible solution, with some support given here for its success. For example, Thembi claimed that the inclusion of Cole, a boy, into a previously all-girls discussion the previous evening, had enlivened the discussion. Mixing the genders in group discussion was tried in subsequent lessons, and did seem to increase their participation (e.g. RJ: 01/02/07). This probably resulted less from this aspect increasing learner openness, but rather increasing the motivation not to appear inactive and uncritical.

The remainder of this extract, given below, exposes the fine line that exists between freedom learners should feel to make errors and the need for these errors to be exposed through critical discourse. The need to protect learners' dignity can be seen in the apparent reason why Tim will go to James (a stronger learner) for help after class, but not during class time. This seems to be that he does not want to appear stupid in front of other learners who might overhear him asking James a seemingly stupid question during class. Similarly, Thandiwe's suggestion that clumping stronger learners (e.g. Lauren and Kim) together is unadvisable, relates to the issue of managing group composition in a manner which protects the dignity of learners and so enhances their willingness to participate. She says that clumping of strong learners together prevents weaker learners placed in the same group from participating. She relates that when, instead, stronger learners are isolated from other strong learners, they are more approachable. On the other hand, on the issue of the need for critical challenge by peers, Agnes raises the point that placing learners of similar ability in one group does not provide the opportunity for the weaker to learn from the stronger learners:

Tim:	I also go to James, but after hours – because I know…
Me:	Then there won't be an audience?
Tim:	Not really; when you're in class I won't understand him. When we're out of the class I'll say, hey James, how do you go about this.
Agnes:	It could be you're tense in the class.
Thandiwe:	How come in class don't you understand?
Tim:	There are many people there.
[Commotion]	
Tim:	I don't get the chance to speak to him.
Thandiwe:	Maybe it's because it's like putting Kim and Lauren together, and if you come then you won't get anywhere.
Me:	Whereas if they were separated it's different?
Thandiwe:	Whereas it might be if James is alone and Tim comes, he thinks he can help him, but maybe if it would be with someone else.
Silindile:	Maybe each must find who they work well with, and work with them, and when they get stuck ask others.
Agnes:	But if you're all of the same level, you need someone to pull you up.
[Commotion]	

(Interview: 18/08/06)

Later in this interview Agnes suggested that I make a list and rotate group composition according to it. As a result of this interview, I started jig-sawing groups, i.e. changing their composition part-way through the discussion. This seemed to help increase the likelihood that at least some of the time positive combinations of learners would arise. The benefits of altering group composition part-way through the discussion are illustrated to a small extent on p. 127. Here the procedure that Johan had previously derived while working in one group was passed on to other members of the class because of a rotation of group compositions. In Lauren's 15/08/07 journal comment (p. 151) she says that at the start of the discussion she "had absolutely no idea" how to explain how a solar panel works. However, with each change in group composition she gained a more complete understanding from various people with whom she discussed the problem, until at the end she understood the whole.

From the discussion above I conclude that pair and group discussions are potentially effective at encouraging safety and openness in struggle, however, their management affects whether this potential is realised or not. One of these management considerations is group composition. The effect of group composition on learning effectiveness is a complex factor. Not only does it affect how free learners feel to openly undergo the struggle normal and necessary to critical thought, but also whether critical discourse occurs to help the struggling learner out of his/her error and what knowledge is shared between group members. Although the data does not apparently suggest the superiority of any particular strategy regarding group composition, it does suggest that changing a group's composition part-way through a discussion, i.e. jig-sawing of groups, is advisable.

Journals

Another strategy found to be effective in supporting struggle was the use of journals. These were initially meant only for data collection for this study, but additionally proved effective for creating an open relationship between learners and the teacher. Learners frequently wrote their feelings in the journal, such as the following:

> Miss Stott ignores us when we're having a debate, she had to come and be a judge. But the subject is getting well and tougher but it's nice and challenging but Miss Stott

> you're too ignorant to people like us, you sort of push us to the side and leave us there to go to those ahead of us and pull them out, then come back to us. Better push one at a time. (Sihle: L J: 01/02/07)

I wrote an apology back to this learner in his journal, explaining that I had not noticed his raised hand. This incident made me more sensitive to this kind of situation, and my heightened sensitivity seemed to be the cause of this particular learner becoming highly motivated to work hard, as can be seen by the following excerpts from the data, concerning him. This list illustrates the power of intrinsic motivation which seems at least partly have been inspired by an open relationship of mutual respect between the learner and the teacher. Corresponding to this attitude change in the learner, he rose from bottom to middle position in the class between 2006 and 2007. Some of his voluntary notes, submitted to me for comment, and written in a question-answer style suggestive of metacognition, are given later.

> Nice day enjoying my work coz you paid attention to us and that sort of encourages us to pay more attention and concentrate more if you come and see our problem we have and work with us to get the answer it was brilliant I wish it carries.(Sihle: LJ: 14/02/07)

Sihle:	Motivation.
Me:	And what gives you motivation?
Sihle:	Speaking to me and encouraging me.
Me:	So the teacher encouraging?
Sihle:	Yes, like if this child isn't coping at school, going to him and saying "you need to spend more time" – it really helped me.

(Interview: 28/03/07)

> Good inspiration through your comments of motivation in the note book and making me look superior from inferior you made me capable of setting good goals in Science because of your motivation. (Sihle: LJ: 15/02/07)

> And obviously afraid to disappoint you with my results, after you have gave a lot of your effort on helping me! (Sihle: LJ: 08/03/07)

Not only did the journals prove to be valuable sources of information to alert the teacher of problem issues due to the openness they encouraged, they also served as ways in which the teacher could provide encouragement and guidance to the learners, as illustrated by this extract:

> Miss, sometimes your end comments even after a lot of mistakes corrected by you (which I don't mind) makes a difference in my attitude to the task. (Agnes: LJ: 31/01/07)

This particular comment was made after I had returned the learner's draft submission of the final task, covered in red marks, but with no encouraging note at the end. The learner, feeling discouraged, had written the entry given above in her journal. I responded to her in her journal, pointing out that it was normal to struggle with the kinds of tasks we were doing, and that if she persevered with the effort she was evidently putting into her work, I was sure she would succeed. The effect of this simple response was immense. Her next journal remark (12/02/07) showed that this simple encouragement was the turning point in the task for her, motivating her to renew her struggle. When interviewed at the end of the task, for which she achieved 83%, she was extremely positive about the experience, again remarking how the encouragement I had given in her journal had helped her to cope (Interview: 01/03/07).

In this section I have shown that struggle is a normal and beneficial component of critical thinking, and therefore a classroom climate which views struggle as such and which gives learners the security to be open in this struggle, is vital for the success of a critical thinking task. I have also provided evidence for the success of two strategies, namely use of pair and group discussion and journal use, in creating such an environment. The importance of the creation of such an environment can further be understood in terms of literature. Research has shown that those learners who are willing to make mistakes learn more effectively than those who shy away from activities which might reveal their errors (Bransford et al., 2000). The struggle inherent to critical thinking (Resnick, 1987), as well as the high cognitive demand which critical thinking must obviously place on learners (Niaz & Logie, 1993), is to be expected to lead to learners making numerous errors during learning. This was found to be the case even for a high achiever whose learning of physical science I studied (Stott, 2002). Without this freedom to make errors within a supportive learning environment, it is unlikely that optimum learning will occur.

However, although creating an environment of openness is necessary, it is insufficient for encouraging critical thought. This is because an environment in which errors are accepted without challenge is inconsistent with critical thinking's nature (Paul & Elder, 2006b). This suggests that an environment in which learners and teachers are free to give and accept intellectual challenge in critical discourse, is necessary to enable learners to learn from the errors emerging from the struggle they undergo. This is discussed below.

5.3.2. Critical discourse

Assertion 3.2: An environment in which learners and teacher are free to give and accept intellectual challenge is vital for a critical thinking task's success. This can be encouraged by various strategies.

Critical discourse is central to critical thinking (Dirks, 1998). It follows, therefore, that an environment which encourages this should promote critical thinking. In this section I analyse examples of cases where critical discourse was clearly being engaged in to illustrate the benefits associated with critical discourse. I then describe strategies which I found to be beneficial in promoting an environment conducive to critical discourse.

As the interview concerning management of group work (pp. 184 to 186) suggested, learners tend not to want to reveal their thinking if they feel they will be ridiculed for this. However, without doing so, limited progress is likely to occur in the sense-making process necessary for a critical thinking task's success. In the examples referred to in the discussion below, learners of all levels of ability participated actively in sharing their ideas even where these were erroneous. This freedom suggests that the learning environment, at least for these particular events, was conducive to encouraging critical discourse. In this discussion I argue that this freedom resulted in the tasks engaged in being successful in promoting critical thinking. The first example refers to a small group discussion, and the second to a period of direct instruction, performed in an interactive manner.

For an example of critical discourse in a small group discussion, refer to the discussion about a silk handkerchief stopping a bullet (pp. 175 to 176). This extract is seen as an example of a group discussion in which learners and teacher undergo critical discourse. At atmosphere of freedom to give and accept intellectual challenge is clearly present. This is evident by the presence of a number of instances of learner-

learner, learner-teacher and teacher-learner rebuttal occurring (Erduran et al., 2004). Besides illustrating critical discourse and an environment conducive to this, the exchange is also interpreted as illustrating the vital role that critical discourse plays in a critical thinking task's success. These include the evident engagement of the learners, evidence that they are undergoing critical thinking, and the fact that the engagement did lead them to the required understanding. Their active engagement is shown, for example, by their exploration of details beyond the minimum requirements of the task, exploring, amongst other things, the effect of distance between the gun and target on the likelihood of the bullet being stopped. The reasoning they underwent suggests reliance on criteria. For example, they point out that N-3 applies in the case of a jersey, so if its presence is the determining criterion, then a bullet should be stopped by it too. They also display sensitivity to context. For example, Thandiwe points out that since an indentation would be made in the silk during the bullet's impact, friction could occur since the bullet's force would have a component parallel to the silk's surface. Further, they are using this reasoning to aid their judgement of why a bullet can be stopped by silk, but not by, for example, the material jerseys are normally made of. In other words, there is evidence that they are undergoing critical thought according to the definition given by Lipman (1991). Further, productive learning did occur as a result of this discussion, as shown by the learners reaching at least a degree of understanding of the issue by the end of the discussion, and by them all performing well in the final task in which they displayed this understanding (see p. 177).

The example referred to above was used to illustrate the process and benefits of critical discourse. The extract below further illustrates this, during direct instruction. In this discussion a wide range of learners: academically weak and strong, shy and bold, participated, all making errors and receiving correction. This example is particularly noteworthy in that the class involved is generally known as being non-participative. This example will, later, also serve as an illustration of some of the strategies used to create an environment effective in eliciting and encouraging critical discourse.

> I first showed them a computer simulation of the reflection of light off a plane mirror for various angles of incidence. I asked them to write down what they saw. I asked

> them to ask me for terms which might help them be clearer. Thabani asked what he should call the line of light going to and from the mirror. Prudence suggested incident and reflected rays. Victoria asked how to refer to angles. I pointed out the difference between magnitude and orientation of an angle and that when referring to an angle one must have two lines that one gets the angle between.
>
> I wrote these things on the board. Then I gave the learners some time to improve what they had written and show it to someone else. I asked Ntombifuthi what she had written. She said she was still writing. I asked her to give me what she had got so far. She said, "The incident ray is the reflecting barrier mirror." I wrote this on the board and asked for comment from the learners. Lindiwe said reflecting barrier and mirror are the same thing, so one could rather say "the incident ray is the reflecting barrier". I asked, though, what this means. Ntombifuthi could not say.
>
> Siphesihle then said "it is perpendicular". I wrote this, and asked, "What is perpendicular to what?" He tried to explain, but could not, so I asked him to come and show it on the screen. He pointed to the normal line. Someone helped by saying, "That line is perpendicular to the reflecting barrier." I then asked what the significance of this line was to explaining what we had observed. Thabani said it separates reflection from refraction. Mike said it is the line that the incident ray in the first demonstration I had performed for them had been on. I said that I could have made the simulation to have started elsewhere, so that was not of much significance. Just after I had said this, Thabani said what Mike had just said, and I repeated my reply.
>
> Jan then said, "It has an angle to the line perpendicular to the reflecting barrier that is the same on both sides". I wrote this down and asked for questions directed to Jan that would help him improve his own answer. Thabani said "What is *it*?" Jan improved his statement to "the reflected ray has an angle to the line perpendicular to the reflecting barrier that is the same on both sides". I wrote this down and asked for questions or comments directed to Jan that would help him improve his own answer. Victoria said that he was referring to "both" - which suggests two, but the reflected ray is just one thing. Jan improved his statement to "the reflected ray and the incident ray have an angle to the line perpendicular to the reflecting barrier that is the same on both sides".
>
> I said this made sense now, but was too long, so we needed to introduce a term which could cut out on some words. I explained the meaning of Normal, and then asked the learners to all improve Jan's statement, and write their improved statement down. Stewart then remarked "but what does 'on both sides' mean?"Later Mike volunteered: "The angle between the incident ray and the normal is identical in magnitude to the angle between the reflected ray and the normal." I wrote this on the board and remarked that it was very clear and precise, but that we could still make it shorter by introducing other terms. I then introduced the terms "angle of incidence" and "angle of reflection". Stewart then said, "Angle of incidence equals angle of reflection". (RJ: 21/04/08)

The fact that I am engaging in critical discourse with the learners in the extract above is evident by the question-answer challenges with which I interact with the learners. Further, the learners are clearly also engaging in critical discourse with one another. This can be seen by their challenges to one another, such as Thabani's question to Jan "What is *it*?" and Stewart' question to Mike "but what does 'on both sides' mean?" This process resulted in the class together deriving the Law of Reflection. They did this by collectively applying a critical evaluation of their attempts to verbalise their observations. Had learners not felt free to participate, which involved making errors, challenging and being challenged, this process would not have been possible. Therefore the freedom to undergo critical discourse was vital to the success of this critical thinking task.

In the discussion above, I have given two examples in which critical discourse occurred. I have briefly referred to the effectiveness of the freedom to give and accept challenge in the promotion of critical thinking, in these two examples. I now turn to an examination of strategies to encourage critical discourse. I will refer to the two examples given above, and others, to support the argument I make concerning this. I found evidence for the success of various strategies which encourage critical discourse. These include modelling and expectation, co-inquiry, prompting through asking initiating and reflective questions, increasing learner-learner accountability and allowing for wait-times and a lag phase. These are discussed in turn.

Modelling and expectation

Continual modelling and expectation of critical discourse by the teacher seems to create an environment in which learners engage in critical discourse amongst one another, as well as internally with themselves. However, this is a long-term process. I approached every lesson throughout the study with this attitude. This includes a continual challenging of learners to examine statements against intellectual standards (Paul & Elder, 2006a) such as clarity, accuracy, precision, relevance, depth, breadth, logic, significance and fairness. This expectation is illustrated in the extract in which learners derived the Law of Reflection (p.191). I expected learners to be clear and precise. For example, I expected Siphesihle to clarify his statement "It is perpendicular" by asking him "What is perpendicular to what?" I expected learners to evaluate what they were saying in terms of its significance to the problem at hand. For example, I asked what the significance of the normal line was in generalising what happens during reflection. I expected learners to consider the relevance of information. For example when Mike said that the normal line was the line the first simulation's incident ray had shone along, I pointed out that this was not relevant to a general rule of reflection, since I need not have started my demonstration in this way.

Evidence which suggests that this expectation and modelling does eventually get emulated by the learners includes numerous observations of learners challenging one another in a similar fashion, using questions such as "Why?", "How do you know?", "How can you test that?" and "So?". Examples in the extract above are Thabani's question to Jan, "What is *it*?" and Stewart' question to Jan, "What does 'on both sides' mean?" Additionally, learners made comments such as the following concerning this matter:

Tim: These holidays my family and friends they started to push me away because every time I talk I try to...
[Laughter and agreement}
Tim: Then I tell the person to be clearer, and the thing is I know actually what the person's saying, but I want the person to be clearer.
[Laughter]
Tim: And they ended up telling me I must write a dictionary and become a teacher.
Kim: It's become a habit. Especially in Biology, someone says something and you say, "clarity!"
(Interview: 03/11/06)

Definitions of critical thinking generally include metacognitive aspects, such as self correction (Lipman, 1991). Consequently, the evidence that at least some learners seemed to apply this critical discourse to their own internal dialogues is particularly interesting. This was seen in the general self-dialogue style a number of them took towards writing summaries of their understanding of the work. Evidence of learners taking this strategy includes statements made during interviews, such as this one:

Silindile: Even in my notes I realised questions are effective.
Agnes: It structures your answer.
Silindile: Because sometimes if you just have to write a paragraph it's overwhelming, but if you ask yourself questions it's much better.
Me: And what gave you that idea?
Agnes: The slide shows.
(Interview: 01/03/07)

An example of this question-answer style taken by many of the learners in voluntary notes they wrote for themselves and gave to me to check, is given in Appendix B, and reproduced below.

> When I kick the ball I apply a force on it which is compression force and it pushes me back, also applying the force I applied. So why don’t I go flying as it does? Because of my mass or weight compared to its mass it’s nothing compared to me. But this ball has got kinetic energy, is that’s why when I kick it, it makes a noise and when it lands on the ground it makes a sound. I’m applying a force on a ball therefore I’m doing work on the ball then KE from me is transferred to the ball.
> The law says when an object moves further away the force of attraction between the two decreases. In other words the gravitational force is inversely proportional to the square distance between the particles. Likewise, if the two particles have a less square distance between them; if they are very close to each other then the force of attraction will increase.
> What I think: Let’s look at this, when a person is in the deepest part of the ocean it’s hard for him to come to the water’s surface:
> Reasons are: (True or false?)
> - He can’t come to the surface cos of the water’s weight on top of him. But why don’t we normally feel the water’s weight when we are in the water?
> - There’s less distance between me and the earth’s centre, therefore the force of attraction is higher.
>
> (Sihle: Voluntary notes given to the teacher for comment: 08/02/07)

Further, a few journal and interview remarks were found to refer to self-corrective metacognition. An example is given below:

> While doing homework I suddenly realised I was asking myself “Why?” “So?” – that, I think, got me thinking more critically. Spent basically my whole evening thinking about the egg issue. (Kim: LJ: 24/02/07)

For some periods of time during the study I had lists of the elements of thought, intellectual standards (Paul, 1993), criteria for causation and research evaluation (Epstein, 2002) as posters on the wall. I would frequently refer to these during teaching and task performance. I found them valuable teaching aids for myself (e.g. RJ 16/05/07). The learners, however, reported, e.g. in an interview on 18/08/07, that they did not spontaneously refer to them much. On the other hand, the learners did comment that my continual reference to these criteria was instrumental in developing a general habit of critical thinking in the class (Interview 03/11/06). This suggests that using and enforcing criteria through modelling and expectation is necessary for them to be internalised. Simply displaying them is insufficient.

Increasing learner-learner accountability

Learners reported that being expected to display individual work to a fellow learner for further discussion motivated them to be more critical, productive and produce higher quality work (Interview: 12/05/06). This seemed to be particularly effective when this involved learners showing their work to learners of the opposite gender (Interview: 03/11/06). This is a form of peer assessment, and the effectiveness observed is consistent with Hiler & Paul's (2005) view that learners are more likely to be self-critical if they know that their work will be examined by peers.

Allowing for lag phases.

The observation of an initial lag period in which little productive activity seemed to be happening, followed by an intense period of learner activity, was a general characteristic of discussions related to a critical thinking task (e.g. RJ: 09/05/06). This initial lag phase can lead to the perception that the task has failed to elicit the desired response, and so should be abandoned, e.g. by the teacher supplying the answer or simplifying the task (Blumenfield et al., 1987). As a teacher, I am aware of the anxiety which arises when learners cannot solve problems soon after they have been posed. Provision of the solution, rather than waiting for a response, can remove this anxiety. However, this practise seems likely to encourage development of the kinds of attitudes Hobden (2000) found in South African learners, taught in traditional style classrooms. These learners displayed no sense of a need to struggle or deal with longer problems. Instead, they had a general perception that it should be possible to solve problems quickly. This suggests that they might not have been expected to undergo long-term struggle with a task. However, it seems reasonable to expect that tasks requiring critical thought should require a good deal of time and mental effort before visible progress is made in the solution. This is supported by the view that during higher order thinking "the total path is 'not visible' (mentally speaking) from any single vantage point" (Resnick, 1987, p. 3).

The discussion above suggests that allowing for a lag period is necessary for the success of a critical thinking task. This means withholding direction for a while despite learners' apparent lack of self-direction. This is consistent with the general finding that learner engagement in each of the critical thinking tasks used in this study began with a lag phase, as well as with occasional evidence of what learners were doing in this time, e.g. "I was thinking: Is acceleration increasing or is it constant? – and that's how we eventually got started" (Kim: Interview: 12/05/07). In this study I made allowance for lag periods, i.e. I did not respond to the learners' apparent inactivity by giving the answer, simplifying the task, or immediately providing guidance. This appears to have been beneficial, as testified to by the success reported on throughout this dissertation. This view also corresponds with research which stresses the value of wait-times to promotion of critical thinking (Tobin, 1987).

Management of lag periods, though, is tricky. While they need to be allowed for, as shown above, there is also the very real possibility that doing so may encourage passivity due to a lack of self-direction and motivation. In such cases, inactivity on the part of the teacher in the name of allowing for lag periods can waste limited time. An example where the potential for this time wastage is illustrated follows.

> Learners were instructed to evaluate various statements for logic, first individually and then in groups. Ten minutes after the instruction had been given, the boys had still not organised themselves into discussion groups, with a number of them sitting passively, and one reading a book. I had to figuratively drag them into groups and get them started. Twenty minutes later their discussion was very animated, but unfortunately I had to bring it to an end, since we had run out of time. (RJ: 24/04/06)

A further difficulty in managing lag periods is the issue of how long they should be provided for before the teacher does provide guidance. As discussed previously, expecting learners to undergo long-term struggles with little direction is incompatible with the time-frame of the curriculum. It is also unlikely to result in sound conceptual development (Driver, 1983). As given by the following reference to findings by Eylon and Reif, 1984 and Dufresne et al., 1992, guidance is vital for efficient time usage, and so lag phases must be ended at some point and provision of guidance begun.

> These examples demonstrate the importance of deliberate practice and of having a "coach" who provides feedback for ways of optimizing performance. If students had simply been given problems to solve on their own (an instructional practice used in all the sciences), it is highly unlikely that they would have spent time efficiently. Students might get stuck for minutes, or even hours, in attempting a solution to a problem and either give up or waste lots of time. (Bransford et al., 2000, pp. 174-175).

Therefore, the teacher is in the difficult position of needing to ensure that time is used effectively while also not removing the expectation that learners do undergo critical discourse and develop an attitude of being prepared to participate in a long-term struggle. I suggest that allowing for lag phases is a strategy which contribution of achievement of critical discourse. This must be done in a manner which displays an expectation that learners undergo critical thinking, but which is monitored with sensitivity to issues of effective time usage and the need for appropriate guidance. This sensitivity should guide decisions on when lag phases should be ended, at which point the teacher may engage other strategies, such as those discussed below.

Co-inquiry

In the discussion about silk stopping a bullet, given on pp.175 to 176, I underwent inquiry together with the learners for part of the discussion. I had not considered the role of friction in the bullet's deceleration, and so Thandiwe's suggestion that friction helped slow the bullet down made me think about whether this seemed reasonable or not. I initially thought that this was not significant unless there was a component of the bullet's motion parallel to the surface. I told the learners this, with motivation, i.e. pointing out that friction only acted in response to a force parallel to a surface. Thandiwe rebutted this by pointing out that the indentation caused by the bullet resulted in sections of the jersey being in contact with and parallel to the force exerted by the bullet. This discussion illustrates both my role as a co-inquirer and the effectiveness of this on promoting learner rebuttal, considered a characteristic of critical thinking (Erduran et al., 2004).

Prompting

Besides undergoing inquiry with the learners during the bullet-silk discussion, I also directed learners' thinking towards the task's solution by using prompting questions. Examples include asking Thandiwe why the bullet loses momentum, asking Lauren what the fact that the silk is getting tighter and tighter causes. These inputs seem to have helped propel the discussion towards the scientifically sound conclusion. This view that active teacher participation in learner discussions is vital to the discussions leading to the development of correct conceptions is consistent with research done in a South African class room by Ankiewicz et al. (2001).

The prompting strategies I found to be effective in directing critical discourse can be divided into two categories on the basis of their purpose: those which initiate discussion and those which encourage critical reflection. Initiating questions include asking learners the meanings of terms, requirements of and information relevant to, the question, and related concepts and principles. Reflective questions include asking learners the meaning of, or calling for greater clarity in, their statements, calling for the relevance of statements to the problem, and asking learners how they could test whether their statements are correct.

Asking initiating questions. In the following extract I transformed learner inactivity into what later became an active and productive discussion, through use of initiating questions. I asked learners the meaning of a term relevant to the problem, namely acceleration. I also asked learners what the requirements of the problem were ("Where are you trying to head?"), although I did not follow through on this here, limiting the usefulness of this question. I expected learners to state information given in the problem ("What do you know?"), which was effective in propelling the discussion forward. Concepts related to the problem include displacement and velocity. I did not question the learners on these in this extract. On reflecting on the lesson after transcription of the audio recording (Teacher Journal: 09/05/06), I realised that this omission was a mistake since the learners' final explanation indicated misconceptions related to a poor distinction between these concepts.

[I went to Seth, Tim, Sihle and Sakhile's group. They were sitting quietly, apparently doing nothing. I asked them what they were doing. They did not answer. I asked them if they were sitting waiting for the answer to fall out of heaven on them. They said yes. I said that does not happen: they have to search for the answer.]

Tim:	Where can you look for it?
Me:	Well, start by thinking what acceleration means.
Seth:	Change in velocity per time.
Me:	So what does an acceleration of 6m/s/s mean?
Seth:	It means every second (long pause) every second it changes 6m/s.
[Pause]	
Me:	Fine.
[Pause]	
Sakhile:	Why is Miss looking like this?
Me:	Because I'm waiting for you to realize that will help you with something.
Sakhile:	Oh.

[There was a pause and then they made some remarks about not knowing how this would help.]

Me:	Where are you trying to head?

[There was laughter and remarks suggesting they did not really know.]

Me:	What do you know?
Tim:	It moves at 6m/s/s.

Me:	It MOVES at 6m/s/s?
Seth:	The velocity changes at 6m/s/s
Me:	And what was the velocity at the start?
Seth:	Zero. After 1 second…..
[Pause.]	
Sakhile:	Miss, you can come back later, we'll try on our own.

(Audio Transcript: 09/05/06)

Asking reflective questions. The discussion on reflection of light off a plane mirror, given on pp. 191 to 192, illustrates how teacher prompting made learners more reflective. Asking Ntombifuthi what she meant in saying "the incident ray is the reflecting barrier" is an example of challenging learners on what they mean by their statements. In this particular example, this challenge did not seem to progress the discussion helpfully, but hopefully did contribute to enhancing learner self-reflection. This challenge, as were all the others too, was asked in a respectful manner in an attempt to preserve the dignity of the learner so as not to abuse her openness. Asking Siphesihle to improve the clarity of his statement, "it is perpendicular" by asking him "What is perpendicular to what?" did propel the discussion forward. It led Siphesihle to indicate what he meant, which led another learner to volunteer that the line was "perpendicular to the reflecting barrier". I then called for an evaluation of the significance of this line, i.e. the normal, to reflection. This is an example of questioning the relevance of a learner's statement to the problem. This led Thabani, Mike and Jan to give suggestions. I questioned Mike's suggestion for relevance, and Thabani questioned Jan's suggestion for clarity. Not only did my reflective questions propel the discussion to a scientifically fruitful conclusion, but they also seem to have been instrumental in getting learners to model my questioning in questions directed to their peers.

Other examples of calling for an evaluation of the relevance of statements to the problem include the following. In the discussion on electrostatics (p. 99), I questioned learners on the relevance of conductivity to determining whether a material would pick up pieces of paper after being rubbed or not. In the discussion on why a silk handkerchief can stop a bullet (p. 175), I questioned learners on the relevance of the silk's elasticity to it being more likely to stop a bullet than a less elastic material would. Additionally, the electrostatics discussion (p. 99) illustrates use of questioning to make learners think of how their statements could be tested. For example, I asked learners how they could test whether heat conductivity was the significant variable in determining whether a material would pick up pieces of paper after being rubbed or not.

In this section I have shown that creation of an environment in which learners and teacher accept and provide intellectual challenge, is vital for the success of a critical thinking task. Such an environment is inconsistent with an authoritarian view of teaching and learning. According to this, teachers, text books and scientists are seen as undisputable sources of knowledge (Watts & Bentley, 1984). Not only is the kind of ideology contrary to the physical science national curriculum's aim of portraying the contested nature of science (PS LO3AS1), but it is also incompatible with the implementation of critical thinking tasks, given the centrality of critical discourse in critical thought (Dirks, 1998). I have also discussed various strategies emerging from this study as being effective in promoting such an environment. These are: modelling and expectation, increasing learner-learner accountability, allowing for lag phases, undergoing co-inquiry, and prompting. These were performed with an awareness of the intellectual traits characteristic of critical thought, such as intellectual courage, humility and perseverance (Paul & Elder, 2006d), and with an intension of developing a disposition to think critically (Bailin, 2002), thus hoping to model and inculcate a belief system conducive to critical thinking, in learners.

5.4. TASK ADJUSTMENT FOR INDIVIDUAL LEARNERS' NEEDS

Assertion 4: Various strategies can improve attainability of a critical thinking task by a wider range of learner abilities than possible without these strategies.

5.4.1. Group discussion

Assertion 4.1: If the majority of the class is to be involved, group discussion is vital for a critical thinking task's success. Management strategies affect the effectiveness of this.

Advantages

Group work was found to increase task attainability by weaker learners. However, its effect was not limited to this. It was found to enhance the performance of all learners through the synergy that a combination of knowledge and insight from a number of learners, each having a partial understanding, results in. The necessity for dialogue, during group work, was also found to contribute to creation of an environment conducive to critical discourse, as has already been discussed. The following response, together with 261 similar comments, testifies to the value of group discussions in the success by all learners of a critical thinking task:

> I just don't know how to express myself. I think it was the best science lesson I've ever had. Group work works for me. At the beginning I wasn't sure when we discussed, but as everyone had an input, I figured out the answer. I enjoyed it because we were open to one another and shared ideas even though you might have been wrong, we helped one another and at the end of the day, we all gained!!! (Cole: LJ: 25/01/07)

Group discussion seems to have improved task attainability. Examples which suggest this include Musa's comment that Johan's explanation helped him to understand (p. 123), as well as the observation that the discussion between Johan, Arthur, Wiseman, Petrus and me led Petrus to make statements which suggested that he had come to understand the concept of average velocity and its value in finding displacements undergone (p.127). Other indications that group discussion improves attainability include a comparison of the 2006 and 2007 grade 10 waves' modules. Much class discussion was allowed for in the first implementation, namely 10 hours, and very little, 2,5 hours, in the second. The first time the task was implemented, it was more attainable for weaker learners than it was the second time around (Figure 4.12, p. 146), when four of the 16 learners achieved below 22%. One of these learners, on being interviewed, remarked:

> Sometimes I couldn't understand actually while you were busy talking... and sometimes I was too afraid sometimes to ask questions which seem sometimes very stupid questions – I was afraid of other people who say it's a stupid question....
> ... While reading alone with no-one explaining things, which are written in the book, it's hard to... (Hlonipha: Interview: 11/05/07)

This learners' statement shows the limitation of direct instruction ("sometimes I couldn't understand actually while you were busy talking"), as well as individual work ("reading alone with no-one explaining things... it's hard to..."). This suggests the need for collaboration during sense-making in order to ensure attainability. However, this clearly needs to be managed in a way which encourages learners to feel safe in exposing their weaknesses ("I was too afraid sometimes to ask questions which seem sometimes very stupid questions"'). These management issues are discussed later.

One of the reasons for group work's potential success is that it enables learners to bring different ideas and individual partial understandings together (Gunter et al., 2007). Comments made by learners to this effect include the one made by Cole, on 25/01/07 (p. 202), and the one made by Kim, below:

> With the Ferrari and Cheetah we started off not knowing how to do it, but then each one said what they thought might help, and then others added, and so we eventually helped one another to see how to do it. That group work was quite good. It also depends on who is in your group. If you've got someone confusing in your group, then eventually you just sit back and give up. Like sometimes you say something and the person believes it but doesn't believe it in that way and then throws you overboard. But the group I worked in really helped. (Kim: Interview: 12/05/06)

Management

Group composition. As Kim mentions above, group composition is a crucial aspect of the effectiveness of group discussions (Webb, Nemer, & Chilzhik, 1997). However, the effect of group composition is complex (Houldsworth & Mathews, 2000). Grouping learners according to mixed ability has the advantage of stronger learners helping weaker learners (Webb et al., 1997). This was found to be beneficial for both parties. Learners commented that they gained by listening to the explanation of another learner. Examples include Musa's comment of being helped to understand by Johan (p. 123), Jabu's remark that "if we get stuck" they would go to Kim for help (p. 185), and Tim's comment that he would go to James for help (p. 186). Further, comments, such as the one below, suggested that the learner doing the explaining also benefited from this. The comment is given by a strong learner. During the group discussion she was referring to here, it had seemed to me that she was personally gaining nothing from helping weaker learners. I was clearly wrong in this impression, as suggested by her comment:

> What also helped was having to explain it over and over. You get to know what words to use. Because usually you've got it in your head, but you don't know how to express

> it, but then slowly by listening to other explanations you get it clear. (Antoinette: Interview: 19/10/06)

On the other hand, this can sometimes be time-consuming and frustrating for learners who have already mastered a section, and are held back from progressing by being required to explain to their peers. For example:

> I enjoy thinking problems out, and the best way of explaining things, though my mouth did become dry explaining the same things over and over just in a different way. I would like discussing the problems with people who understand as much as I do. I would enjoy that much more. (Sofia: LJ: 29/01/07)

Further, weaker learners might feel intimidated when put together with stronger learners, particularly when outnumbered by them. This is suggested by Silindile's comment, below:

> If I'm put with Sonja, Kim and Lauren I feel very small and I just have to listen to them because they just understand. (Silindile: Interview: 18/08/06)

As has already been discussed, jig-sawing the group composition (Gunter et al., 2007), i.e. splitting and recombining groups with different compositions part way through a discussion, seems to reduce the problems raised above. It seems to increase the likelihood that a profitable combination of learners in a group will exist for each learner for at least some of the time. It also aids cross-pollination of ideas and so increases the likelihood that the various fragmented understandings of the whole will be shared amongst the learners in a way that completes the whole. This is testified to by Lauren's comment on p.151 and by J-P in the comment below:

> I think it was also with mixing of the group. Because I remember in one case there was a certain point that was overlooked. And in the group we were thinking about it and wondering why can't we get to it, and then we switched, and they brought in that point, and all of a sudden we realised that we'd missed a step. (Phil: Interview: 19/10/06)

Group size. Group size is also important in determining success of group interactions (Houldsworth & Mathews, 2000). Fairly small group sizes of approximately 4 learners per group, were generally used in the study. This appeared to create the necessary climate to encourage participation of all members, as suggested by Bongiwe's comment, below, while still having sufficient membership to ensure that the combined knowledge of the members would be sufficient to allow for satisfactory progress in the task.

Bongiwe: In a big group you don't get enough time to say what you know about it, or if you've got a problem, you can't express it easily, because you're like the other one is talking, and you don't get time, then you just forget about the question you wanted to ask and what the other one asked, and then you eventually get mixed up without looking into your real problem.
Me: So the groups mustn't be too big. About how many?
Phil: I think 3-4
(Interview:19/10/06)

Teacher activity. Active participation of the teacher in learner group work was found to be a vital ingredient of an effective task, as well as being consistent with literature (Ankiewicz et al., 2001). In this study this was done through questioning, probing, and information supply, as was discussed earlier. In a questionnaire response to the item "What was helpful in this task", completed after a group discussion during grade 10 electricity in 2006, 12 comments were made by the 23 learners referring to the importance of the teacher participating actively in group discussions. These included the following:

When ma'am was with us she made us think twice whereas we thought we'd come up with the best solution.
It was not easy, I struggled on it and I couldn't cope without a teacher.
The discussion had a great effect and I understand it even better when Miss Stott adds something to what we had said or she corrects us on what we as a group had said.
(Questionnaire Responses: 01/02/07)

Comments such as these are abundant in the data. Other examples include: "Having Miss around really helped me a lot because she kept asking questions until I understood" (Phindile: LJ: 25/01/07), and "appreciated the way you taught us and then walked around and checked on us" (Cole: LJ: 13/02/07).

The above discussion suggests that group work increases attainability by weaker learners and is therefore vital if a critical thinking task is to be successful for a wide range of learners. This is consistent with other research done in the area (Webb et al., 1997). It can be explained by the scaffolding which stronger learners offer, enabling weaker learners to progress into their ZPD (Bransford et al., 2000). Additionally, it has other positive effects applicable to all learners, not only the weakest. As previously discussed, it is, however, time-consuming, and therefore cannot be used on a very large scale within the context of the SA PS curriculum. When used moderately in conjunction with scaffolding tools, however, both the advantages of group discussions as well as an appropriate usage of time can be achieved. For it to be used to optimum advantage, group discussions need to be managed appropriately. This includes attention to issues of group composition and size, where it seems that small groups, which are jig-sawed, i.e. the composition of which is changed through the course of the discussion, are generally the most favourable. Active teacher participation in group discussions is vital to their success.

5.4.2. Scaffolding

Assertion 4.2: Scaffolding tools are required to increase the attainability of tasks to more learners.

It was found that scaffolding tools supporting engagement with the subsuming problem were vital for ensuring task attainability by academically weaker learners. Samples of scaffolding tools found to be effective are given in Appendixes J and K. The value of these, when answered individually, followed by group discussion, for promoting critical thinking, has already been discussed (pp. 142). Their value for enabling a wide variety of individual learners to undergo an effective critical thinking learning experience, as well as findings concerning their composition to ensure this, are discussed here.

Value

A comparison of the second and third implementations of the *Tsunami* module underlines the value of scaffolding tools. This is particularly so for weaker learners and those with poorly developed time management skills. My 2008 grade 10 physical science class was weaker than my 2007 grade 10 class. Despite this, all 16 learners in 2008 managed this task, whereas four out of the 16 learners in the 2007 group had failed it. The strategy differed between the years primarily in that five interim reports were introduced as scaffolding tools in 2008, and these served as homework and group discussion foci. In contrast, in 2007 these had been absent, with only a loosely structured mind-map provided as a guide to information collection during the teaching period.

A closer look at the statistics of performance, (p. 146), shows that the performance of the top learners in 2007 differed little from that in 2008. In both years seven out of the total of 16 learners scored A's and three learners scored B's. However, a look at the weaker learners' performance shows that the gains between the two years were made on the lower end of the spectrum. In 2007 four of the 16 learners scored 22% or lower. In contrast, only two of the 2008 learners scored below 60%, with all of these above 40%. Interviews with each of the four learners who had failed this task in 2007 revealed the need for a time-pacing strategy. They also said they needed a resource they could refer to when producing the final presentation. For example, Hlonipha remarked that he did not know where to find the answers, and that:

> sometimes we feel like lazy and we postpone things and then suddenly when it's close to the deadline, then... (Hlonipha: Interview: 11/05/07)

The scaffolding worksheets provided both of these requirements. They paced the learners' engagement with the problem, since they had to be submitted on certain dates for formative assessment by peers during group discussions, and by the teacher. They served as an opportunity to amass information relevant to the target presentation, and thus served as an easy reference resource during its production. These benefits were not confined to helping academically weaker learners, as testified to by statements such as the following, from a 2008 grade 10 learner who scored only A symbols for every assessment throughout the year.

> I needed a little help with the reasoning out of the problems, but once I understood it was easy. The interim reports were a great help. Without them the final task would have been difficult. They helped me to understand the problem. Without them I did not really know what to do. (Victoria: LJ: 27/02/08)

The value of the scaffolding tools can be understood in terms of Black's work on the value of formative assessment (Atkin & Black, 2003), as well as seeing them as aids which reduce cognitive load within the limited space of working memory (Niaz & Logie, 1993). Their particular value for increasing attainability for weaker learners can be explained by the view that for such learners, working memory limitation is more pronounced than for stronger learners, and therefore the aid offered by the tool is more necessary.

Composition

During the study, I found that scaffolding tools should include closed basic knowledge questions, such as definitions, units, symbols, and equations, as well as open conceptual and application guiding questions. The importance of inclusion of closed basic knowledge questions in scaffolding tools and preparatory exercises is seen by comments made by learners to this effect in response to the 2006 grade 10 mechanics module, where all questions asked were higher order questions. An example is given below:

> When you start to kick a ball, someone has to teach you. So we can't do a difficult task. When you haven't been kicking the ball for long. (Jabulani: Interview: 12/05/06)

> Thandiwe: Wouldn't it be possible that the tasks have some parts that can involve someone who is low down, and other parts that involves the clever ones?
> Me: Not all difficult?
> Thandiwe: Not all difficult; otherwise we're not growing; we're not all the same, and maybe I'm trying to get something, and then all of a sudden you have to have this question and you've got to start struggling, and its all over the board, and then you just sit and stare at the teacher.
> (Interview: 12/05/06)

The need for inclusion of basic knowledge questions is consistent with an understanding of the limiting effect of cognitive load on learning (Niaz & Logie, 1993). Summarisation, and, hopefully, to an extent, routinisation, of the basic information, which answering such questions aims at achieving, should free up space within working memory to enable the learner to deal with the deeper aspects of the task. Even if such an activity fails to routinise the basic knowledge for the learner, it at least provides an easy reference source which can also serve as an aid to cognitive load reduction. The importance of including both procedural and conceptual questions in scaffolding tools, which has been discussed earlier, is understood in terms of the curriculum valuing both of these forms of knowledge (DoE, 2003b).

Monitoring

I found that it was necessary for the teacher to be firm about expecting quality work, since this is not produced inherently by learners. It was found to be usual for learners' written responses to be scant, with homework often not being done (e.g.

RJ:13/02/06, 20/03/07, 15/05/08). Until learners become self-regulated, they need this kind of extrinsic motivation monitoring their work quality (Slavin, 2000), and without this are not likely to undergo extended internal critical discourse and develop the necessary knowledge and skill base to be able to undergo critical discourse with their peers. Hence, monitoring the quality of learners' responses to the intermediate scaffolding tools is crucial to the success of a critical thinking task.

Evidence to support this is given in the 2008 grade 11 mechanics task (p. 139). Here, the learners performed poorly in the section of the final task corresponding to an interim report which I had not checked, relative to those sections I had checked. Besides the monitoring of interim reports, it was generally found that many learners did not do homework of any nature faithfully unless monitored directly, even in grade 12 (RJ: 15/05/08). The importance of enforcing the time-schedule of the scaffolding tools is suggested by the poor performance of four of the 2007 grade 10 learners in their summative assessment task on waves, due to poor time management. In contrast, enforcing the completion of interim reports within a predetermined time-schedule, in 2008, was associated with attainability by all learners. These findings are understood in terms of the need for extrinsic regulation until learners are able to self-direct their own learning (Slavin, 2000).

Despite the general observation that learners need continual monitoring to ensure production of quality work, a number of learners were found to be highly intrinsically motivated to work beyond minimum requirements, especially in relation to the long rich problem tasks used. Evidence for this include five learners from each of grade 10 and 11 submitting extra tasks for bonus for the mechanics section in 2007, and learners frequently submitting voluntary notes for me to check (see, for example, Sihle's thoughts on p. 195). Such learners seemed to respond better to support than monitoring (LJs: 13/03/07). These learners included both academically weak and strong learners. This suggests that it is too simplistic to assign the strategies suggested in this section to being needed for improvement of the performance of academically weak learners. In some cases, it is rather the less motivated learners or those with poorer time-management skills, for whom these strategies are crucial for task success.

However, I suggest that these strategies improve the success of the instructional strategy for all learners when applied with sensitivity to individual needs.

The discussion above suggests that use and enforcement of scaffolding tools can enhance a critical thinking task's attainability for weaker or less motivated learners, or those whose time-management skills are less well developed, while also benefiting learners who do not fall into any of these categories. The discussion has also pointed out that attention should be paid to the composition and management of such scaffolding tools.

5.5. CONCLUSION

In this chapter a number of assertions have been made in answer to the study's research questions. These have been supported from the study's data. I assert that the following are influential in determining the effectiveness of an instructional strategy aimed at promoting critical thinking: certain task design characteristics, the sequencing of task engagement relative to direct instruction, and hence the kind of reasoning it requires, teaching strategies which create an appropriate learning and teaching environment, and strategies for providing for task attainability by a wide range of learners. Task design characteristics which are particularly influential in determining success are the task's ability to capture learners' interest, the task complexity, and a focus on conceptual explanation. It was found that both inductive and deductive teaching strategies can promote critical thinking, but that inductive strategies should be used with caution, particularly in the context of the confines of a content-rich curriculum. A variety of strategies have been proposed for the creation of an environment conducive to critical thinking promotion. These encourage safety and openness to engage in struggle while also promoting engagement in critical discourse. Two strategies, namely use of group and pair discussions, and use of scaffolding tools, have been proposed to expand applicability of instruction to a wider range of learner abilities.

These assertions are grounded in the data, and are considered to be valuable in aiding the improvement of practice (Zuber-Skerritt, 2001). It is hoped that readers have been able to abstract elements relevant to their localised conditions so that the impact of this study will extend beyond the confines of my classroom (Stake, 1994). I end this dissertation by giving a summary of the study, and suggest its implications for research and practice, in the final chapter, which follows.

CHAPTER 6
SUMMARY AND IMPLICATIONS
FOR RESEARCH AND PRACTICE

This was an action research study aimed at improving my teaching practice by improving the promotion of critical thinking amongst learners while learning physical science within the South African national curriculum. Unlike some positivistic approaches to research, in which variables are controlled from without, a study such as this is situated within actual practise with the purpose of understanding, from within, the complexity of a real situation (in Mc Niff & Whitehead, 2006, p. 17). While the purpose of my study was primarily the improvement of the localised case under study, a number of authorities in education research suggest that the telling of stories by practitioner-researchers is potentially the most effective way of improving practise, as readers are able to abstract from the accounts aspects relevant to their localised setting (e.g.Atkin & Black, 2003; Hollingsworth et al., 1997; Mc Niff & Whitehead, 2006; Zuber-Skerritt, 2001). It was my intention that this would happen in my case.

Taking a pragmatic approach to research (Cresswell, 2003) and guided by my realist leanings (Krauss, 2005), qualitative data was gathered by participant observation aimed at sensing the complexities of the situation under study (Merriam, 1988). The accumulated data corpus spans three years and is composed of audio- and video- recorded lessons and interviews, my personal field notes, learner questionnaires, learner journal entries and much learner written material emanating from their working with the tasks I designed. Data collection, analysis and interpretation were done in a reflective, inductive, cyclic manner (Taber, 2000), guided by research questions with a focus on task characteristics, the most effective teaching sequence, the role of the learning environment, and meeting the needs of different learners, so as to effectively promote critical thinking.

A detailed description has been given, in Chapter Four, of my journey of action and reflection during the three years, to enable readers to understand my viewpoints and to form naturalistic generalisations of their own (Henning, 2004; Merriam, 1988; Stake, 1994). This was followed by my analysis, interpretation and construction of assertions concerning the promotion of critical thinking. This analysis and interpretation was done keeping in mind the constraints of working within the South African physical science national curriculum, and guided by both the theoretical framework, and the research questions. A summary of the knowledge claims I am making arising from this study is given below, followed by more detailed exposition of two models generated to make these claims more accessible. I then comment on limitations of this study and its implications to further research and practice.

6.1. SUMMARY OF KNOWLEDGE CLAIMS

Having completed this study I am convinced that it is possible to promote critical thinking while meeting the physical science (PS) outcomes in the South African (SA) national curriculum, although the intense syllabus pressure makes this very challenging. Additionally, I have made the following assertions:

Assertion 1: The design characteristics dealing with a task's ability to capture a learner's interest, its complexity, and its focus on conceptual explanation all play an essential role in promoting critical thinking.

Assertion 1.1: Intriguing tasks that capture learners' interest are more likely to promote critical thinking.

Assertion 1.2: Tasks that have a degree of complexity and require a longer time to solve are more likely to promote critical thinking.

Assertion 1.3: Subsuming tasks which have a primary focus on conceptual explanation are most effective in promoting critical thinking.

Assertion 2: Under certain conditions both inductive and deductive approaches to developing understanding can promote critical thinking.

Assertion 2.1: The use of group work at the beginning stages of instruction to generating new conceptual understanding, before direct instruction, should be used with caution.

Assertion 2.2: Deductive application, following direct teaching, is effective in promoting sense-making using critical thinking.

Assertion 3: Critical thinking is encouraged by an environment in which struggle is accepted as normal, and participants are free to accept intellectual challenge.

Assertion 3.1: An environment in which struggle is accepted as normal and beneficial is vital for a critical thinking task's success. This can be encouraged by various strategies.

Assertion 3.2: An environment in which learners and teacher are free to give and accept intellectual challenge is vital for a critical thinking task's success. This can be encouraged by various strategies.

Assertion 4: Various strategies can improve attainability of a critical thinking task by a wider range of learner abilities than possible without these strategies.

Assertion 4.1: If the majority of the class is to be involved, group discussion is vital for a critical thinking task's success. Management strategies affect the effectiveness of this.

Assertion 4.2: Scaffolding tools are required to increase the attainability of tasks to more learners.

These assertions are condensed into two models I have generated. The first is a system of task classification, and the second a model of instruction. I have termed the task classification system the *CPAG Quadrant,* and the instructional model, *The Ladder Approach.* The CPAG quadrant locates tasks along each of two axes: a concept-procedure axis and an application-generation axis. This yields four categories of tasks with regard to the traits mentioned in these axes. These categories are concept application, procedure application, concept generation and procedure generation. Emerging from this study, I make claims about each of these categories of tasks. The Ladder Approach is an instructional model which was found to be effective when evaluated against criteria of being compatible with the curriculum, characterised by learners displaying critical thinking traits and being actively engaged and interested while engaging with a task which is attainable with effort. In the Ladder Approach an interesting problem is posed at the start of a section. After the introduction of this problem, direct instruction and learner engagement with the problem run parallel to one another, linked by scaffolding tools which are engaged in individually and collaboratively. Each of the CPAG Quadrant and The Ladder Approach is discussed in greater detail, below. These discussions will clarify the intended meanings of terms used above.

6.2 THE CPAG QUADRANT

The CPAG Quadrant provides a communication tool to refer to the kinds of tasks often used in physical science teaching. It appears in Figure 6.1, where I have used it to link claims emerging from this study with each of its four task categories. CPAG stands for Concept/Procedure, Application/Generation. This system evolved through a number of intermediate stages as a result of individual and collaborative reflection during the final reflection cycle of this study. The degree of conceptual versus procedural focus of a task is indicated on the y-axis and the degree of application versus generation required by learners, on the x-axis. A conceptual focus is one that stresses concepts, i.e. generalisations bounded by consistent rules of inclusion and exclusion (Bruner, 1971). Such a task would probably be language-rich (Paul & Elder, 2001). A procedural task focuses on routinisable procedures such as equation manipulation and graph-drawing (Hobden, 2006). Such a task is usually language-poor. Application, which involves deduction, involves the learner applying previously learnt generic knowledge to a specific case. Inference, which involves induction, requires the learner to extend specific supplied information to arrive at generic knowledge (Epstein, 2002).

The term *concept application* is used to refer to a task in which learners use language to apply previously learnt generic knowledge to a new case. One in which learners use previously learnt procedures within a new case is termed a *procedure application* task. A task in which learners use language to create generic concepts from supplied information is termed a *concept generation* task, and one in which learners use supplied information to derive a procedure, a *procedure generation* task.

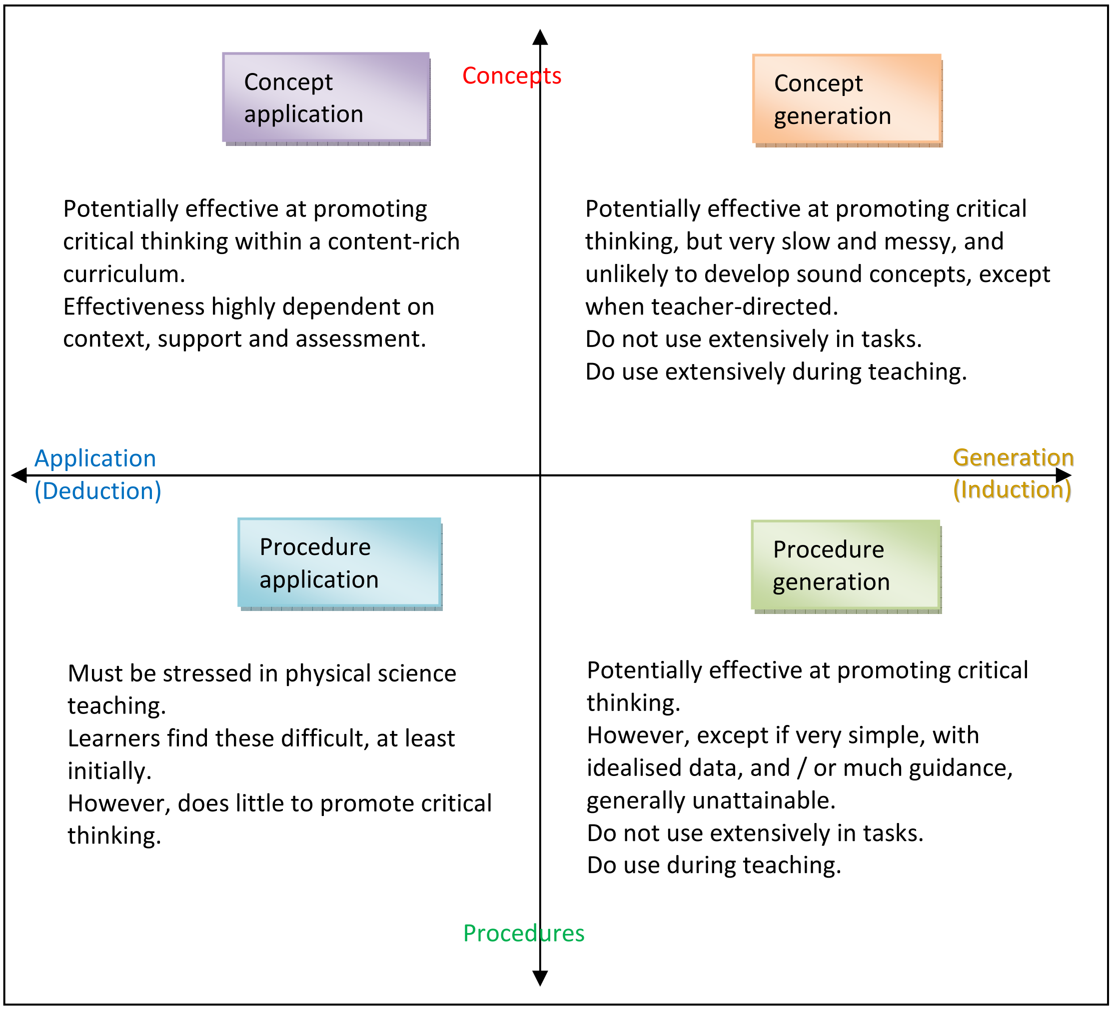

Figure 6.1: The CPAG Quadrant: A task classification system.

Prior teaching and learning experiences affect the location of the task along the x axis of the classification system. Some tasks' location along the y axis can be altered by a change in expectation or by learners' interpretation of the question. For example, consider the task:

> A cheetah accelerates at $6m/s^2$. Determine how far and how fast it will be 4 seconds after starting to accelerate from rest.

If the equations of motion have already been taught, learners will probably use them even if not directly instructed to do so. This is then a procedure application task. If the equations of motion have not been taught, although the concepts have, the learners may apply their conceptual knowledge to discuss the issue qualitatively, making it a concept application task. They might also represent the information in a graph or numerical pattern and from this solve the problem. This might be a procedure application task if they had previously mastered the use of graphs in answering such tasks. Alternatively, it might be a concept application task if the learners use a qualitative understanding of the graph to solve the problem. If they would, from their graph or pattern, generate a formula for calculating other cases, this would involve procedure generation. If the question would lead the learners to formulate a general conceptual rule, stated in language, concept generation would have been induced. From the above discussion it is clear that this classification can be used to describe the process the task designer or assigner intends to induce through use of the task, or the realised outcome undergone by the learners in response to the task.

The research described in this dissertation has led me to the view that while an inductive strategy is potentially effective at promoting critical thinking, it is very slow and messy and unlikely to lead learners to develop a sound conceptual understanding. I formed the impression that while an inductive strategy could be used under the teacher's direction during teaching, and on a small scale in learner tasks, it should be avoided for long-term tasks. The research also led me to the view that both conceptual and procedural foci are needed in the teaching of physical science, and that these should be integrated. While procedure application seems unlikely to develop critical thinking when performed in a manner divorced from concept application (Paul & Elder, 2006c), it must be stressed in physical science teaching to ensure curriculum compatibility. Learners tend to find such questions difficult, particularly initially. These claims have been summarised on Figure 6.1.

6.3. THE LADDER APPROACH

The Ladder Approach emerged from this research as an instructional model which can be effective in promoting critical thinking while also complying with the curriculum requirements. I found the metaphor of a ladder useful in describing this teaching model. In this metaphor the parallel-running sides of the ladder can be seen to represent the two main components of this model, which run parallel to one another. These are direct teaching and engagement in the subsuming problem task. Although the focus of classroom instruction shifts between the two during the course of the learning sequence, the influence of each of these components should be present throughout this time. This means, for example, that even during periods of the teaching sequence where direct instruction occurs in the classroom, learners should at some time be reflecting on the subsuming problem in an attempt to make sense of both it and the information being taught by the teacher. This reflection may be prompted by the teacher during the direct instruction, or engaged in by learners outside the classroom as a result of the inherent interest of the problem. To more formally induce this reflection between instruction and task, scaffolding tools are provided.

The rungs of a ladder, which hold the two sides together, can be likened to the scaffolding tools used to tie direct teaching and problem engagement together. Consequently, I have termed this instructional model The Ladder Approach. This instructional model supports learners as they climb towards the parallel goals of improvement of critical thought and attainment of competence in knowledge and skills. For this reason it is effective in promoting critical thinking while also operating within a content-rich curriculum, such as the SA PS curriculum. I now systematically summarise the model's implementation, in the form of a list, after which I will expound on this more fully. The Ladder Approach is illustrated in Figure 6.2 (p. 220). Note that the list, and explanation, given below, for the sake of simplicity, focus on the aspect achieving emphasis at each stage in the sequence. However, the discussion, above, concerning the parallel, rather than sequential, intension of the approach, should be born in mind.

1. *Initial problem engagement*: the teacher poses the problem, the learners briefly brainstorm the problem. (This aims to develop learning anticipation.)
2. *Direct instruction*: the teacher teaches a part of the work relevant to the subsuming problem. This is done in line with the curriculum statement. It is done in an interactive way, frequently posing questions which encourage sense-making by the learners, particularly with reference to the subsuming problem. (This aims at developing procedural knowledge and an understanding of the relevant fundamental knowledge, as well as encouraging reflection of this in terms of the problem.)
3. *Scaffolding worksheet engagement*:
    a) Learners answer a scaffolding worksheet individually in writing. This is designed to induce sense-making of the information recently taught, in terms of application to the subsuming problem. (Critical thinking during guided self-reflection is aimed for here.)
    b) Learners discuss their answers to the scaffolding worksheet in small groups, the composition of which is occasionally rotated. They modify their written answers based on this discussion. (Critical thinking through critical discourse is aimed for here.)
    c) The teacher checks learners' written responses to the scaffolding worksheets, and gives feedback, including correction and guidance where necessary. (In this way the scaffolding worksheet acts as a formative assessment tool.)
4. Steps 2 and 3 are repeated as many times as is necessary to cover all the relevant work stipulated by the curriculum and empower learners to produce an answer to the subsuming problem.
5. *Problem task solution*:
    a) Learners answer the subsuming problem in rough, individually in writing, guided by a scaffolding worksheet. (This requires learners to use their conceptual understanding and procedural knowledge in new and creative ways to solve the subsuming problem, and in so doing requires critical thought.)

b) Learners present their solution, verbally, guided by their rough written work, to their peers in pair or small group discussions. Learners critique one another. Learners modify their final answer based on this discussion, producing their final submission. (Critical thinking through discourse is aimed at here.)

c) The teacher assesses the learners' final written response summatively.

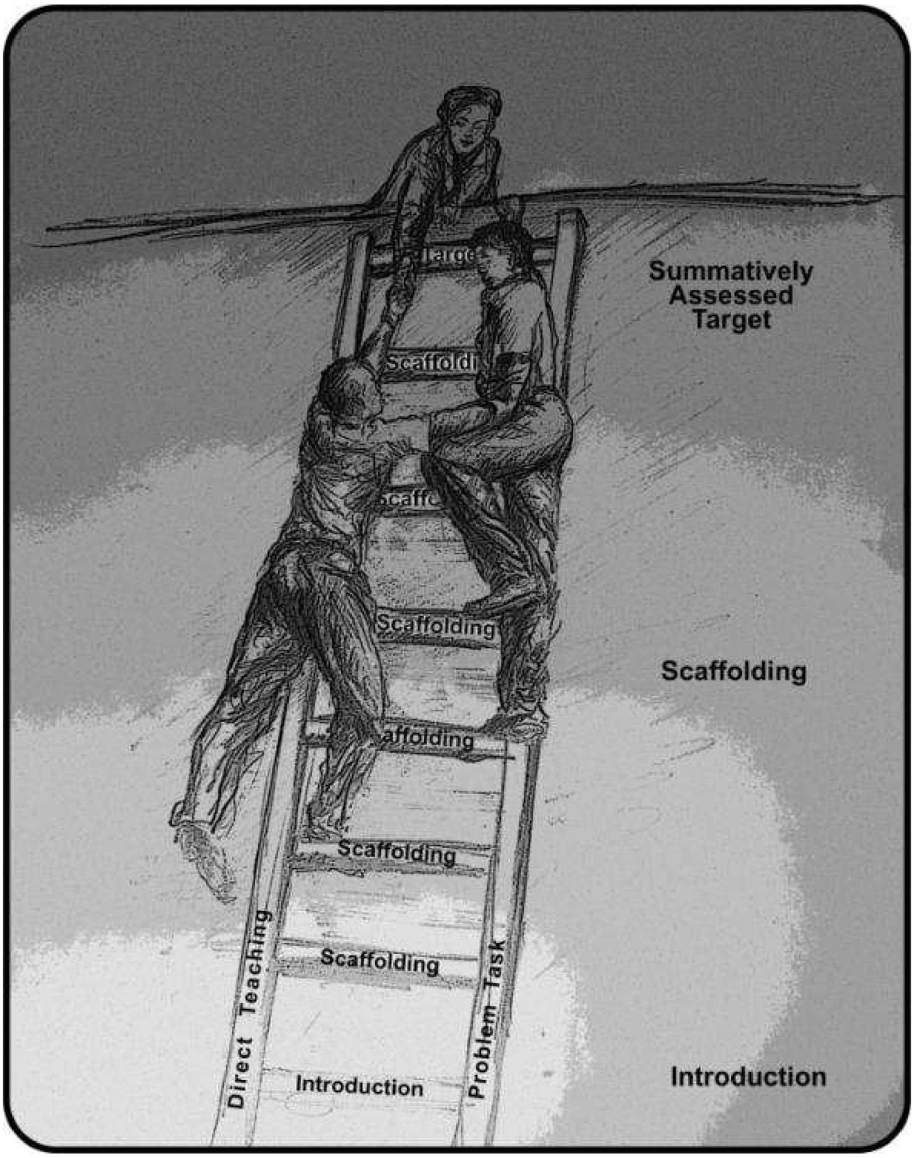

Figure 6.2: The Ladder Approach.

Illustration by J Greyling

6.3.1. <u>Designing the learning material</u>

Design of the learning material is a crucial stage in The Ladder Approach. Examples of some of the learning material I designed for this study are given in Appendixes J and K. During this process the content to be taught is identified. A context which will be interesting and novel to the learners, in which the required content can appropriately be embedded, is chosen. This is consistent with an understanding that interesting, novel contexts are conducive to engaging high levels of learner intrinsic motivation (Alvarez et al., 2000; Anderson & Roth, 1989; Brown et al., 1989). It is also consistent with the understanding that motivation positively affects any learning experience (Cotton, 2001; Schoenfeld, 1985) through the increased time and quality of engagement it causes. Further, motivation expands working memory capacity, thus reducing this limitation to learning (Niaz & Logie, 1993). These considerations are expected to be particularly important for a task demanding critical thinking, given the high cognitive demand inherent to higher order thinking (Resnick, 1987).

A suitable problem task is decided on. By referring to a problem I mean a task for which learners do not already know the solution, and which cannot be solved by simply looking up the solution in an available source (Hobden, 2006). The problem should be interesting and novel. It should intrigue learners, therefore exciting both their affective and cognitive faculties. Where appropriate, this problem should be a concept explanation task with procedure application elements integrated into it. Its content should be central to the curriculum content required to be taught. This task should preferably take a substantial amount of time to complete, although it is may be advisable that sometimes within the duration of a course, the problem require less time. In this study I found that tasks requiring long-term engagement tended to promote critical thinking to a greater extent than shorter tasks for those learners who found such a task attainable. However, they were attainable for fewer learners than shorter tasks were. Also, long tasks were found to pose considerably more work pressure than shorter tasks. Therefore, a mix of the two seems to combine the merits of each across the entire learning experience. This is consistent with literature which suggests that either long (Fraker, 1995; Sparapani, 1998) or short (Chamberlain et al.,

2004) tasks can be effective in promoting critical thinking and that while longer and more complex tasks tend to be more interesting to learners, the effort they require tends to reduce their popularity (Blumenfield et al., 1987).

At this stage, the planning of the teaching occurs. Questions such as; what prior learning do learners bring to this; what concepts are they required to understand in order to deal with the subsuming problem, what procedures and skills do they need to interact fully with the subsuming task. The teaching sequence must then take these into consideration. A possible solution to the problem should also be thought through, and key aspects of understanding identified and linked to the content to be learnt. From this, the problem task is broken into parts, each of which will be engaged with at an appropriate point in the teaching sequence, supported by a scaffolding tool. These scaffolding tools, such as interim reports and final presentation templates, are then drawn up. A time schedule in which the sections to be taught, and the times for performance of each scaffolding tool are indicated, is compiled. An example of such a schedule is given in Table 4.1 (p. 121). The scaffolding tools should include ways of reinforcing the basic knowledge pertinent to the task as well as promoting critical thinking while learners apply their learning to the problem task. For example, the learners could be asked to give definitions, symbols, units and equations for each of the concepts relevant to the task, in order to reinforce basic knowledge and reduce cognitive load when thinking critically (Niaz & Logie, 1993). To prompt critical thinking, they could be required to list and justify relevant criteria to aid decision making, and evaluate each of a number of options against each criterion, with motivation, or they could be asked to explain one aspect of the final problem task. These traits are illustrated in the scaffolding tools given in Appendixes J and K. The scaffolding tools serve as opportunities for formative assessment (Atkin & Black, 2003), and the structure they provide increases the likelihood that critical thinking and beneficial time-management will occur (Ankiewicz et al., 2001).

When designing the task and accompanying scaffolding tools, it is important to consider both the need for learners to develop conceptual understanding of the main conceptual ideas associated with the topic, as well as proficiency with numerical computations associated with the topic. Therefore it may be desirable to include aspects of each of these in the task requirements for learners. The scaffolding will also need to be designed in such a way that neither of these two prevents the other from occurring. For example, in a task with a high numerical focus e.g. involving the equations of motion, learners may be encouraged to choose the easier procedural route of equation manipulation, precluding any need for conceptual thinking about the issue. On the other hand, in a task with a high conceptual focus, learners might not develop the proficiency to be able to solve numerical problems, and so might not be well prepared for examinations which stress such questions. This marriage of conceptual and procedural foci to improve problem solving capability in physical science learners is consistent with findings by Dufresne et al. (1992) that getting learners to engage conceptually with a problem situation, followed by an algorithmic solution to the problem, is effective in developing problem-solving capability and flexibility.

Teaching notes, such as PowerPoint slides or paper notes, should also be drawn up at this stage, in accordance with the teaching sequence decided. Considerations should be made of points at which engagement with the problem task can be inserted. Examples of such PowerPoint slides are given in Appendix L. Other homework activities necessary to empower learners to meet the curriculum objectives, such as standard text book type exercises, should also be identified and slotted into the appropriate places within the time schedule. This attention to planning detail was found to be a necessary component of this approach It is accepted that this is inconsistent with research which suggests that greater time and content flexibility can be more conducive to learning (Atkin & Black, 2003; Moodley, 2000) but is necessary to fit the necessary curriculum-specified work into the available time. However, some degree of scheduling flexibility needs to be allowed for.

6.3.2. Introducing the task to learners

An interesting introduction to the problem situation is valuable in capturing the attention of the learners. Learners could then be asked to identify what they already know about the subsuming problem, and what they still need to know in order to solve this. This could be done individually, in writing, followed by group and then class discussions, with written lists being updated at each stage. The learners should also be given an overview of the instructional model to be used. A booklet containing the learning schedule, printouts of the problem task and its scaffolding tools, and possibly also PowerPoint handouts and / or other notes and exercises, could be given to the learners and briefly gone through as an overview of the module. This orientation and reconnoitre of the learning and problem area is consistent with the finding by Dufresne et al. that such preparation enhances the effectiveness of learning (1992). The provision of handouts to support learning was found to be important to support effective learning.

6.3.3. Teaching

Teaching should be done bearing in mind that learning occurs through understanding construction as learners use new and prior knowledge in a sense-making process (Cobern, 1995; Wheatley, 1995). It is therefore necessary to elicit prior understanding and try to design situations, such as appropriate questions or demonstrations, that will challenge incorrect conceptions. Hopefully this should create dissonance in the learner's mind, which should encourage the learner to modify their misconception in a process of conceptual change (Hewson & Lemberger, 2001). It is also necessary to teach for understanding, rather than just for rote recall. Understanding increases the likelihood that learners will be able to transfer their knowledge to new contexts (Bruner, 1971; Lavoie, 1995; Willis, 1993). This can be done by making a need for the new knowledge clear, as well as emphasising links between new and existing knowledge and within the new knowledge (Perkins & Salomon, 1989). Learning with understanding requires learners to be aware of alternative perceptions, and to apply critical thinking as they make judgements about these. A pedagogy which expects learners to make these judgements, and supports and guides them to do this in both a logically and socially sound manner, is understood to aid knowledge construction while also promoting critical thinking (Dirks, 1998). This is contrasted with an authoritarian, traditional pedagogy, where knowledge is seen to be transferred from teacher to learner and is accepted without question and examination. This requires careful design of the manner and sequence in which concepts are introduced, as well as consideration of appropriate interactive opportunities. Examples I found useful include asking questions requiring individual decision-making, possibly indicated by a show of hands or a short written response, or requiring short pair, group or whole-class discussions. All these promote minds-on involvement by learners.

While implementing the planned teaching sequence, it is also important for the teacher to be sensitive to the needs of the learners. This might indicate difficulties the teacher had not anticipated, which may mean that the teacher needs to make adjustments to the planned strategy. This flexibility, although potentially important for effective learning (Atkin & Black, 2003; Moodley, 2000), needs, however, to be managed with the curriculum objectives and the needs of the whole class in mind in order to remain compatible with the curriculum's time schedule. Frequent reference to and promptings concerning, the subsuming problem should be made during the teaching so that some form of engagement with the subsuming task occurs throughout the teaching period, rather than only at episodic moments. This serves to contextualise the learning and so make it more meaningful (Brown et al., 1989). It was also found to enhance interest and depth of engagement during direct instruction.

6.3.4. Scaffolding

Although some form of engagement with the subsuming problem should be encouraged throughout engagement with the section of work subsumed by the problem, at certain times focus is particularly shifted to it. This should occur at appropriate points in the teaching sequence, and should involve the learners being required to link and apply their learning to the problem task, guided by a relevant scaffolding tool. These should provide support for learning ranging from the basic development and construction of concepts to their application, using critical thinking, to the subsuming problem. Examples of such scaffolding tools are given in Appendixes J and K. This might involve the learners answering the questions in an interim report individually in writing, possibly for homework. Group discussion is an effective means of developing critical thinking if used correctly (Resnick, 1987; Sparapani, 1998), but has the potential not to be critical where criteria of accountability are not present (Elder, 1997), and where structure is not provided to the discussion (Adam, 1999). The previously individually answered interim report can serve as a spring-board for a group discussion, providing these necessary criteria and structure.

Jig-sawing of groups i.e. splitting the composition of each group and re-forming the groups with different compositions for the next discussion session, helps to share expertise (Gunter et al., 2007) and reduce the likelihood of extended periods of unproductive social combinations. The teacher must play an active role in group discussions, moving between the groups and prompting, challenging, guiding and keeping in touch with the learners (Ankiewicz et al., 2001; Elder, 1997). For example, the teacher may challenge the learners to be more precise and logical, direct them to think in other directions, provide necessary information where gaps become clear, and listen to learners to develop an increase of their understanding. At all times the focus during this stage is promoting critical thinking using the basic concepts and procedures recently developed.

It is also important that the teacher monitors the learners' answers to the scaffolding tools (Atkin & Black, 2003). This includes ensuring that homework is done, challenging errors, or re-explaining sections, and providing probing questions to help direct learners to become more critical (Elder, 1997). If possible, this should be done by the teacher collecting and responding to each learner's written answers. However, time considerations may not allow this. In such a case, the teacher should at least check each learner's work for completion, and respond verbally to errors or answer weaknesses which become clear through the group discussions and quick perusal of the written work.

Assigning academically more successful learners the task of explaining to weaker learners during class discussion time, as needs become clear, can also help improve learners' performance without adding extra pressure on the teacher (Webb et al., 1997). The scaffolding tools should collectively empower the learners to be able to answer the final presentation of the solution to the subsuming problem, i.e. the target, successfully. This could also be guided by a scaffolding tool, such as a template. It is important, though, that the scaffolding tools do not provide so much support as to prevent critical thought by the learners.

One of the advantages of scaffolding worksheets is that they direct learners' attention to the task requirements, therefore reducing the likelihood that learners will waste time on superficial details, rather spending time on the required thinking (Blumenfield et al., 1987). This also helps to decreases the limitation posed by the limiting capacity of working memory (Niaz & Logie, 1993). Group interaction and teacher prompting can also serve to scaffold learning, and can therefore have this effect too (Baron, 1987).

6.3.5. Resources and Assessment

The scaffolding tools, group discussions and teacher-monitoring revolving around these tools, are crucial to the success of a critical thinking task. Scaffolding worksheets serve as excellent forms of formative assessment (Atkin & Black, 2003). They are effective in guiding learners towards having to give thoroughly substantiated answers relative to sound criteria, rather than merely weakly supported subjective opinion. Additionally, they serve as a resource for the final submission, which is assessed summatively. It is also vital that the learners have access to resources concerning the content knowledge applicable to the task This might include a text book, PowerPoint handouts and / or other Photostatted and / or handwritten notes. These are particularly useful as reference sources during the learners' completion of the scaffolding tools. Learners reported that computer-based resources are also very helpful. These may include video-recordings of teaching for those learners who might have missed something in class, interactive software to reinforce or further advance learning, and collaborative opportunities.

An assessment tool which credits correct factual information, as well as sound reasoning and motivation is required. Examples of attempts at creation of such tools are given in Appendixes J and K. For both the examples given, however, repeatable marking was found difficult due to the subjective nature of the criteria. Inclusion of greater detail might have helped with this, although this could have meant that giving the rubric to the learners beforehand would have defeated the purposes of the assessment. Not showing the learners the rubric beforehand, though, has the disadvantage of not providing learners with guidance as to what they will be assessed on. Scaffolding can solve some of these problems, by guiding the learners towards the task requirements.

6.3.6. Summary

In this discussion I have described and provided support for an instructional model I have called The Ladder Approach. This involves direct teaching and engagement in a subsuming problem task, with scaffolding tools linking these two together. This model was developed after going through a number of action research cycles during the three-year duration of this study. I found it to be effective in promoting critical thinking and inducing interest and active engagement during an effortful, but attainable, learning process compatible with the South African national physical science curriculum. I believe that this model could be implemented in a similar form by other teachers, and that similar success could be expected. I see this model as a valuable contribution to both research and practise, particularly in, although not confined to, the South African context. This is because it provides a much needed contribution to how the curriculum should be implemented in practise.

6.4. LIMITATIONS

The teaching and learning situation I researched is not representative of all South African FET physical science classes. In many senses it is a unique situation. However, in some senses it does represent a large number of typical learners because it involved learners of both genders who come from a wide variety of socio-economic, educational and cultural backgrounds. However, class sizes were relatively small (16 to 23), which is not typical of our schools. In addition I, as the teacher, was prepared and able to spend extensive periods of time developing materials aimed at promoting critical thinking, which would often not be the case with other teachers. Nevertheless, I believe that my study does give insight into potentially effective ways to promote critical thinking in physical science within the South African national curriculum. It is hoped that readers can abstract those aspects of the narrative given in these pages which are relevant to their local situation, and so construct an understanding which would work for them.

In this way, it is hoped that this study will be useful in informing practise. The likelihood of this is increased by the fact that the suggestions made from this study have emerged from an action-research process within the complexities of real practice. This increases the likelihood that practitioners will view the findings as applicable to their situations (Mc Niff et al., 2003; Mc Niff & Whitehead, 2006; Zuber-Skerritt, 2001). On the other hand, the strategy I put forward does require considerable effort, time and skill from the teacher. It reveals the importance of the teacher as a co-inquirer in the struggle involved in sense-making. It requires the teacher to monitor work in contexts where quality is unlikely to be produced without considerable effort, time and guidance. It also suggests the importance of the teacher modelling and encouraging critical thinking on a daily basis. Further, it suggests use of rich open-ended problems, and a number of scaffolding worksheets, which can be time-consuming and difficult to set up and assess. Such problems also require the teacher to have a very thorough conceptual understanding to be able to guide learners through their sense-making struggle, as well as to be able to make appropriate decisions when marking the open-ended scaffolding worksheet and final submissions. These findings correspond to Cohen's (1988) remark that hard work and risk on the part of the teacher is required by the more complex, interactive teacher-learner relationship associated with a constructivist teaching-learning scenario, relative to a traditional view of transmission and absorption. These aspects seem to reduce the likelihood that the instructional strategy emerging from this study will be employed widely by many practitioners. Research shows that many of our teachers are not qualified and do not have the skills mentioned (Adam, 1999; Ankiewicz et al., 2001; Jina & Brodie, 2008; Msimanga & Lelliot, 2008).

As mentioned by Blumenfield et al. (1987), teachers tend to simplify tasks in order to reduce insecurity and confrontation. The descriptions given in this work show that The Ladder Approach, emerging from this study, does often lead to feelings of insecurity, and should, at least for some modules, involve a long-term, struggle-filled process. Should teachers modify this strategy in a manner that removes the need for this struggle, in order to make implementation easier, the strategy is unlikely to be effective in promoting critical thinking (Resnick, 1987). This simplification process is viewed as the main reason for the failure of the process-oriented instructional strategies developed by scientists and implemented in the US after World War II (Atkin & Black, 2003). It has also been shown by South African researchers to be a reason for a mismatch between curriculum ideals and actual practise in the South African Outcomes Based Curriculum (Stoffels, 2005a, 2005b).

On the other hand, there does seem to be a willingness on the part of South African teachers to undergo change. A lack of clarity on how to do this in practise, without compromising learning quality, seems to be the limiting factor in actually effecting this change (Jina & Brodie, 2008; Stoffels, 2005a, 2005b). This is consistent with my experience arrived at through informal interaction with teachers. This increases the likelihood that some teachers would embrace a method, such as The Ladder Approach, which has shown promise and is grounded in real practise.

6.5. IMPLICATIONS

Since the FET national curriculum was only introduced into schools in 2006, no research had yet been done into its implementation by the time of commencement of this study. While critical thinking had been studied to an extent in the South African context, only one study could be found focussing on physical science education (Mashike, 2000), and this applied to the old curriculum. Much of the South African work done concerning critical thinking, up to that point, had been to do with nursing (e.g. El-Kantar, 2002; Kaddoura, 2002; Madolo, 1998; Mogale, 2000), with some work having been done on improvement of instruction at school level for subjects such as Technology, Geography, Biology and English (e.g. Adam, 1999; Ankiewicz et al., 2001; du Preez, 1998; Swanepoel, 1999), and some having surveyed various groups' perceptions of, or abilities to engage in, critical thinking (e.g. Bester & Pienaar, 2002; Kaminsky, 2004; Lombard & Grosser, 2004; van den Berg, 2000).

The results of these studies have already been discussed. They show low levels of critical thinking and limited understandings of what critical thinking is and how to promote it, despite the great deal of emphasis placed on critical thinking in the national curriculum (DoE, 2003a). I concluded from this that there was a need for understanding how to promote critical thinking amongst South African learners.

However, an extensive study of the literature at the start of the study had not revealed much practical advice on how to achieve this successfully, and none on doing this within the context of the newly implemented South African national curriculum. Also, no empirically tested exemplars to guide teachers and curriculum writers into the setting of critical thinking tasks could be found. This study is a move towards filling this gap in the literature in a practical way. Other South African-based research activities currently operating in the area of critical thinking promotion appear to be focussing mainly on the use of argument to promote critical thinking. This is being done in teacher-training (Scholtz, et. al., 2006), amongst primary school learners (Msimanga & Lelliot, 2008), high school learners (Braund, et al, 2007), and at tertiary level (Lubben et al, 2008). Findings from these studies provide cautious optimism and practical advice concerning the promotion of critical thinking, as do I, based on the research I have described.

Practical guidance of this sort is needed in helping South African teachers implement the South African national curriculum if it is not to fail. One of the findings of this study was that implementation of the curriculum is difficult. This corresponds to the view, given by Jansen, an outspoken opponent of South Africa’s transition to OBE, that OBE places great demands on teachers.

> I made the original argument that OBE would fail based on two interrelated insights: my practical experiences as a teacher in impoverished school environments and my graduate training as a curriculum theorist and comparativist. Combining theory and practice, I argued that even if one agreed that this highly sophisticated curriculum was philosophically and politically agreeable (which it was not), the sheer demands it would place on teachers struggling to teach large classes were simply unattainable. (Jansen, 2008, p. 26)

While The Ladder Approach is more demanding and sophisticated than traditional teaching, this is viewed as an inescapable consequence of a desire to promote critical thinking and, consequently, effective learning. If, therefore, the curricular ideal of promoting critical thinking is to be retained, the structure provided by this model could be helpful in empowering teachers to promote critical thinking despite the demands this places on them.

I propose The Ladder Approach as an instructional model which can be seen as a subset of problem-centred inquiry. I see it as distinct from the current models which fall into this category. For example, while it meets certain criteria of problem based learning (PBL) it does not meet others. Both The Ladder Approach and PBL aim at promoting critical thinking through engagement with a problem question. However, whereas in PBL the information needed for this engagement with the problem question would be accessed by learners in largely autonomous investigation (Thomas, 2000), in The Ladder Approach, this information is supplied by the teacher during direct instruction. Further, although PBL's criterion of using authentic real-life problems was strived for in this study, this criterion was found to be needlessly restrictive. Many of the problems used in this study e.g. Tsunami would be referred to as *simulated*, rather than authentic (Thomas, 2000) Other problems would probably be referred to as *academic* (Thomas, 2000), such as explaining why an egg breaks on concrete but not on grass. These particular problems were used, rather than truly authentic problems because I was unable to find or self-design any of the latter. Nevertheless, I believe that I have shown, in this study, that the contexts used were effective in promoting critical thinking and interest in the problem task. On the other hand, more authentic problems may have done this to a greater extent.

I believe that through this proposal of a new instruction model, this study contributes to an understanding of beneficial pedagogy. This is particularly so in the context of promotion of critical thinking within the South African physical science curriculum, but not limited to this. I believe that this model has similarities to the analysis offered by Cronjé's (2007) in which it is proposed that so called instructivist, or traditional, and constructivist, pedagogies can be integrated with effectiveness.

Further, this study contributes to research methodology in two ways. First, I suggest that the framework given in Table 3.3 (p. 80) is valuable for determining the effectiveness of an instructional strategy which promotes critical thinking while being compatible with a content-rich curriculum. I found this to be both feasible to use and appropriate. Second, in this study I have grouped the cycles of action and research undergone, which I termed section cycles, into theme cycles, each of which revealed a particular principle. Although this was not observed in literature on the reporting of action research, I suggest that this is a useful tool for researchers using action research. A large number of action-research cycles occurred. Their chronological sequencing was largely beyond the researcher's control, with cycles which lend themselves to advancing knowledge about a particular theme not necessarily occurring contiguously, and with some cycles occurring simultaneously as a result of more than one grade being involved in the research. Many studies are very clean with clearly defined cycles. In the case of a more messy study, this is one strategy to help reflection and interpretation.

This study has a number of implications for further investigation. Research on implementation of The Ladder Approach in other physical science classrooms in South Africa, in other countries, and for the teaching of disciplines other than physical science, would enhance an understanding of its applicability to contexts other than my classroom. It would also be interesting to investigate whether attempts at promoting critical thinking, such as this one, have value beyond the discipline in which they are implemented, and beyond the time-frame of the implementation. This could be done by studying learners exposed to an instructional model such as used in this study in other contexts and once no longer exposed to the intervention. Almost all the learners who participated in this study showed improvement in a test of scientific reasoning over the intervention period. Also, their scores in comparison with those tested and reported by Hobden (2008), were higher, on average, than most practicing teachers', and considerably higher than grade 10 learners from a variety of South African schools. It will be interesting to see how these learners' grade 12 examination performances compare with learners from other schools, and whether there is any correlation between these examination results and those given by the critical thinking test.

6.6. CONCLUSION

In this chapter I have summarised the knowledge claims I have made in this study, with a focus on the assertions made in Chapter Five in answer to the study's research questions. I have also expounded on two models generated for the purpose of making these assertions accessible. These are The CPAG Quadrant and The Ladder Approach. The CPAG Quadrant is proposed as a task classification system, and in so doing be used to help predict the likelihood of a task promoting critical thinking when used in various contexts. The Ladder Approach is an instructional model emerging from this research. I have also mentioned limitations of this study and outlined some implications of this work. Action research intends to inform practise through an in-depth study of localised situations, presented in a manner sufficiently rich for readers to form naturalistic generalisations which are applicable to their particular contexts. Consistent with this, it is hoped that this study will have some impact on practice, particularly in the teaching of physical science in South African schools.

The central thesis I make is that it is possible to promote critical thinking within the constraints of a content-rich curriculum. The specific instructional model I found effective in doing this, called The Ladder Approach, stresses the value of both direct instruction and collaborative interaction with interesting subsuming problem tasks. It also highlights the importance of scaffolding during learning, and shows how this can bind the parallel-running traditional and constructivist aspects of this strategy together in a manner that enhances attainability for a large range of learners.

I entered this study with enthusiasm, optimistic that I would be able to ride the wave of curricular change with my learners, and in so doing help transform them into being more critical thinkers at the same time as inspiring an excitement and wonder for learning physical science. While this enthusiasm and optimism have survived this study, these feelings are now tempered with a good deal of respect for the effort required to promote critical thinking, especially while operating within the confines of a content-rich curriculum. The rewards I reaped from this study, though, more than compensated for the dedication and struggle it demanded. These rewards lay in the satisfaction of watching learners change into more reflective people, and the exhilaration of seeing learners being passionate about a subject traditionally thought to be dry and boring.

Following the progress of a girl I have referred to as Agnes, through the course of the study, illustrates this. She was new to the school at the start of the study, scored low on the initial test of scientific reasoning I administered and did poorly in early science assessments. She commented that she found my teaching very different to what she was used to: “I was used to just writing notes from the board in Science... it was much easier, much on the surface" (Interview 18/08/06). During the second year she remarked, "Before I wasn't really interested in science, but now I'm so interested, and even just in normal life I just mention something to do with science" (Interview, 01/03/07). By the end of the three-year intervention period she had more than doubled her reasoning test score and scored a B for physical science. She also remarked on the habit of thinking critically rubbing off on her, and her even transferring this skill and disposition to new contexts:

> An interesting thing I found out, when I was studying for maths, I began to ask myself, "why" questions when applying formulae, like we were taught in science. This curiosity helped my understanding and it was more fun than just the usual practise I used to do. (Agnes: LJ: 25/03/07)

The inherent resistance of learners to exert themselves mentally often tired me during the course of this study, tempting me to take the easier road of traditional instruction and to lower the expectation I had that I could promote learners to become more critical. Cases such as Agnes' encouraged me through these periods and motivated me to continue my own journey of learning in a critical manner. This journey has developed in me a belief about learning and critical thinking and its promotion which I hope I have also managed to impress on my learners. This is characterised by two main thoughts, referred to, somewhat, by Petrus, below. These are that both engaging, and seeking to promote engagement, in critical thought involve struggle, but that these processes cause meaningful learning which lasts:

> I love Miss Stott's lessons because she doesn't just spoon-feed us but allows us to think for ourselves. She gets us to explain things to other people so that we can see for ourselves if we understand or not. We are also allowed to struggle through a question ourselves so that when we understand we remember the problem for a long time and this helps us a lot in the future because we remember the problem and the solution better. (Petrus: LJ: 10/02/07)

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APPENDIXES

Appendix A: Example of a completed questionnaire

QUESTIONNAIRE

Name: ____ Date: 14/08/06

Task: Tsunami

1. What was your attitude to the task at the START?

Tick as many blocks as are appropriate, and add comments if necessary

very interested ☑ slightly interested ☐ neither interested nor bored ☐ bored ☐

looked forward to the task ☑ neither looked forward to, nor dreaded the task ☐ dreaded the task ☐

thought it would be challenging, but possible for me to do ☑

thought it would be too difficult for me to manage ☐ thought it would be easy ☐

I enjoy working with nature + causes of nature; what is actually going on behind that we observe (waves). For some/other reason I have a peception ~~about~~ that everything in science is challenging but I can do it. Is it bad miss?

2. What is your attitude to the task now at the END?

Tick as many blocks as are appropriate, and add comments if necessary

very interesting ☑ slightly interesting ☐ neither interesting nor boring ☐ boring ☐

I learnt a lot through it ☑ I learnt a little through it ☐ I learnt nothing through it ☐

it was too difficult ☐ it was difficult, but not too difficult ☑ it was neither difficult nor easy ☐

it was too easy ☐

I learned on how to be clearer; although somewhere along I thought I was definitely precise only to find there are missing gaps.

3. What did you do that was helpful towards answering the task?

Wrote notes to the teacher to mark; gave work to friends to check. I also discussed a lot with a group of class-mates. Visualized it. Drew pictures to illustrate ect.

4. What was different between this task and others you have done before?

It was very much real and can be use in reality to save people's lives, money and it got me to think beyond my small world. I thought on how to solve a practical problem.

5. Was there anything difficult or puzzling about this task? If so, what?

As I worked on there were quite a few eg. Ice will cause wave speed (not particle speed) to decrease as a result of tempreture change. But with help I could figure out. I had to think in terms of money + time.

6. How would you have made this task different if you were the teacher, and why?

Just a suggestion.

A pair assessment for marks, though each party shall report in their own definitions. Grouped by the teacher herself formally.

* Take a trip to the beach; and expriment pratically about waves, exposure!!

Because it'll be a different way of learning; fun + work (if there is time)

Appendix B: Example of voluntary learner reflections with teacher response

A force is a push or a pull measured with a spring balance in Newtons. A force is a vector, i.e. they have magnitude and direction.

N3: When two bodies interact, the forces that they exert on each other is equal in magnitude and opposite in direction. Action over re action.

What if it's more then two bodies interacting, like one person kicking the other side and you kicking the other side? I gues the (forces will cancel one another) forces acting on one body may cancel ~~out~~ one another out if angles & magnitudes are right to do this, yes. if the forces are equal force then the ball will be at same place, such as equilibrium. Each interaction is between 2 bodies then [you + ball] = + op. to one another and [~~you~~ ball + other person] = + op. to one another interact (i.e. 2 interactions). not necessarily = + op. to one another; if so, then ball will be in equilibrium, yes.

When ever two bodies act on open air there's always a frictional force caused by air resistance and it also it's not out of space.

When I kick the ball I oply a force on it wich is compression force ~~and frictional force~~ and it pushes me back, also aplying the strength of force I aplied. So why don't I go flying as it does? Because of my mass or weight compared to it mass it's nothing compared to me.

so? what does that have to do with it? (explain... I'm not saying you're wrong, I just want you to explain)

Note: this answer, on its own, doesn't ~~explain~~ answer your qn. You are kept in equilibrium by frictional force between you & ground, which is = but opposite to force ball exerts on you,

But this ball has got kinetic Energy, is it before or after you kick it? that's why when I kick it, it makes a noise and when it lands on the ground it makes a sound.

I'm aplying a force on a ball therefore I'm doing work on the ball then KE from me is transferred to

Appendix C: Sections which made up this study

Section	Strategy	Strengths	Weaknesses	Reflection
1. Electricity Gr 10, 2006	Short argument-focussed tasks, some inducing, some applying content knowledge learning. Much group discussion with strong teacher guidance. Argument taught directly. Direct whole-class instruction of content interspersed between tasks.	Enjoyment, active engagement. Critical thinking evident, but strongly dependent on teacher prompting.	Teacher dependent, slow; Learners developed a fear and dislike for argument, thinking they always have to be complicated.	Perhaps if teacher withdraws somewhat, learners would be forced to be self-directed? Perhaps content-inducing tasks demanding critical thinking could reduce time usage by 'killing two birds with one stone'? Perhaps expecting learners to do more of the work for homework could speed up the process? Go to 2
2. Mechanics Gr 10, 2006	Short argument- or logic–focused tasks designed to induce content knowledge, and done partly for homework, followed by group discussion in class, with strong teacher guidance. Little direct whole-class teaching of content. Logic taught directly.	Learners enjoyed logic puzzles. Active engagement and critical thinking evident (but mostly not fruitful in developing content understanding)	Most learners did not learn content knowledge effectively. Much guessing in homework where data-argument matching required. Dislike for mechanics and argument. Slow. Teacher input repetitive between groups. Frustrating.	Answer to all questions above: no. Clearly not a good idea to replace direct instruction with activity-based strategy, at least for this section. Go to 5.
3. Waves Gr 10, 2006	Tsunami: A 'real-life' interesting decision-making open-ended, complex task was presented at the start of the section. Group discussions were interspersed between direct content teaching. Voluntary drafts were encouraged and shared between learners. Optics: Criteria for causation taught directly and applied in group discussion criterion-judgement task. Cell phone research: Criteria for good research taught directly and applied in group and individual criterion-judgement task.	Tsunami and optics: learners highly engaged and interested in and out of class. Evidence of critical thinking. Effortful but attainable.	Tsunami and optics: slow Tsunami: complexity and open-endedness caused insecurity for teacher and learners. Cell phone research: learners were overwhelmed, many didn't manage it, few enjoyed it.	Tsunami task needs greater structure to reduce insecurity. Due to time pressure, only tsunami task will be used for this section in the future. Perhaps some group discussion can be cut down on to get through the work in time? Go to 10 and 20
4. Chemistry Gr 10, 2007	Direct instruction aimed at developing concepts incrementally and engaging learners interactively.	Pace high. Less messy, noisy and tiring than other strategies.	Although learners were active during class time, few thought deeply about the material out of school hours.	A long target task involving learner discussion needs to be answered incrementally interspersed between the direct instruction, as

				had been the case in section 3. Go to section 7.
5 Mechanics Gr 11, 2006	Direct systematic teaching followed by application questions done partly at home, and reported back on and advanced, through group discussion.	Quicker. Less messy and frustrating. Learners reported enjoyment, clarity, yet depth of thought	While stronger learners engaged deeply with concepts, weaker learners picked up phrases from stronger learners and used these without understanding (perhaps this is unavoidable?).	Direct instruction which systematically develops and models use of concepts and algorithms should form the backbone of the strategy. However, isn't there a way to engage learners in deeper thinking throughout the process? Go to 7 and 8.
6. Mechanics Gr 10, 2006, re-teach	Direct instruction	Learners reported feeling more secure.	As with 5.	As with 5.
7. Mechanics Gr 10, 2007	Motion: Long 'real-life' interesting explanation-type, complex tasks were presented at the start of the section. Interim reports, answered individually for homework, followed by group discussion in class, and controlled by the teacher, were interspersed between direct content teaching. Energy: Similar to above, but short task with no interim report – only group discussion. Teaching strategy similar to section 3, except that interim reports and their discussion interspersed the teaching.	Active engagement and interest, struggle and eventual attainability for most. Evidence of critical thinking.	Long task (motion): Much writing. Difficult. Attainable only after weeks of struggle, so possibly discouraging as a first introduction to FET PS?	For those learners for whom long task was attainability, it was, generally, more effective than the short tasks. However, short tasks were less taxing and more attainable by more learners.
8. Mechanics Gr 11, 2007	Momentum: similar strategy to section 6, motion. Gravity: similar strategy to section 6, energy.	As above.	Long task: much writing. Not effective in developing competence in numerical calculations.	This strategy seems to be the model pattern except that some plan needs to be made to improve performance in numerical calculations. Go to 11 and 18.
9. Waves Gr 11, 2007	As in section 6 and 7, except that the target task involved the making of a video and each group dealt with only one aspect of the task.	As above, except that learners reported to only learning the section assigned to them well.	Technical difficulties detracted from the content learning.	While making a video is fun, unless the technical problems experienced can be overcome, this is not an effective medium for learning content.
10. Waves Gr 10, 2007	As section 4, except only Tsunami task was done. Less class time was devoted to group discussion. Learners were given a loosely structured mind-map to complete to help guide their final answer.	Effective (struggle, interest – although less so than section 3 – critical thinking, attainability) for those learners with good time management skills.	Learners with poor time-management skills did very poorly. Learners complained of not having necessary resources. The mind-map didn't seem adequate for the majority of	An interim report system is needed, must be enforced by the teacher, and discussed during class-time in groups, to help learners manage the task, remove insecurity which leads to unattainability, and plan

			learners.	their time effectively. The interim reports serve as resources for the final presentation, and help learners use their learning and class discussion as resources.
11. Electricity Gr 11, 2007	Electrostatics: medium-length data-handing task. Circuits (design task as target task): As sections 6 and 7 motion except numerically focused exercises for homework every day. Learners mark these at home from provided memos.	Seemed to have the strengths of sections 6 and 7, with reduction in weakness of poor numerical competence.	Much homework. Time pressure did not allow for going through common problems to the numerical questions in class time – which lead to some learners not being helped effectively.	Is it reasonable to give so much homework? What effect does this have on attitude? Learners did not complain to me, although I heard that the gr 10s were afraid of going to gr 11 due to work pressure.
12. Electricity Gr 10, 2007	As in section 1			
13. Matter and materials and chemical change Gr 10, 2007	No long task (one was presented– requiring learners to refer to elements of thought, but due to time pressure and evident difficulty, it was dropped). Teacher-dominated strategy, with focus on elements of thought and questioning.	Strong learners came up with excellent questions and seemed able to identify the elements of thought.	Weaker learners said they 'switched off' during peers' questions. Frustrating for teacher since weaker learners seemed not to be able to grasp and identify the elements of thought.	Encouraging questioning needs to be done primarily in groups, not in a whole class settings (go to 14)
14. Matter and materials and chemical change Gr 11, 2007	Critical thinking focus: questioning. Solar panel explanation: Learners required to figure out how a solar panel works by asking questions which would propel the thought process to a fruitful outcome. Group dialogue, teacher prompting, and mind-maps in various stages of completion, given out at various stages in the process, were used to guide the process. A similar process was used in explaining working of a capacitor microphone: Gr 11 2006 and 2007, with similar results	After an initial lag phase in some cases, the learners were very active, engaged, interested. High levels of enjoyment. Evidence of critical thinking. Evidence of transferability of this style of thinking to aid self-direction in other contexts.		An effective short-task strategy. Also an effective strategy to infuse into all teaching and expectations.
15. Chemical systems Gr 11, 2007	Acid rain decision-making task: learners required to list criteria and evaluate suggestions against these; Fossil fuel argument task: learners required to draw up an argument 'map' (using template provided) to guide structuring of final answer.	Learners active, produced high quality work, reported liking the direction offered by the structure.		An effective way of guiding decision-making (used in section 19) and argument structure.

16. Chemical systems Gr 10, 2007	Learners prepared a PhotoStory presentation on a topic they self-researched. No structure and guidance was given.	Learners were excited about the idea of making a little movie.	Technical difficulties dominated the process. Poor quality work produced on the whole.	I think this failed largely due to the lack of scaffolding (as well as technical problems). It seems that leaving learners to do a research project unguided is not effective.
17. Mechanics Gr 10, 2008	As section 7	As section 7	As section 7	
18. Mechanics Gr 11, 2008	As section 8, except that numerical application was added to the explanation type task (learners required to invent and manipulate data to illustrate the concepts they explained)		Unfortunately the interim report dealing with numerical questions was not checked on by the teacher. Many learners seemed to ignore this section of the target task.	It seems that the teacher has to check interim reports. One can't trust learners to do their work faithfully.
19. Mechanics Gr 12, 2008	A strongly numerical strategy was taken, with examples worked out from the front by the teacher, and much numerical homework assigned.	Not messy or effortful or frustrating (except the test results), from the teacher's perspective.	Learners scored an average of 40% on a numerically focused test. Only one learner drew pictures to accompany problem solution in the test, possibly suggesting that conceptual understanding was not applied.	How does one get learners to apply conceptual understanding to a numerical question? How does one get learners to do well in numerical questions?
20. Waves Gr 10, 2008	As section 4, except compulsory interim reports, monitored by the teacher, were incorporated interspersed between teaching, answered individually for homework, then discussed in groups.	Task effective in all areas.		This section, relative to section 10, provided confirmation of the importance of scaffolding to task success.

Appendix D: Example of an NVivo Query: Gr 10 Mechanics 2007

	B : 6a Mech M...	C : 6aa Mech ...	D : 6b Mech G...	E : 6c Mech E...
3 : Active engagement and or interest NOT	17	2	1	1
5 : too slow	2	0	0	0
6 : novel NOT	4	1	0	0
7 : Attainability NOT	18	1	1	1
9 : confusion	3	0	0	0
11 : lack of necessary vocabulary or conceptual kno...	2	1	0	0
12 : too fast	5	0	0	0
14 : lost	3	3	0	0
16 : Effort NOT	3	0	5	5
23 : Content NOT	5	0	0	0
24 : Critical thinking NOT	1	0	1	0
32 : Self-direction NOT	1	1	0	0
35 : short circuit to thinking	1	0	0	0
42 : Active	48	5	4	7
43 : Interest and enjoyment	57	4	6	5
44 : novel	2	0	0	0
45 : Effort	39	5	1	1
48 : Attainability	38	3	10	9
59 : Content	10	0	2	2
60 : misconceptions revealed	1	0	0	0
61 : Critical thinking	1	0	0	0
64 : Self correction	0	1	0	0
65 : Sensitivity to context	2	0	0	1
69 : Rebuttal	1	1	0	0
71 : Questioning	3	0	0	1
73 : Multiple perspectives	2	0	0	1
78 : have to apply syllabus knowledge to task	3	0	0	0
80 : Adjustment for individual learner's needs	2	0	1	1
81 : Range	1	0	0	0
82 : Drafts	1	0	0	0
83 : Interim reports	6	1	0	0
84 : Classroom climate	1	0	0	0
86 : Motivation	2	0	0	0
88 : Time pressure's consequences	1	0	0	0
90 : Messiness	2	2	0	0
91 : Lag	5	0	1	1
94 : marks	4	0	0	0
100 : Collaboration	36	6	2	2
101 : Complexity	0	0	0	2
104 : Length	4	0	1	2
108 : Teacher prodding	4	5	0	2
110 : Teacher information-giving	1	2	0	0
115 : teacher has to check up	1	0	0	0
117 : Time	1	0	1	1

Appendix E: Validity checks

The lists and brief descriptions given here, as well as the sources to which these are hyperlinked, document the main events in which I subjected my work to the scrutiny of peers and superiors, reflected on ideas emerging from the data, together with these people, and modified my work in response to this process.

Validation Group

1. 01/01/07: Validation group and critical friend summary was e-mailed to MP, HP, HL, DN, IV, PB.
2. 28/02/07; Meeting in DSS Computer classroom
   Present: MP, HP, HL, DN
   I gave my research questions, criteria for evaluating effectiveness, synopsis of findings so far, evaluated against the criteria for evaluating effectiveness. (See PowerPoint presentation)
   This was followed by critique, given by the validation group. I audio-recorded this and wrote a summarising report.
3. 02/03/07: I e-mailed my reflections arising from the 28/02/07 validation group meeting, and reported on data collection which occurred since the validation group meeting, and interpreted in the light of the critique given at this meeting.
4. 12/03/07: I e-mailed reflections to the validation group. I received an e-mailed response from HP, and a verbal response from DN.
5. 13/05/07: sent the e-mail I wrote to Clive Long to the validation group. 15/05/07: MP replied, suggesting I analyse exemplars for guidance on the issues raised. I did this later in the year (24/11/07).
6. 31/10/07: e-mailed my paper on numerical vs conceptual learning to MP, asking whether I had represented his position correctly in it. He replied that I had.
7. 26/11/07: made a screen-capture video of the presentation I gave at Kearsney College, and distributed to validation group for comment.
8. 13/04/08: Distributed a PowerPoint summary of my research and reflections thus far, as well as a screen-capture video which I narrated, to validation group, with request for feedback. In the video I demonstrated how I use NVivo for coding, going into specific, randomly chosen, data, and motivating the coding used.
   I received e-mails from HP and JP on 14/04/08, which I responded to on the same day, and again from on JP on 29/04/08. The latter made me realise that I needed to produce a more comprehensive presentation, as outlined below.
9. 11/05/08: Distributed a CD, containing a comprehensive outline of my research, to validation group members, and invited feedback. Received verbal feedback from IV as well as from JP.
10. 17/06/08: Sent an e-mail, and attachment, giving two models of question classification, together with claims arising out of my data. These were products of analysis of the data, followed by a discussion with HP, resulting in the document given here.

11. 11/11/08: Held a 2 hour meeting with Drs B, V and P, where I subjected my work to their scrutiny against criteria from Heikkinen et al. (2007), Lincoln & Guba (1985), Feldman (2007), Morse (2002) and Winter (2002). E-mailed report on their feedback. They signed forms agreeing that they were satisfied that work was valid.

Critical Friends

Note: The reports given below represent the extended (each over an hour long) discussion periods I underwent with my critical friends. Numerous other shorter, less formal, discussions were conducted. Note, also, that the two critical friends are also part of the larger validation group.

1. 04/02/07: HL raised some questions she'd developed from the written (01/01/07) and verbal summaries I had given her on numerous occasions in the past.
2. 09/03/07: In car to Pmb, I briefed HP on recent thoughts emerging from research. This discussion helped crystallise my thoughts, which I then put into an e-mail to the whole validation group and my supervisor on 02/03/07.
3. 06/05/07: 3-hour discussion with HL about the failure of *Tsunami* for weaker learners. Emerging from this, I designed a remediation program, and scaffolding tools for the next implementation of *Tsunami*.
4. 12/05/07: A discussion with HP on the way to, at, and after an IEB grade 12 moderation meeting crystallised my thoughts on ambiguities in the assessment standards, and difficulties in striking an appropriate balance between algorithmic and conceptual foci, which I then wrote about in an e-mail to Clive Long, and sent on 13/05/07. Continued discussion on this issue with H and MP around lunch, 13/05/07.
5. 16/06/08: Grappled with HP over two representations I had come up with, emerging from my data, on how to classify tasks, together with claims made on effectiveness of each in promoting critical thinking in various situations. Discussion led to alterations in my models.
6. 11/10/08, 12/10/08: Speaking to HL and HP, I mentioned some specific examples of how incorrect rough ideas about what data showed was shown not to be entirely correct on closer scrutiny of the data, causing me to modify some claims I was making in the dissertation.
7. 14/10/08: I shared some findings I'd made during qualitative comparisons of performance and class time-usage across the three years for the Tsunami task, with HP and MPas we drove back from a meeting in Pietermaritzburg. We discussed the value of scaffolding which this data suggested.
8. 29/10/08: In a discussion with HL, I summarised the conclusions I had reached. She asked me questions about this, which I answered, but which made me realise that I needed to expand my literature review into some areas which I had not covered yet. She lent me a number of books and articles from the BEd (Hons) course she is busy with, for this purpose.

Other occasions when my work was subject to external scrutiny:

1. 03/02/06: Gave a verbal presentation to supplement my written proposal to evaluation committee at UKZN. I received a written report of suggestion from the committee, and incorporated these suggestions in my research design.
2. 13/05/07, 17/05/07: E-mail to Clive Long (IEB Physical Science subject specialist): 13/05/07. To which he responded: 17/05/07.
3. 18/06/07-22/06/07: SAARMSTE research school. Presented a poster display of my research, and received feedback from Dr Mitch O'Tool and Dr Peter Hewston. Reflections on this recorded: 23/06/07.
4. 15/08/07: Sent paper reporting on a section of this study, concerning the inductive and deductive use of group work in the teaching of Physical Science, to SAARMSTE. Unfortunately this was somehow misplaced, and so not published. However, I submitted it for review at the 2008 SAARMSTE research school (see below).
5. 03/07/08: Modified the synthesis and question classification model I had discussed with Hanna and sent to the validation group, in response to further reflection. Gave this to Dr John Mergendollar, while at an Oracle training session in Pretoria. He gave me verbal feedback.
6. 06/11/07: Sent paper I wrote for SAARMSTE, concerning algorithmic practice and conceptual explanation, to Clive Long.
7. 26/11/07: Presented research findings concerning algorithmic practice and conceptual explanation, to the IEB Durban Physical Science user group meeting held at Kearsney College.
8. 17/01/08: Presented a paper on a section of this research (Balancing numerical practise and conceptual explanation in a crowded curriculum) at the SAARMSTE conference in Lesotho.
9. 23/06/08-27/06/08: Presented a poster and verbal presentation at the SAARMSTE research school at Roodevallei near Pretoria. Received feedback from peers and superiors. Also submitted a paper concerning inductive and deductive use of group work for review. Received feedback from Estelle Geiger.
10. 13/11/08: Displayed my research at the UKZN Poster Competition

Appendix F: Sample of minutes: validation group

28/02/07
Validation Group Meeting 1

Present: MP, HP, HL, DN, A Stott
Absent: IV, PB
1. I gave a PowerPoint presentation summarising my research up to this point
2. Discussion summary (not transcribed word for word):

MP: A lot of your research focuses on the teacher. But, the levels on which the children are cognitively: wouldn't that also affect the approach?
Me: that is one of my research questions, and it is at present what I least know the answer to
MP: Language ability. There are different ways of communication. Some people find it difficult to communicate with language, while others may be better stimulated to think critically with pictures.Your data is very much based on your teaching – and very subjective to you. It could be that another teacher may use this approach of yours, and not receive the same results, since a lot of the success also depends on the teacher's skills.
Me: That is a limitation inherent to this methodology. This kind of study is not done for the purpose, primarily, of generalisation to other cases.
DN: Your subquestions are focussed away from the child, and you're not considering the affective factors – like the emotional stage of the child. Children at that age are going through stages of development which would very likely affect learning of critical thinking.
Me: The sub-question about classroom environment has an affective dimension. I can obviously not look at all the factors that would affect the learning of critical thinking– I have to focus.
DN: I think that mood would greatly affect whether learners are prepared to think critically.
HP: I had the same thought when you showed the quote about the child who said she doesn't like thinking at home. You commented that that maybe showed that there was something wrong with the task. Maybe it wasn't the task that was the problem.
Me: In that respect, I do bear that in mind. When I analyse my data and consider how much weight to put on a certain statement, I do bear the possibility of moods in mind. I used those two statements simply because they were the only negative ones I could find.
DN: Maybe the quote that said that the child seemed to understand your task, but then didn't manage when they got to the textbook activity may be a pointer to the fact that children learn in such different ways. Some acquire language and have no idea of the rules, whereas others need to learn the rules. Its similar to whether you must focus on the component or the complexity. I think you have to cater for both. Maybe a task needs to have components from a concept point of view, and a component from an angle of learning the rules – or one task needs to be from one angle and another from another.
Me: I have been trying to take both approaches, but obviously you have to make time sacrifices.

DN: Maybe you should compare which children feature in an open-ended approach, and which find a more theoretical approach useful.
MP: What control are you using as a comparison?
Me: This type of methodology does not control from without. It is action research, not an experiment. In it I try to understand from within. If I were working in a positivist paradigm, controlling from without, my results would be more generalisable to other situations, although it may be less close to the natural truth of this situation. People are so complex that the idea of control is less applicable to social science studies than to studies of the natural sciences.
MP: I think that you can generalise that when they get a rich task like this, it engages them, and that is what any teacher tries to do. I think that is a valid result that has come out that one can generalise. It could be that more than one child who says that the textbook exercises tire them, in contrast. That it a positive, and concrete result that has come out. Whether that is still the most effective science teaching is still a different question, because in science there’s a lot of discipline that must go into the learning – that’s not necessarily what a child enjoys doing. Obviously if they’re not interested in all they’re not going to do it at all, but there is also another side of it – and I don’t know if that fits in with critical thinking, or if its just effective science teaching – its maybe a different question. Because there are also certain skills they need – that they can answer certain questions. That is one of the outcomes one would expect them to reach, but maybe that’s a little bit away from your question.
Me: This year I have done more of a mix, compared to last year, between critical thinking tasks and exercise work. I do do quite a bit drilling – but obviously it can’t be as much as if I were just to drill.
MP: Because once learners have the basic skills, that frees their minds to be able to cope with other work. It would be interesting to see whether those with basic skills are able to cope with critical thinking tasks.
HP: There’s a lack of basic skills of basic operations (e.g. algebra) in the Gr 10 class, and this could be because of OBE.
DN: In the transition period towards OBE, teachers were grappling with issues about discovery etc, and that group of learners lost something in the process as teachers swung too far from traditional methods.
Children learn in different ways.
Children place different value on different motivating sources, and you aren’t stressing this enough.
Me: What you say links to the issue of transferability. One would think that having a good conceptual understanding would make one do well in numerical questions too, but this isn’t automatically so. Skills are transferable only to an extent.
HL: are you going to expect them to transfer their understanding to a new situation in the exam?
Me: yes
HP: and that raises another issue: that of time constraints
HL: If we all start giving them tasks which keep them busy until 1 o’clock, they’re not going to be able to do it.
HP: but that was voluntary: they were working for bonus marks
Me: What I found as a spin-off from the research is the value of communication between learners and teachers.

Appendix G: Final validation group validity check form

Techniques to ensure validity and reliability in qualitative research

Lincoln & Guba (1985):

- Credibility
  - o Prolonged engagement, persistent observation, triangulation of sources, methods and investigators
  - o Peer debriefing
  - o Negative case analysis (disconfirming evidence)
  - o Referential adequacy (well developed data corpus)
  - o Member checks (in-process and terminal)
- Transferability: thick description (enough info so readers can use)
- Dependability: audit trail
- Confirmability: audit trail

Winter (2002) Heikkinen et al. (2007):

Critical reflection ('to reduce mechanisms which hide the truth'):

- Reflexivity (self-questioning).
  - o examine relationship with objects of research.
  - o question presumptions of knowledge and reality.
  - o make materials and methods transparent.
- Dialectic ('collaborative process that reflects a plurality of perspectives').

Feldman (2007):

- State explicitly how and why data was collected and what counts as data.
- State explicitly how narratives were constructed from data.
- Seek other ways to represent the same data, use this to critique one's views.
- Situate claims in theory and subject this to critique.

Morse (2002):

- Methodological coherence (method matches research questions).
- Sampling: appropriate and sufficient.
- Collection and analysis concurrent.
- Thinking theoretically.
- Theory development.
- Investigator responsiveness: remain open, sensitive, willing to relinquish poorly supported ideas

I Dr. Ilsa Uermaah (title and name)

qualifications: B.Sc; H.O.D; Hon B.Sc; B.Ed; M.Sc; PhD

position: Vice Director institution: Cedar College of Education.

have participated as a validation group member / critical friend for Angela Stott's PhD study, "Promoting Critical Thinking in School Physical Science" over the past two years, as outlined in the relevant Appendix of the dissertation of this study. Although time constraints made an in-depth scrutiny of all aspects of this study impossible, what I have seen strongly suggests to me that the study can be taken as valid and reliable. This statement is made based on evaluation of sections of the study in terms of the criteria for validity and reliability, or trustworthiness, of qualitative research. These were taken from Heikkinen et al. (2007), Lincoln & Guba (1985), Feldman (2007), Morse (2002) and Winter (2002), as outlined on the attached summary, "Techniques to ensure validity and reliability in qualitative research".

Additional remarks:

Excellent work; a thorough and comprehensive study! Creative and original research. I think the "Ladder approach" will become a champion in learning theories.
Well done.

Signed: IUermaah

Date: 2008 – 11 – 11

Appendix H: Learner and parent consent letter and form

INFORMED CONSENT INFORMATION DOCUMENT: LEARNERS AND PARENTS

A STUDY OF CHARACTERISTICS OF PHYSICAL SCIENCE TASKS THAT PROMOTE THE USE OF CRITICAL THINKING WITHIN THE FET PHASE OF THE SOUTH AFRICAN NATIONAL CURRICULUM

The researcher, Miss Angela Stott, under the supervision of Professor Paul Hobden of UKZN, requests permission to collect data from you / your child.

The research aims at exploring the relationship between task characteristics and their success in promoting critical thinking. Critical thinking, sometimes also called higher order thinking, is a very important skill since it empowers a person to solve problems, learn effectively and make sound judgement. Critical thinking is central to South Africa's new curriculum. Therefore participation in this study should be beneficial to you / your child at the same time as increasing educators' understanding of how to improve the teaching and learning process.

The researcher will be teaching the 2006 to 2008 [SCHOOL'S NAME] grade 10 to 12 physical science classes while performing the research. Since you / your child will be a [SCHOOL'S NAME] grade 10 / 11 / 12 physical science learner during either of these years, you / your child is a candidate for this research. Data will mainly be collected by audio and video recording, throughout the year during the normal physical science classroom activities. Written work will also be examined. Additionally, occasional interviews will be conducted with selected learners out of school hours if and when convenient for the learner. The data will be stored securely and treated with strict confidentiality: no unauthorized persons will be given access to the recordings, and learners will be referred to by pseudonyms when the research is reported. When appropriate, the data will be destroyed.

While your co-operation would be greatly appreciated, if you choose not to participate in this research you will not be disadvantaged in any way. Learners who do not participate in the research will be taught together with the rest of the class, but they will not be used as data sources. Participation as a data source is voluntary, and you / your child may withdraw from the study at any stage and for any reason.

Contact information:

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[SCHOOL'S NAME] School
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DECLARATION: LEARNERS AND PARENTS

A STUDY OF CHARACTERISTICS OF PHYSICAL SCIENCE TASKS THAT PROMOTE THE USE OF CRITICAL THINKING WITHIN THE FET PHASE OF THE SOUTH AFRICAN NATIONAL CURRICULUM

I…………………………………………………………………….(full names of learner) and

I…………………………………………………………………….(full names of parent) hereby confirm that we understand the contents of this document and the nature of the research project, and we consent to participating in the research project.

We understand that we are at liberty to withdraw from the project at any time, should we so desire.

SIGNATURE OF LEARNER DATE

……………………………………………………………………………………………………

SIGNATURE OF PARENT DATE

……………………………………………………………………………………………………

Appendix I: School governing body consent letter and form

INFORMED CONSENT INFORMATION DOCUMENT: [SCHOOL'S NAME] SCHOOL GOVERNING BODY

A STUDY OF CHARACTERISTICS OF PHYSICAL SCIENCE TASKS THAT PROMOTE THE USE OF CRITICAL THINKING WITHIN THE FET PHASE OF THE SOUTH AFRICAN NATIONAL CURRICULUM

The researcher, Miss Angela Stott, under the supervision of Professor Paul Hobden of UKZN, requests permission to collect data at [SCHOOL'S NAME] School in 2006 and 2007.

The research aims at exploring the relationship between task characteristics and their success in promoting critical thinking. Critical thinking, sometimes also called higher order thinking, is a very important skill since it empowers a person to solve problems, learn effectively and make sound judgement. Critical thinking is central to South Africa's new curriculum. Therefore participation in this study should be beneficial to the school at the same time as increasing educators' understanding of how to improve the teaching and learning process.

The researcher will be teaching the 2006 to 2008 [SCHOOL'S NAME] grade 10 and 11 physical science classes while performing the research. Data will mainly be collected by audio, and, possibly, video, recording, throughout the year during the normal physical science classroom activities. Written work will also be examined. Additionally, occasional interviews will be conducted with selected learners out of school hours if and when convenient for the learner. The data will be stored securely and treated with strict confidentiality: no unauthorized persons will be given access to the recordings, and learners will be referred to by pseudonyms when the research is reported. When appropriate, the data will be destroyed.

The research will be explained to the relevant learners and parents, and their consent requested. Should any choose not to participate in this research they will not be disadvantaged in any way. Learners who do not participate in the research will be taught together with the rest of the class, but they will not be used as data sources. Participation as a data source is voluntary, and participants may withdraw from the study at any stage and for any reason.

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DECLARATION: [SCHOOL'S NAME] SCHOOL GOVERNING BODY

A STUDY OF CHARACTERISTICS OF PHYSICAL SCIENCE TASKS THAT PROMOTE THE USE OF CRITICAL THINKING WITHIN THE FET PHASE OF THE SOUTH AFRICAN NATIONAL CURRICULUM

I, Dorothy Newlands, principal of [SCHOOL'S NAME] School, on behalf of the [SCHOOL'S NAME] School governing body, hereby confirm that we understand the contents of this document and the nature of the research project, and we consent to conduction of the research project in [SCHOOL'S NAME] School.

SIGNATURE OF PRINCIPAL Dnewlands ***DATE*** ***14 December 2005***

…………………………………………………………………………………………………….

Appendix J: *Tsunami* task

1. Read the two letters below.
2. Complete the support worksheets.
3. Then write two reports:
    a. From Wisecrac to the DCTHHMC presenting the criteria for evaluating the options and arguing for a particular plan of action by referring to the positive aspects of this and negative aspects of alternatives in light of these criteria, while also pointing out counterarguments to this proposal, and acknowledging strengths of other alternatives
    b. From Popeye, explaining the meaning of each term mentioned in the letter to him, how to measure each of these variables, and what significance each has to determining whether the wave is a tsunami or not.
4. Your teacher will assess you using a rubric.

30 May 200?

Dear Professor Wisecrak

A huge tsunami is expected to form within the Indian Ocean due to tectonic activity which has been observed within the mid-oceanic ridge. This tsunami will threaten the coast of South Africa. The following strategies have been proposed. Please evaluate each and submit a report arguing for or against each method, with clear justification to support your view.

1. Place a huge reflecting barrier between the mid-oceanic ridge and South Africa.
2. Sink a massive 1 000 000 km^3 chunk of concrete next to South Africa's shore line, making the water around our shore shallower.
3. Put billions of tons of ice into the sea around us, cooling the water's temperature noticeably.
4. Place huge vibrators in the water, and use them to make waves of our own as soon as a tsunami strategyes.

Your country looks to you, honourable professor, to ward off the impending doom.

With thanks

President of DCTHHMC (Disaster, Crisis, Trauma and Horrible Happenings Management Council)

3 June 200?

SOS: Urgent Immediate Attention: Mr Popeye!!!!!

We have received alarming reports that a tsunami is heading for South Africa RIGHT NOW, and that your little ship lies in its path. The tsunami (if it is a tsunami) will pass the place where you are in 13 minutes 29 seconds' time. Please take measurements of the waves' amplitude, wave speed, particle speed, frequency, period and wavelength, and from this form a substantiated opinion of whether the waves are really part of a tsunami, or if we have been given a false warning. It is vital that you give us correct *information because we will act on whatever you advise us, and if that needlessly costs us either money or lives you will be held responsible.*

Interim Reports:

1 (variables)
2 (reflection)
3 (refraction)
4 (interference)
5 (preparation for final)

Preparatory worksheets:

Simulations and meanings of concepts
Movement between media
Interference

Tsunami Interim Report 1

Complete:

Variable	Meaning	Symbol	Unit	How could Popeye Measure this?
Frequency				
Period				
Wavelength				
Amplitude				
Wave speed				
Average particle speed				

Tsunami Interim Report 2

1. List at least 4 criteria that a method of protecting SA from a possible tsunami must meet for it to be considered a good solution:

a)____

b)____

c)____

d)____

2. Reflection

Define reflection ____

____

Reflection viewed 1-dimensionally:

Give the difference between reflection off a free boundary and a fixed boundary:

free:____

____

fixed:____

____

a. Which applies to water waves? (free / fixed)

Reflection viewed 2-dimensionally:

b. Define:

- incident wave:____

- reflected wave: ____

- normal line:____

- incident angle:____

- reflected angle:____

c. Give the law of reflection and a diagram illustrating this.

d. How are waves that strike a boundary normally reflected?

____

What is the angle of incidence here? ____________

What is the angle of reflection here? ____________

Does the law of reflection apply? _______________

e. What would happen if a large reflecting barrier were placed in the path of a tsunami? Consider different scenarios (if ___ then ___).

/

f. Evaluate the placement of a large reflecting barrier in the path of a tsunami in the light of the criteria you named in 1.

Criterion	Key word of criterion	Evaluation of reflecting barrier in comparison to criterion
a		
b		
c		
d		

Tsunami Interim Report 3

1. 1-dimensional view of effect of movement of waves between media

Variable	Effect on variable of moving from less resistant to more resistant medium (e.g. deep to shallow / warm to cold)	Significance to Popeye task: To recognise a tsunami, remember that:	Significance to Wisecrac task: Effect of sinking a concrete block / cooling a section of water
Frequency			
Period			
Wave speed			
Particle speed (average)			
Wavelength			
Amplitude			

2. 2-dimensional view of effect of movement of waves between media

a. Define refraction ____

____

b. Give 2 conditions for refraction:

____

____

____

____

c. A rectangular block is sunk into some water, making the water above it shallower than the water around it. Water waves strike the boundary between the deep and shallower area obliquely. Draw a labelled diagram showing this.
Label (2x each: 1 for each of the two refracting boundaries): incident ray, angle of incidence, Normal, refracted ray, angle of refraction

d. Explain why refraction occurs.

____

____

____

____

e. Evaluate the placement of a large concrete block in the water in the path of a tsunami in the light of the criteria you named in Interim Report 2.

Criterion	Key word of criterion	Evaluation of using a large concrete block in the water in comparison to criterion
a		
b		
c		
d		

f. Evaluate the cooling of a section of water in the path of a tsunami in the light of the criteria you named in Interim Report 2.

Criterion	Key word of criterion	Evaluation of cooling a section of water (using ice-blocks) in comparison to criterion
a		
b		
c		
d		

Tsunami Interim Report 4

1. What happens during completely constructive interference? Draw a diagram.

2. What happens during completely destructive interference? Draw a diagram.

3. What would the consequence of placing large vibrators in the water and making them vibrate as a tsunami strategyes?
Consider different scenarios (if __ then ___)

Evaluate the placement of a vibrators in the water in the path of a tsunami in the light of the criteria you named in Interim Report 2

Criterion	Key word of criterion	Evaluation of vibrators in comparison to criterion
a		
b		
c		
d		

Tsunami Interim Report 5

Final answer plan

This is only an outline for the final answer, on behalf of Prof Wisecrak and Popeye.
You need only give **key words** here, although in the final answer you will use full sentences.

Popeye:

Variable	Meaning	How measured	How useful to work out if tsunami or not
Frequency			
Period			
Wavelength			
Amplitude			
Wave speed			
Particle speed			

Wisecrac:

Mitigating measure	What effect will this have	Evaluation in reference to criteria:			
		1:	2:	3:	4:
Reflecting block					
Refracting block					
Cooling water					
Vibrators					
Other suggestion					

Summative Assessment: Tsunami

Total marks: 35

LO1AS4: communicate information and conclusions with clarity and precision
LO2AS3: apply scientific knowledge in familiar, simple contexts
LO3AS2: describe the interrelationship and impact of science and technology on socio-economic and human development
LO3AS3: discuss the impact of scientific and technological knowledge on sustainable local development of resources and on the immediate environment

Criterion	**Description of performance**			
	7-8	**5-6**	**3-4**	**2-0**
Presents options and criteria for evaluation of options clearly	Clear, thorough, logical, concise	Good in most areas	Acceptable	Poor
Argues for one option over others, referring to criteria	Well-supported answer to the initial decision question. Provides a useful discussion of issues and insights that arose during the selection process. Counterarguments integrated into argument in a logical, relevant, fair-minded way.	Good in most areas	Acceptable	Poor
Communicates accurately, clearly, systematically, logically, precisely, concisely and cohesively	Uses scientific and technological terminology appropriately. Links premises logically to one another and to a conclusion, and presents these clearly, systematically, concisely and cohesively.	Most use of scientific and technological terminology is appropriate. Most premises are linked logically to one another and to a conclusion, and these are presented clearly, systematically, concisely and cohesively to a large extent.	Some use of scientific and technological terminology is appropriate. Some premises are linked logically to one another and to a conclusion, and these are presented clearly, systematically, concisely and cohesively to a fair extent.	Most of the presentation is incoherent, unsystematic, and illogical.
Effort		2: Impressive	1: Pleasing	0: Poor

Checklist:

- reflection correctly explained ☐
- refraction correctly explained ☐
- interference correctly explained ☐
- meaning and measurement of frequency are given correctly ☐
- meaning and measurement of period are given correctly ☐
- meaning and measurement of wave speed are given correctly ☐
- meaning and measurement of particle speed are given correctly ☐
- meaning and measurement of wavelength are given correctly ☐
- meaning and measurement of amplitude are given correctly ☐

Appendix K: Grade 10 motion introduction and one task

Motion

- You will be assigned a number and a letter. The number tells you which task you must do and which group you will mainly work in. The letter tells you which jigsaw group you will give your presentation to.
- Tasks:
  1. Must he pay?
  2. Which car to be in?
  3. What's in the plunge?
  4. Can you top Tesla? (optional)
- Assessment:
  Formative: (not for marks)
  K-W-L (Know Wonder Learn) chart
  Interim reports
  (if a learner is able to submit the final presentation before the deadline for an interim report, he/she is exempt from the interim report)
  Summative: (for marks)
  A presentation in which you answer the task's question, using the supplied template.
  This will be marked with a rubric. (27 marks)
- Enrichment and bonus marks:
  You could submit more than one presentation for summative assessment. If you do this, the best one's mark will be recorded, and 1/20th of the mark of each of the other submissions will be added to this as bonus, unless this would result in a mark greater than 100%.
- Time allocation:
  Deadline for submission of presentation: 13 February

	Class time allocated
Introduction and initial K-W-L chart	1 hour
Basic concepts of motion: distance, displacement, speed, velocity, acceleration: Teacher presentation and Car module activities. Update K-W-L chart.	
Interim report 1 (first answered individually for homework)	1 hour
Teacher presentation: graphical representation. Update K-W-L chart.	
Ferrari and cheetah task	1 hour
Feedback on Ferrari and cheetah task. Update K-W-L chart.	
Interim report 2 (first answered individually for homework)	1 hour
Teacher presentation: equations of motion. Update K-W-L chart.	
Interim report 3 (first answered individually for homework)	1 hour
Presentation	1 hour
Present presentation to jigsaw group	1 hour

- <u>Resources</u>:
  - <u>Written:</u>

    Kinematics
    Cars

  - <u>Videos:</u>

    Kinematics:
    1. Position, Distance, Displacement (20’09’’)
    2. Speed, Velocity (32’26’’)
    3. Acceleration (40’26’’)
    4. Frames of reference (4’14’’)
    5. Graphical representation (38’04’’)
    6. Equations of motion (53’14’’)
    7. Working with graphs (39’02’’)

    Gravity and energy (37’42’’)

Task 1: Must he pay?

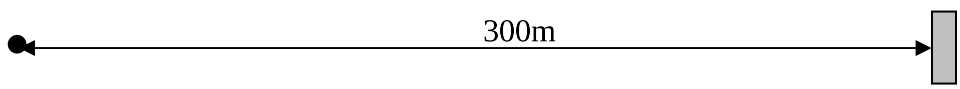
<u>The problem</u>

You are a Judge. You receive the following letter. You have to evaluate whether the taxi driver should have to pay Miss Fortune's bill or not. Explain your judgement.

Dear Judge Sort-it-out

A distressed lady called Miss Fortune claims that her foot was run over by a taxi of registration number GO007. She wants the driver held financially responsible for her medical bills. However, there are no witnesses to agree to her story. The taxi driver says he managed to stop in time to miss her even though she was standing in the middle of a road, and all the passengers in the taxi were sleeping at the time. However, there was a camera, which takes photographs at half-second intervals (i.e. 0,5s), of most of the long straight road where the taxi was driving just before midnight. Also, there is an automatic speed-detector which records information about the speeds of vehicles on that road at half-second intervals. Unfortunately, the range of both of these devices is a little short of the point where Miss Fortune claims to have been hit. Please examine the information from these two devices, and then give a supported evaluation of the likelihood that the taxi did indeed hit the distressed damsel.

Map:



Point where Miss Fortune stood Traffic light

Photograph number	Position of taxi relative to traffic light	Taxi's speed
1	0m	0m/s
2	2m	8m/s
3	8m	16m/s
4	18m	24m/s
5	32m	32m/s
6	50m	40m/s
7	72m	48m/s
8	98m	56m/s
9	126m	56m/s
10	154m	56m/s
11	182m	56m/s
12	210m	56m/s
13	235,5m	46m/s
14	256m	36m/s
15	271,5m	26m/s

Scaffolding:

1. K-W-L chart (to be used and submitted daily, if possible)
2. Interim report 1:
    - do individually (homework)
    - then discuss with your task group (number group) (1/2 hour)
    - improve individually (1/2 hour)
    - submit to teacher
3. Interim report 2:
    - do individually (homework)
    - then discuss with your task group (number group) (1/2 hour)
    - improve individually (1/2 hour)
    - submit to teacher
4. Interim report 3:
    - do individually (homework)
    - then discuss with your task group (number group) (1/2 hour)
    - improve individually (1/2 hour)
    - submit to teacher
5. Presentation:
    - do individually (use the template)
    - self assess yourself using the checklist and rubric your teacher will use
    - present to your jigsaw group (letter group); get feedback
    - improve individually
    - submit to teacher by saving in ‘Grade 10’ ‘Mechanics’ ‘Submissions’ folder, as ‘**yourname** Pay presentation **daymonth**.doc’
6. Extension: choose the Car, Plunge, or Tesla task, and work on it while you wait for others to catch up.

K-W-L chart

Know (What do I already know that might be relevant to this situation?)	Wonder (What questions do I need answering to help me?)	Learn (What have I now learnt that might be relevant to this situation?)

Must he pay?: Interim report 1

A Work Individually

It is compulsory to fill in the grey areas.

1. Complete:

Variable	Symbol	Unit	Meaning	Relationship to other variables
position				
distance				
displacement				
a moment in time				
duration of time interval				
average speed				
average velocity				
Instantaneous velocity				
initial velocity				
final velocity				
change in velocity				
acceleration				

2. Complete:

Given	Related variable(s)	How to get variable(s) from given information
Photograph number		
Position of taxi relative to traffic light		
instantaneous velocity for a moment when a particular photograph was taken		

Related variable(s)	How to get variable(s) from given information
Change in position (i.e. displacement) of taxi between photograph numbers	
average velocity for an interval	
acceleration	

3. Describe the patterns you see in the data the judge was given.

B Discuss your answers in your task group (number group).

Must he pay?: Interim report 2

A Work Individually

1. Draw up a table which will help you to plot position-time and velocity-time graphs for this motion.

(modify this one if you like)

Photo no.	Position of taxi relative to traffic light (m)	Velocity (m/s)
1	0	0
2	2	8
3	8	16
4	18	24
5	32	32
6	50	40
7	72	48
8	98	56
9	126	56
10	154	56
11	182	56
12	210	56
13	235,5	46
14	256	36
15	271,5	26

2. Draw the following graphs

a) A position-time graph for the taxi’s motion

b) A velocity-time graph for the taxi’s motion

3. Describe each graph.

Divide the motion up into intervals and describe each. (e.g. ‘during the first ___ seconds, the taxi ___’, shown by the graph being ____, during the next ____ seconds, ___’:.

a)

b)

4. Explain how these graphs will help you answer the problem.

B Discuss your answers in your task group (number group).

Must he pay?: Interim report 3

A Work Individually

1. Draw a picture of the taxi's motion.
   Divide the motion into stages.
   Give relevant information about moments in time, time interval durations, average and instantaneous velocities.

2. Focus only on the last motion interval.
   List known variables.
   Choose the appropriate equation to find out if the taxi could have stopped in time.
   Substitute and solve.
   Check.

3. Must he pay?

Steps in building up a good answer	Response

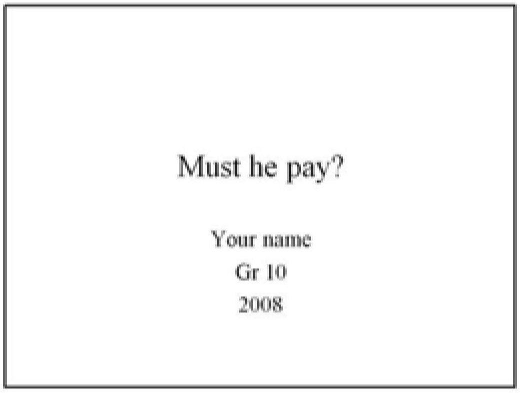
final answer:

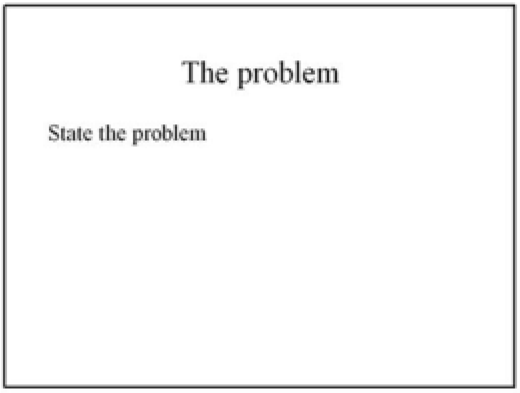
B Discuss your answers in your task group (number group).

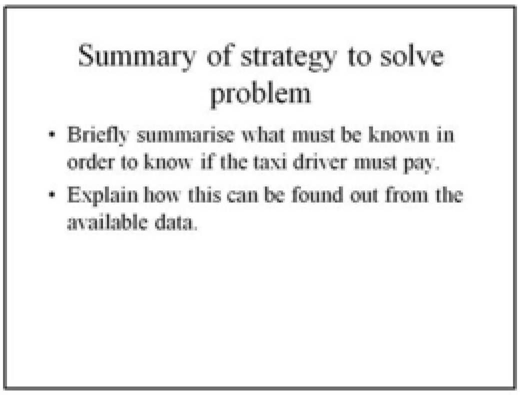
Must he pay?: Final Presentation Template

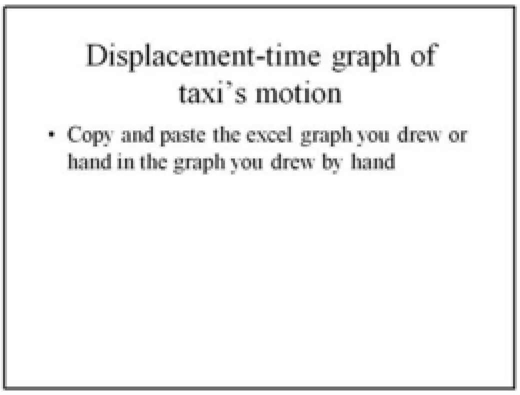
A Work Individually

Modify the following template to present your solution to the problem "Must he pay". You can either do this in PowerPoint, or by hand on paper.









Velocity-time graph of taxi's motion

- Copy and paste the excel graph you drew or hand in the graph you drew by hand

Graphs

- Explain how the graphs can be used to give an answer to the question.
- According to the graph, can the taxi stop in time?
- What limitation is there in using the graph to decide if he should pay?

Calculation

- Explain for which period of the motion the calculation you will use applies.
- Explain the significance of the calculation. (If the answer is ___ then I know ___)
- Explain the limitation of the calculation.

Calculation

- State the given values
- Give the relevant equation of motion
- Substitute and solve
- According to the calculation, can the taxi stop in time?
- What limitations are there to this information?

Judge Sort-It-Out's answer

Give the Judge's conclusion (Must he pay?).

Support the conclusion with claims and backing.

B Present your work to peers who did:

- the same task as you
- different tasks to you.

Improve your work.

Hand it in to your teacher for formal assessment.

Summative Assessment: Pay / Car / Plunge task

Total marks: 27

Learning Outcomes

LO1AS2: seek patterns and trends in the information collected and link it to existing scientific knowledge to help draw conclusions
LO1AS3: apply given steps in a problem-solving strategy to solve standard exercises
LO1AS4: communicate information and conclusions with clarity and precision
LO2AS3: apply scientific knowledge in familiar, simple contexts

Teacher assessment Rubric

The presentation:	completely	almost completely	partially to an acceptable, but not pleasing, level	unacceptably not
is complete	3	2	1	0
is scientifically accurate in its written explanations	6 5	4 3	2 1	0
is scientifically accurate in its graphical representations and calculations	6 5	4 3	2 1	0
is clear and precise (it isn't necessary to ask 'what do you mean?')	3	2	1	0
is concise (isn't unnecessarily wordy)	3	2	1	0
is logical and relevant (it isn't necessary to ask 'so?')	3	2	1	0
shows awareness of assumptions and is sensitive to context	3	2	1	0

Teacher comment:

Appendix L: Extracts from a PowerPoint presentation: gr 10 mechanics

How far

If both One-Way and Back-and-Forth move as shown:

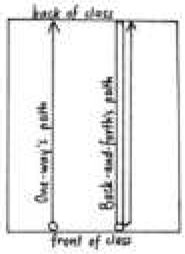
Compare how far they go:
Choose:
A: both same
B: One-way further
C: Back-and-forth further

How far

It depends what you mean by how far.

In a way they go equally far.
In a way, back and forth goes further.

Explain



Distance and displacement

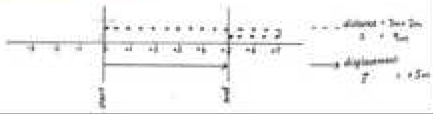
Distance is the length of the path travelled.
Displacement is the net change of position.

Both are measured in meters (m), or its derivatives (e.g. mm, cm, km).

The symbol for distance is $\bar{s}$, and for displacement *s*, or **s**, or s.

Distance and displacement

- Positions to the right of the principal's door are taken as positive, and those to the left as negative.
- Joyce starts at the principal's door, where her position is 0.
- She walks seven meters to the right. Her position is now +7m.
- She turns around and walks two meters to the left. Her position is now +5m.
- The distance she has covered is 7m+2m = 9m.
- Her displacement is +5m.



Distance and displacement

Joyce walks 3m in the positive direction, turns around, and walks 7m in the negative direction. What is

a) the distance she has covered?

b) her displacement?

Distance and displacement

Joyce walks along a straight line, staying on the positive side of her starting point. The distance she covers is 10m. Is it possible for her displacement to be (Yes or No)

A zero?
B between zero and 10m?
C 10m?
D more than 10m?

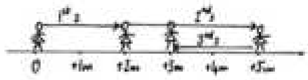
Distance and displacement

Displacement (change in position) is calculated as final (ending) position minus initial (starting) position.

The starting position need not be zero.

Joyce walks along one dimension for three seconds.

- At the start of the 1st s she is at position 0.
- At the end of the 1st s she is at +2m.
- At the end of the 2nd s, she is at +5m.
- At the end of the 3rd s, she is at +3m.



Her displacements during each of the three seconds are:

1st s: +2m (2–0) (as she moved 2m in the positive direction)
2nd s: +3m (5–2) (as she moved 3m in the positive direction)
3rd s: -2m (3–5) (as she moved 2m in the negative direction)

A car changes its position as follows:

- It starts at position 0.
- A second later is at position +10m.
- A second later it is at position -15m.
- A second later it is at position -5m.

Give the car's displacement for the:

a) 1st second
b) 2nd second
c) 3rd second

Displacement in one dimension

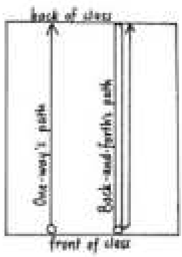
Displacement in one dimension is the direction (+ or –) and length of the line from start to end of motion.

A positive sign (+) is often omitted.

Distance and displacement

Compare One-Way and Back and Forth's:

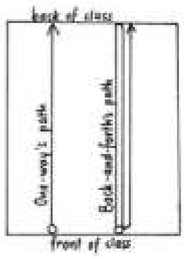
- Distance travelled
  - A: equal
  - B: back-and-forth more?
- Displacement undergone
  - A: equal
  - B: back-and-forth more?



Distance and displacement

Compare One-Way and Back and Forth's:

- Distance travelled
  - A: equal
  - B: back-and-forth more?
- Displacement undergone
  - A: equal
  - B: back-and-forth more?

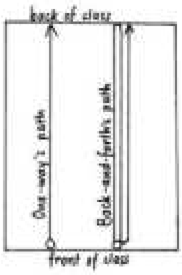


How fast?

One-way and Back-and-forth take the same time for this motion.

Compare how fast they travel.

Choose:
A both same
B Back-and-forth faster

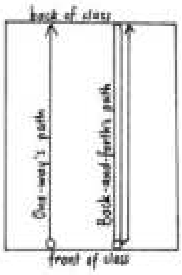


How fast?

One-way and Back-and-forth take the same time for this motion.

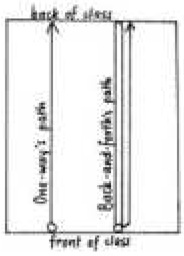
Depending on what we mean by how fast, we could say this is:
- both the same
- Back-and-forth faster

Explain:
- In words
- With two formulae for 'how fast'



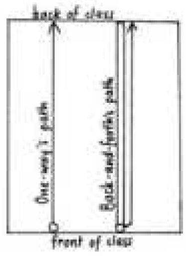
Speed and velocity

If they take the same time for their motions:
Compare One-Way and Back and Forth's:
- Speed (distance/time)
  A: equal
  B: back-and-forth more?
- Velocity (velocity)
  A: equal
  B: back-and-forth more?



Speed and velocity

If they take the same time for their motions:
Compare One-Way and Back and Forth's:
- Speed (distance/time)
  A: equal
  B: back-and-forth more?
- Velocity (velocity)
  A: equal
  B: back-and-forth more?



Speed and velocity

Speed is the rate at which distance is covered.

Velocity is the rate at which displacement is undergone.

Both speed and velocity can be measured in meters per second (m/s, i.e. $m.s^{-1}$), or its derivatives (e.g. km/h).

The symbol for speed is v, and for velocity $\vec{v}$ or $\boldsymbol{v}$ or $\mathbf{v}$.

Average speed and velocity

The average speed for a period of time is calculated as: distance travelled / time passed

The average velocity for a period of time is calculated as: displacement undergone / time passed

The symbol for average speed is $\bar{v}$, and for average velocity $\bar{\vec{v}}$ or $\bar{\boldsymbol{v}}$ or $\bar{\mathbf{v}}$.