Dimensions of meta-"Conceptual Change Learning" in science education: The role of metacognition in the durability and contextual use of primary pupils’ conceptions

by

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ABSTRACT

The problems of pupils exhibiting limited ability to use school-learned science in contexts other than the ones in which learning takes place, and of pupils forgetting what they learn in very short time after initial instruction, are two very important problems for classroom practitioners. This thesis is a study of the way these problems can be confronted by incorporating situated metacognition in the learning environment of science. It draws upon four overlapping areas: conceptual change learning (CCL) is the broad subject area that sets the epistemological background, and metacognition, context, and durability of pupils' conceptions are the three specialised fields under scrutiny.

Two important notions emerge from this study. First, is the introduction of the concept-life and decay model (CLD), which is a theoretical model for representing the nature of CCL and the impact of time on pupils' conceptions. Second, situated metacognition is advocated as a new approach to practising metacognition by means of the metacognitive instances approach, implemented at selected points of the teaching sequence.

The research presented in this thesis was implemented with Year 5 pupils in primary schools in Cyprus, studying the subject-unit 'Current electricity', and followed a quasi-experimental design. Data were collected by means of tests, interviews and classroom observation, during the main four-week intervention period of this research and at three follow-up instances, one week, two months and eight months after completion of teaching.

Results showed that pupils who practised situated metacognition in general maintained deeper understanding of taught concepts over a period of one school year, compared to their counterparts from the comparative group, and performed better in exercises requiring the use of their conceptions in different contexts. A number of implications for science education, in general, and the teaching of electricity in primary science, in particular, emerge from the outcomes of this study.
Dimensions of meta-'Conceptual Change Learning' in science education: The role of metacognition in the durability and contextual use of primary pupils' conceptions

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This thesis is dedicated to my parents

George and Irene
INTRODUCTION

Were all instructors to realize that the quality of mental process, not the production of correct answers, is the measure of educative growth something hardly less than revolution in teaching would be worked (Dewey, 1916).

Nearly nine decades since John Dewey's wishful remark and following a plethora of educational policy and curriculum reforms world-wide, the fact is that such a revolution never happened, and in spite of recent attempts for a shift towards the teaching of learning skills and processes, the production of correct answers maintains a central position in contemporary schooling. Interestingly, and contrary to the expectations such attention to subject knowledge would reasonably justify, school-obtained knowledge is often short-lived and rarely, if at all, utilised in contexts other than the one in which learning takes place.

This thesis addresses the problems of pupils forgetting what they appear to learn in very short time after initial instruction, and of pupils exhibiting limited ability to use their knowledge in different contexts. Both problems that triggered the writing of this thesis emerged from this writer's experience as a primary school teacher, considering these to be of high practical significance for science education. This is a view that enjoys ample support in the literature (e.g. DES, 1985; Fensham, Gunstone and White, 1994). The fact that classroom practitioners admit to these problems and appear to be conscious of the inefficiency of their methods (Mitchell, 1986a) suggests that these are more than a theoretical concern or an object for pure academic elaboration.

Research outcomes support that most information learned in schools is lost within a matter of a few weeks (Hagerman, 1966), the explanation behind this being that it is a consequence of rote rather than meaningful learning (Novak, 1998). This is a problem of high significance, not only because of the loss of pieces of knowledge as such but, most importantly, because of the progressive character of knowledge construction through schooling. By gradually progressing from simple, easy to comprehend ideas to more advanced, complex or sophisticated ones, the pre-existence of valid and well founded concepts (or knowledge in its broader sense) at each point is a prerequisite for further advancement and enrichment of one's knowledge. Seen in relation to the long-term nature of contemporary education comprising a number of years of schooling, and the gradual mastering of knowledge, an indirect, yet important, consequence of this is that inadequate or partial learning early in a
person’s school-life can have a negative impact at a much later stage. The emerging implication is that any attempt to treat this problem should commence in the early years of schooling, a position that is fully adopted by this thesis that targets primary school populations.

The second area of interest to this thesis relates to the discovery that successful students accumulate a great deal of passive knowledge but often very little ‘knowledge for practical action’ (Layton, 1992; Fensham, Gunstone and White, 1994). In other words, students appear unable to use their knowledge successfully under different circumstances, usually exhibiting abilities restricted to memorising and reciting information.

The view of schooling as a specialised practice with its own conventions, organisation and concerns, which are of little value to society (Hennessy, 1993), in essence questions how useful school-generated knowledge is, if such knowledge cannot be utilised in out-of-school contexts. Evidence of such inability comes from the Assessment of Performance Unit (APU) in the U.K., which reported that pupils’ performance was low when they were asked to apply concepts in contexts other than the ones in which the concepts were taught (DES, 1985). One explanation to this problem is that this could be attributed to

...either a form of barrier when there is a shift of context or a selective access of their acquired knowledge (Toh and Woolnough, 1994, p.32).

Consequently, voices advocating greater consideration of science content in relation to practical action (Fensham, Gunstone and White, 1994) are now growing in the literature.

This thesis regards that ‘knowledge for practical’ action deserves a central position in the teaching of science, sharing the view that

...a training program should provide a learned representation that permits the learner to recognize when the knowledge and skills acquired during training are and are not applicable to new problems (Bjork, 1996, p.186).

The choice to place emphasis on the importance of learners’ ability to use knowledge across different contexts is further supported by the view expressed by Gestalt psychologists that the difference between senseless and meaningful learning lies in the learner’s ability to transfer knowledge. They claimed that although little or no transfer would take place with senseless learning, meaningful learning would show considerable transfer, resulting in putting to use one’s constructed understanding (Singley and Anderson, 1989). It can therefore be concluded that failure to put one’s knowledge to use, in essence questions the depth and quality of constructed knowledge, something that raises further questions with regards to the efficacy
and success of one's education.

The two problems discussed by this thesis add to the long list of problems identified within systems of formal education world-wide, and contribute to the fierce critique made of schools, teachers and curricula developers alike. Intensifying the problem is the fact that both the processes and the outcomes of education are open to public scrutiny, the general feeling being that education should become more meaningful and more useful to the citizens of tomorrow (AAAS, 1995). In the eye of the storm lies the discovery that

...schools are not as effective as had been thought in their long-accepted task of disseminating knowledge. While facts have been taught and drilled, understanding is often inadequate (White, 1986a, p.3).

Science education offers no exception to this critique. Quite the contrary, it is no overstatement that these problems apply to a greater extent in science education, because its object of study is always considered complex and hard to comprehend fully, in addition to being 'remote' and 'authoritative' (Driver et al., 1994b).

Against this backcloth, the starting point for research and development in science education for the past two decades was an unprecedented interest in children's own understanding of science. The idea behind this was that pupils' poor understanding of science could be attributed to the existence of incorrect explanatory frameworks held by children prior to instruction that, in the eyes of the children, served to explain scientific phenomena, but at the same time inhibited the learning of the scientific version of the explanation (Driver and Easley, 1978; Strike et al., 1982; Gilbert and Watts, 1983; Driver et al., 1994b). Consequently, the predominant feature of research agendas since the late 1970s was a plethora of attempts to identify and make explicit children's 'alternative frameworks' (Driver and Easley, 1978) and, to a lesser degree, the construction of theoretical models for the teaching of science (Strike and Posner, 1985) that took children's ideas as their starting points.

The central role acknowledged for children's ideas in the learning process and the flourish of constructivism as a philosophical framework advocating the active and personal construction of knowledge by learners (Solomon, 1994; Osborne, 1996), set the foundations for the rise of conceptual change learning (CCL) (Gilbert and Watts, 1983; Strike and Posner, 1985; Driver, 1989; Georgiades, 2000). The main idea behind CCL is that learning in science can be achieved by the gradual change brought about in learners' existing conceptions for explaining scientific phenomena. In order to do so, teachers have to initiate their teaching by
finding out children’s own ideas or alternative explanatory frameworks and then address these ideas in order to change them towards orthodox science.

CCL proved to be the monopolising trend in science education, enjoying such attention that one might reasonably expect it to have acted in the form of a panacea on the problems associated with the learning of science. Things, however, did not turn out exactly like that. The literature has recently come to admit that CCL failed to bring about significant improvement in children’s learning of science, being generally unsuccessful in establishing understanding and effective learning even in the range of ‘good’ learners. Research outcomes suggest that even knowledge successfully constructed through the process of conceptual change has proved in many cases to be neither durable, nor useable (DES, 1985; Duit, 1989). The main achievement of the CCL movement was to offer detailed reports and analyses on children’s understanding of numerous scientific concepts and their attempts to employ their own explanatory theories or frameworks. Important areas were left unaddressed and the problems associated with them unresolved. As Alsop (1998) recently discussed:

Throughout the last twenty years science educators have paid an ever increasing attention to the informal ideas which pupils bring into the classroom, the ‘outside-in’ (...) the ‘inside-out’, has escaped due consideration (p.377).

Although Alsop (1998) focused primarily on the public understanding of science, seen in relation to learners’ ability to utilise constructed knowledge, his statement applies perfectly to the context of this thesis, for too little attention was paid to the way the ‘output’ is used, if at all. The need, therefore, for reconsidering the CCL working framework towards enhancing pupils’ ability to successfully use constructed conceptions in different settings and increasing the durability of such knowledge is, in the eyes of this writer, evident.

Although CCL remains the stepping-stone for this study, a slightly different story will be told. The claim put forward is not that the contribution made from the outcomes of this research could bring the CCL story to an end. Rather it reflects an attempt to offer a different perspective of viewing the same landscape and possibly help to extend its horizon. The focus of this thesis has much in common with the views expressed by Jamieson (1976) 25 years ago regarding retention and transfer of students’ learning:

The importance of retention of learning is self-evident, and one of the central objectives of teaching is that students will be able ‘to go beyond the information given’, that is, they will transfer their learning to new situations without any further instruction (p.164).

Jamieson (1976) examined the effect that different methods of learning have on the decline in retention of newly learned concepts, and in promoting transfer of learning, with adults of 24-
71 years old. The difference in focus in the case of the present study lies in the participants’ age, which is approximately 11 years old and the fact that metacognitive instruction is incorporated as the experimental ‘different method of learning’.

Metacognition is a notion that has also enjoyed increased attention over recent years since its inception by John Flavell in the early 1970s. It is generally acknowledged within the literature to mean ‘thinking about one’s own thinking’ (Adey and Shayer, 1994) or as referring to ‘cognitions about cognitions’ (Meichenbaum et al., 1985). Although first employed in areas other than science education (Flavell, 1976; Brown, 1987; Weinert and Kluwe, 1987; Nelson, 1992), interest in its potentials resulted in a number of studies focusing on different dimensions of the teaching and learning of science, usually originating from the Australian camp at the Monash University (e.g. White and Gunstone, 1989; Fensham, Gunstone and White, 1994; Gunstone and Northfield, 1994). Albeit placed within the broader CCL framework most of these studies examined metacognition as a general cognitive skill and not as an integrated element of the CCL process. By pointing this out, this thesis is not suggesting that programmes aiming towards improving general cognitive or thinking skills (e.g. Baird and Mitchell, 1986; Adey, Shayer and Yates, 1989a,b; Fisher, 1995) are not important or viable; quite the contrary, as the discussion in the following chapters will show, it acknowledges important links and overlapping areas with such studies. What this thesis anticipates to do, however, is to bring the two areas of metacognition and CCL together in a more focused way, namely propose metacognition as the step forward for solving the two problems associated with CCL by attempting an indirect impact on understanding of content rather than on practising process.

Rapidly growing literature in metacognition highlights direct links between metacognition and the two problems described, and advocates the potentials of a positive impact of metacognition in treating the latter (Metcalfe and Shimamura, 1996; Hacker, Dunlosky and Graesser, 1998). It has been suggested, for instance, that the gap between what learners can do in terms of the skills, strategies and knowledge they acquire and what they actually do under normal learning conditions can be narrowed by increased ‘mindfulness’, hence treating poor learning and difficulties to effect transfer (Salomon and Globerson, 1987). Others, on the other hand, attempt more indirect connections. For example, metacognition is perceived by a number of scholars as a process acting in the direction of better organisation of input knowledge which is in turn regarded as a factor determining longer retention of learned material (Baddeley, 1990; Groome et al., 1999). In a similar vein, Shaddock and Carroll (1997) suggested that:
If... a relationship exists between metacognitive monitoring and later recall, then by improving students’ ability to monitor their learning more accurately (...) it should be possible to enhance students’ actual performance (p.21).

Part of the objectives of this thesis is to investigate the existence of such a relationship. The important role metacognition can play is further reflected in the words of Blagg, Ballinger and Gardner (1988) who refer specifically to problem solving:

*The ultimate aim of problem-solving work is to prepare children to handle unfamiliar problems and learning tasks independently. In order to do this they need to be able to transfer and generalise skills, strategies and procedures learnt in particular situations to new contexts. Again the key to this area seems to be metacognition...* (p.15).

They emphasise the significance of practising such skills by pointing out that in a rapidly-changing technological world, when it is difficult to predict what knowledge will be useful for the future, developing one’s self-knowledge and the ability to ‘learn to learn’ is more important than ever before (Blagg, Ballinger and Gardner, 1998).

Metacognition completes the presentation of the three main areas covered by this thesis, the other two being durability of conceptions and ability to utilise conceptions across different contexts. The way these areas are addressed is reflected in the two core research questions of this thesis formulated as follows:

1) **Does metacognitive instruction have a positive impact in prolonging durability of pupils’ newly-constructed conceptions of scientific phenomena?**
2) **Does metacognitive instruction have a positive impact on pupils’ ability to use their conceptions of scientific phenomena across different contexts?**

A breakdown of the research objectives of this study can be found in Appendix I.

In trying to reach sufficient answers to the above research questions and bring its objectives to life, this thesis demonstrates an explicitly *practical orientation*, strongly disagreeing with approaches established by early philosophers such as Aristotle. According to Scribner (1984):

*Aristotle (1963) considered theoretical thinking characteristic of philosophers and those who pursue the why of things; practical thinking is characteristic of artisans and others whose social task is to get things done. He believed theoretical thought to be the superior of the two, the fount of wisdom and the true object of metaphysics. Practical thinking simply fell out of his sphere of interest* (Scribner, 1984, p.9).

This thesis does not share the Aristotelian divide of the two doings. Practical thinking does not fall out of its sphere of interest, rather it advocates and applies the blend of theoretical reasoning with thinking that leads to *purposeful* and *feasible* practical action. The view that
'The application of philosophical ideas to social research must not lose touch with the practices and aims of social researchers' (Bryman, 1988, p.174) is all too compatible with the rationale underpinning this thesis. Without depreciating the significance of portraying a solid philosophical framework, this writer argues very strongly for a grounded and realistic approach. Consequently the research presented by this thesis is placed in everyday school settings with ordinary pupils undergoing processes that can be replicated by the average teacher. In other words, every effort was made to maintain normal classroom conditions in order to avoid artificiality in the design -hence the outcomes- of this study, and to establish 'ecological validity' (Neisser, 1976) for the endeavour.

At the same time, this writer considers very seriously Novak’s (1998) critique of the lack of theoretical or philosophical depth characterising much of educational research.

Most research in education, Novak (1998) says, is method driven rather than theory driven. That is, researchers have often compared two or more methods of instruction, usually with little or no theoretical justification for the design of the instruction, or they have used a variety of tests or scales as methods for assessing achievement, often with little or no theory behind the choice of these instruments (p.16).

Consciously attempting to avoid such a pitfall, a substantial part of this thesis is dedicated to extensive theoretical elaboration that moves beyond the discussion of existing literature to making this writer’s views, preferences and assumptions explicit. In addition to the theoretical founding of the ideas expressed by this writer, equal attention is paid to demonstrating sufficient research awareness with regards to the methodology followed, and presenting a philosophical framework to analysis of data, congruent to the theoretical claims of this thesis. The research presented by this thesis, therefore, claims a ‘theory driven status’ in the sense used by Novak (1998). The theory prevailing throughout this thesis sums up to the belief that metacognitive instruction enhances deeper understanding of concepts of science, resulting in longer durability of pupils’ constructed conceptions and increased ability to use these across different contexts.

Before concluding the introduction to this thesis, a word on the writing (and teaching) style of this writer is needed. In order to deal with the problem of addressing mostly abstract concepts in the theoretical chapters of this thesis (and in teaching electricity to the pupils participating in this research), this researcher makes extensive use of analogies. This choice is based on his belief that analogies can be a valuable tool for representing or teaching abstract concepts in a way that makes them more accessible to the reader (or learner, respectively). Analogies have been widely used both in educational studies and applied classroom teaching, mainly as a means of portraying complex or multidimensional, hence
hard to conceive concepts or phenomena. A resembling event or arrangement that is already known to the learner - or one that might be easier to comprehend, if new - is used as an example from which parallels are drawn, either at a descriptive or an operational level. The important role analogies can play in teaching is reflected in the fact that teachers' knowledge of analogies is regarded by some as an essential element of pedagogical content knowledge (Shulman, 1986). Science as a subject area with a plethora of complex phenomena has provided fertile ground for the use of numerous analogies as an additional teaching tool (e.g. Stocklmayer and Treagust, 1994; Georghiades, 1999b) and relevant research is constantly emerging in the field (Duit, 1991; Lawson, 1993). In employing analogies in his work, this researcher acknowledges that these bear a number of limitations since detailed elaboration on the connections between the original phenomenon and the analogy is bound to reveal some conflicting points. This writer, therefore, believes that use of analogies should be accompanied by a selective philosophy, enabling one to focus only on those dimensions that serve sufficiently the purposes of the analogy.

This completes the introductory background against which the chapters that follow will move. In conclusion, and prior to embarking on reading the main body of this thesis, the reader is urged to consider the rationale underpinning its writing, best expressed through the words of Richard T. White used elsewhere:

Although the insights expressed in the chapters that follow may be biased and can be wrong, there is nothing artificial about them. They apply to the real world (in this case, the science classroom), and need to be taken seriously (White, 1986, p.7).
Outline of the thesis

Chapter 1 sets the broad framework to this thesis addressing constructivism and conceptual change learning (CCL). It discusses the constructivist philosophy as the underpinning ideology to this study and presents a review of CCL literature extending mainly over the past two decades, highlighting both areas that were extensively covered and areas that were largely under-studied. The first chapter concludes with the introduction of the model of Concept-Life and Decay (CLD) that describes the constructing and decaying process in which conceptions are engaged. Chapter 2 discusses the notion of durability of pupils’ conceptions of science, looking at its nature from a number of different perspectives. It argues for the operational importance of durability within a CCL framework, reviews previous studies in the field that include a time dimension, and makes explicit how the notion of durability is treated by this writer. The third chapter takes on pupils’ ability to use constructed knowledge across different contexts. It discusses the role of context in the learning process; presents the debate over the feasibility of transfer of knowledge; and specifies the way context is used within this research in an attempt to differentiate its focus from similar studies in the field. Chapter 4 is the chapter that addresses the notion of metacognition. A brief historical review of the term is offered, followed by a list of definitions and a review of related studies along with the underlying assumptions of this thesis over the nature of metacognition. A section on situated cognition is included in order to draw links with situated metacognition and the metacognitive instances approach, which is the main proposal put forward by this thesis for dealing with the two problems under study. Chapter 5 is the methodology chapter. It discusses the theoretical and philosophical background to the conduct of this research, placing particular emphasis on the importance of demonstrating research awareness throughout the enquiry. This is followed by detailed description of the research design and the way this was implemented. Methods of enquiry and collection of data are discussed and methodological checks and other practical concerns are placed under scrutiny. The sixth chapter attends to the description and analysis of the results of this study, moving in two main directions: one between quantitative and qualitative data, and one between results from pupils of comparative classes and those from experimental classes. Comparative reference to the outcomes with respect to class size is also included at selected points. This is followed by the discussion of the results in Chapter 7. The outcomes of this study are contrasted with the initial claims and theoretical argumentation of this thesis, conclusions are reached and links are drawn between the research outcomes and related literature. Chapter 8 lists implications for classroom practice deriving from the outcomes of this study, looking at both science
education, in general, and the teaching of electricity in primary science, in particular. This thesis concludes with a number of recommendations for further research, in the directions of the core areas of CCL, durability, context and metacognition.

Following is a graphic summary of the thesis that should give the reader a first taste of the areas addressed in the following chapters. Similar figures are included at the end of each chapter throughout the thesis.
Figure 0.1. Graphic summary of the thesis
CHAPTER 1 - CONCEPTUAL CHANGE LEARNING - Broad Subject Area

1.1. Introduction to Chapter 1

1.2. Constructivism – The underpinning philosophy
   1.2.1. History of constructivism
   1.2.2. The content and nature of constructivism
   1.2.3. Constructivist teaching - Practical issues of constructivism
   1.2.4. Critique of constructivism
       1.2.4.1. The divide between constructivist theory and practice

1.3. Conceptual Change Learning – The working framework
   1.3.1. The content and nature of CCL
       1.3.1.1. Some definitions
       What is a ‘concept’? Concepts versus conceptions
       ‘Misconceptions’, ‘alternative frameworks’ or ‘children’s science’?
       What is ‘change’?
       What constitutes learning? The notion of understanding
   1.3.2. Models of CCL
   1.3.3. The process of CCL – Practical issues
       1.3.3.1. Problems with CCL
       1.3.3.2. Cognitive conflict - The ‘how’ of the research

1.4. CCL research and the focus of this thesis
   1.4.1. Contemporary CCL research and under-explored areas
   1.4.2. Focus of this thesis

1.5. Model of Concept-Life and Decay (CLD)
   1.5.1. Drawing parallels in the analogy between radioactivity and human learning.
   1.5.2. Key-elements of the CLD model
   1.5.3. Points of conflict
   1.5.4. Conclusion to the model

1.6. Research on children’s ideas of electricity

1.7. Summary
1.1. Introduction to Chapter 1

If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly (Ausubel, 1968, p.iv)

This first chapter sets the broad theoretical framework to this thesis by looking at important aspects of conceptual change learning (CCL). Following a brief presentation of constructivism as the underpinning philosophy to CCL is the discussion of the nature and the processes of CCL. This chapter briefly describes the main stands in the literature on terms and issues that are not clearly defined and offers its own definitions. This is followed by a review of CCL-oriented research in the field of science education in order to highlight the differentiated focus of this thesis and also to justify the necessity and significance of the present research. The model of concept-life and decay (CLD) is then presented offering a new outlook of the processes involved in CCL. The chapter concludes with a brief review of research on children’s ideas of electricity, which is the science topic in which this research is accommodated.

1.2. Constructivism – The underpinning philosophy

1.2.1. History of constructivism

Constructivism has been a growing trend in science education for the past twenty-five years coming as a response to approaches and philosophies that shared a transmissive view of learning drawing from behaviouristic traditions, and a reaction against an epistemology of naïve empiricism (Harris and Taylor, 1983). Reaction to these traditions was triggered when Driver and Easley (1978) in a seminal paper put forward the claim that achievement in school science depends more on students’ specific abilities and prior experience rather than on general levels of cognitive functioning. Ever since constructivism responded to the outcomes of research that was based on traditional philosophies in a twofold manner (Osborne, 1996) by initiating an attack at the notion that children are atheoretical (Carey, 1985) and the view of teaching as a process of ‘filling empty minds’ (Hewson, 1981; Driver, 1989).

Albeit in a flourishing state in science education from the late 1970s onwards, the principles advocated by constructivism are not a product of this period. Quite the opposite, it can be claimed that seeds of the constructivist philosophy can be traced back to some Greek
philosophers, like Socrates, for a distinctive feature of their work was that construction of meaning was left with their audience. In more recent times the ideas of constructivism pre-existed mostly in the work of Jean Piaget, George Kelly, Lev Vygotsky, Jerome Bruner and David Ausubel, yet they were accommodated within a considerably different vocabulary to the one used by Driver and Easley (1978) in launching constructivism in the form that it is known today in science education (Solomon, 1994).

Growth of interest in constructivism within the broader field of educational studies has been intense, attempting to offer a moderate alternative to the philosophies available by the early 1970s, which were often diametrically different. In this respect Osborne (1996) believes that

*Constructivism has been invaluable in attempting to untie the Gordian knot between objectivism and didacticism...* (p.77).

Matthews (1994), on the other hand, regards constructivism as an attempt to

*...steer a path between teacher-dominated instruction, the traditional didactic model of education, and student-led discovery learning, the progressive model of education* (p.146).

Science education was probably the area of the most widespread application of the theory with arguments in favour of constructivism coming from mainly two directions, namely the history and philosophy of science and the psychology of learning. As a result, the teaching and learning of science experienced such a profound influence from psychological constructivism that research in science education and curriculum reforms currently appear to operate exclusively within a psychological constructivist paradigm (Alsop, 1998). Fensham (1991) regards the constructivist view of learning as 'The most conspicuous psychological influence on curriculum thinking in science since 1980...' (p.801). Osborne (1996) refers to ‘dominance’ and ‘hegemony’ of constructivism as a school of thought; Tobin *et al.* (1994) consider it as a new paradigm for science education; and Lyotard (1984) refers to its implicit status of ‘grand theory’. Notably Tobin and Tippins (1993) suggest that viewing constructivism as a method instead of a more general referent that offers a wide-ranging theory of learning is a devaluation of its power. As a result of the tremendous interest in constructivism to speak of thousands of publications with a constructivist-oriented content is no overstatement (Carmichael *et al.*, 1990; Pfundt and Duit, 1991; Duit, 1993).

1.2.2. The content and nature of constructivism

Constructivism mainly affirms two principles: a) knowledge is constructed by learners rather than transmitted by teachers; and b) knowledge is constructed on students’ pre-existing
knowledge. According to Driver et al. (1995) the key feature of a constructivist epistemology is the learners' construction of mental models of their world and the interpretation of new experiences in relation to their existing mental models and schemes. The constructivist framework portrays an active human learner who comes to know the world by transforming and actively adapting to the constraints imposed on him (Bidell and Fischer, 1992).

Contrary to the views advocated by objectivists and modernists, constructivism affirms that constructions do not exist outside of the person who creates them. It further rejects the view that constructions are part of an 'objective' world that exists apart from one's constructions (Guba and Lincoln, 1989) or independently from human mental activity and human symbolic language (Bruner, 1990). Consequently Tobin et al. (1994) regard constructivism as

...a set of beliefs about knowledge that begins with the assumption that reality exists but cannot be known as a set of truths (p.47).

Schwandt (1998) discusses that constructivists are deeply committed to the view that knowledge is the result of perspective, for knowledge and truth are created by individuals rather than discovered by mind. He points out that constructivists believe in the pluralistic character of reality that can be expressed by means of different symbol and language systems. This is in addition to its plastic character in the sense that '...reality is stretched and shaped to fit purposeful acts of intentional human agents' (Schwandt, 1998, p.236).

A review of existing literature clearly reveals that constructivism is indeed a heterogenous movement (Matthews, 1994). The list of its ‘varieties’ includes ‘contextual’, ‘dialectical’, ‘empirical’, ‘information-processing’, ‘methodological’, ‘moderate’, ‘Piagetian’, ‘postepistemological’, ‘pragmatic’, ‘radical’, ‘realist’, ‘social’ and ‘sociohistorical constructivism’ (Good, Wandersee and St Julien, 1993), allowing one to assume with certainty that the list is not exhaustive. In order to give a flavour of the difference in essence between such ‘varieties’ of the constructivist philosophy, it is worth briefly presenting the most commonly acknowledged divide within the constructivism paradigm, the one between psychological and sociological constructivism.

Psychological constructivism stems from the work of scholars such as Jean Piaget (1929) and George Kelly (1955) that viewed learning as a process of personal, intellectual construction of meaning through activity in the surrounding world. Apart from this more personal tradition psychological constructivism also includes the psycho-social constructive tradition which is grounded in Vygotsky’s social constructivism (Vygotsky, 1978; Lave, 1988) that highlights the role of the social world and social interactions, along with the importance of language
communities for the cognitive constructions of learners (Duckworth, 1987; Lave, 1988). 

Sociological constructivism, on the other hand, originates with Emile Durkheim and primarily investigates the construction of knowledge in a social context. According to Matthews (1994) sociological constructivism ‘... maintains that scientific knowledge is socially constructed and vindicated, and it investigates the circumstances and dynamics of science’s construction’ (p.138). Contrary to the Piagetian and Vygotskian traditions sociological constructivism ignores the individual psychological mechanisms of belief construction, focusing upon the extraindividual social circumstances that presumably determine the beliefs of individuals (Matthews, 1994).

Without depreciating the importance of reaching sufficient answers to questions regarding the ‘validity’ of each of the two, or other traditions, this thesis regards the divide between them as more of a philosophical nature that does not conform to the practice-oriented rationale previously declared. It will therefore not elaborate on these fragmented subdivisions of constructivism, not only because such an endeavour lies beyond its scope, but also because the belief that science as a learning activity is a blend of personal experience, language and socialisation (Driver et al., 1994a) sets the necessity of such a divide at question.

1.2.3. Constructivist teaching - Practical issues of constructivism

Making the transition from theory to practice and looking at constructivist teaching there are numerous teaching methods that share a similar constructivist philosophy. Driver and Oldham (1986), for example, suggested the following stages:

1. Orientation – Students are offered some motivation and helped to develop some sense of purpose for learning the topic.
2. Elicitation – Students make their existing ideas on the topic explicit.
3. Restructuring of ideas – Ideas are being clarified and exchanged; new ideas are being constructed; the new ideas are being evaluated either by means of experimental work or by considering their implications.
4. Application of ideas – Students are called to use their newly developed ideas in different contexts.
5. Review – Students are asked to revisit the learning process and reflect on how their thinking at the end of the lesson has changed compared to their thinking at the beginning of the lesson.
The active role of the learner as reflected in the teaching sequence just described clearly marks a shift away from traditional teacher-centred approaches. However, as a number of scholars point out, although the contrast between constructivism and extreme forms of didacticism is explicit, the contrast with discovery learning is not clearly established (Matthews, 1994). In making such a contrast Harlen (1998) points out that children already have formed ideas which they bring into new science investigations influencing both what they do and what sense they make out of what they find. Their learning therefore is not a discovery of some new ideas, rather the development of the ideas they bring and are constructing for themselves. Schwandt (1998), on the other hand, argues that:

_In a fairly unremarkable sense, we are all constructivists if we believe that the mind is active in the construction of knowledge. Most of us would agree that knowing is not passive - a simple imprinting of sense data on the mind - but active; mind does something with these impressions, at the very least forms abstractions or concepts. In this sense, constructivism means that human beings do not find or discover knowledge so much as construct or make it. We invent concepts, models and schemes to make sense of experience and, further, we continually test and modify these constructions in the light of new experience_ (Schwandt, 1998, p.237).

The active role of the learner, therefore, entails more than ‘finding out’ something that was out there waiting to be discovered, hence largely differentiating itself from the stands of discovery learning.

Moving beyond constructivism’s heterogeneity with relation to the influence it received from different schools of thought, an equally heterogenous feature of constructivist teaching is the one of multiple potential learning outcomes. This is a characteristic that results from the personal nature of constructivist learning which maintains that each learner bases understanding on different ‘starting points’ and constructs meaning at different rates by means of different techniques. The reaching, therefore, of different ‘ends’ or levels by different learners of what is perceived as sufficient understanding, should come as no surprise since it is an outcome that is in line with the broader constructivist philosophy. Clearly, sharing such a view Gilbert et al. (1982) listed the following possible outcomes from constructivism-based teaching:

- a) Unified scientific outcome (learned meanings closely matching the ones intended)
- b) Two perspectives outcome (children’s pre-existing conceptions co-exists with newly learned material)
- c) Children’s ideas undisturbed by ‘teaching’ (teaching of new ideas having no impact on existing conceptions)
- d) Reinforced outcome (taught material misunderstood by the children as supporting their own existing conceptions)
e) Partial learning (only so much material could be learned at one time so that ideas would not be fully integrated in cognitive structure and could be contradictory).

This list by Gilbert et al. (1982) is of course only indicative and serves in offering a more spherical presentation of practical issues of the constructivist philosophy. The discussion on potential learning outcomes is taken further on in a proceeding section (1.3.1) where the nature of constructivist conceptual change learning is treated in more detail. Before doing so, though, the discussion needs to change direction as the attempted presentation of constructivism would have been severely flawed if only the bright side of the philosophy was captured.

1.2.4. Critique of constructivism

The two preceding sections that addressed the content and nature of constructivism and related practical issues, consist of only a very condensed summary of prevailing notions within the vast constructivist literature, a compromise that is inevitable in cases of extensively studied and researched areas. Not surprisingly, the extensive constructivist literature does not necessarily denote that all is well with constructivism. Quite the contrary, signs are evident that expectations accrued to constructivism were indeed overblown (Solomon, 1994).

Just like any other grand theory that has enjoyed massive support, constructivism is not short of criticism (e.g. Millar, 1989; Matthews, 1994; Solomon, 1994; Osborne, 1996) on a number of different grounds varying from the philosophical to the practical, the general feeling being that initial euphoria for constructivism has worn off (Jofili et al., 1999).

In a balanced critique to constructivism Osborne (1996) notes that

_The failure of constructivism to recognise its own limitations has led to it enjoying a hegemony in the research community which is undeserved_ (p.53).

He acknowledges constructivism’s success in its critique of didacticism and he agrees with Solomon (1994) that constructivism has generated alternative learning strategies that have made an important contribution to our understanding of both the learner and the learning process. He further regards the huge body of data generated by research in this field as seminal in improving teachers’ knowledge and understanding of their pupils’ scientific thinking, yet, he does not hesitate to state that constructivism

...suffers from flaws which will always restrict its potential and any claims to universality (p.54).
Osborne (1996) criticises the fact that constructivism has focused very strongly on the resilience of the learner's beliefs and the social construction of reality, something that resulted in leaving other important features out of focus. He regards that this has lead to serious epistemological flaws in the theory about the way in which new knowledge is made. He further asserts that

... to the extent that the personal and social has been given priority over the obdurateness of the natural world, it is contended that it fails to distinguish between real and theoretical entities. The result is an instrumentalist epistemology and a misrepresentation of the nature of science through an overemphasis of the construction of the concepts, either personally or through discourse, and a failure to elaborate any methodology of theory adjudication (Osborne, 1996, p.54).

Lastly, Osborne (1996) suggests that a fallacious connection is often made by constructivist pedagogy between the way new scientific knowledge is created and the way existing scientific knowledge is learned.

Matthews (1994), being by far more sceptical with regard to the claims of the constructivist philosophy, has strongly criticised the post-positivist epistemology of psychological constructivism claiming that

Constructivism amounts to a restatement of standard empiricist theory of science, and suffers all the well-known faults of that theory (p.161).

VonGiaserfield’s (1984) radical constructivism, which suggests that learner’s alternative scientific constructions can be of equal validity to the ones of scientists, has been at the core of Matthews’ attack due to its strong relativistic stance. He further argues that constructivism wrongly uses claims about learning processes and developmental psychology in order to establish wider educational positions

Learning theory, he says, may indicate how something should be taught, but what and how much should be taught to whom follow from different or additional considerations. (...)Constructivists frequently ignore, or implicitly assume, such considerations in extrapolating from learning theory to curriculum matters, and to educational theory more generally (Matthews, 1994, p.145).

Similarly Bliss (1995) criticises constructivism on the ground that it rarely distinguishes between one’s making personal sense of the real world and gaining an understanding of the socially constructed world of scientific ideas. She points out that constructivism that derives from the work of Piaget or Kelly does not attribute a sufficient role to the teacher, parent or peer; something, she says, that rightly led to giving more attention to Vygotsky’s views on the role of adults in the pupil’s learning. She further argues that

Von Glaserfeld’s constructivism reduces all understanding (including science) to making personal sense of the world. Social constructivism reduces all understanding...
Interestingly, even constructivism's own success has been the cause for criticism since there are scholars who regard its impressive spread to be a disadvantage. Solomon (1994), for example, suggests that when a new theory dominates its field,

*The problem is that other paths and viewpoints are not just ignored, they become disused and impassable. If constructivism obscures other perspectives, either by its popularity or its blandness, that could be damaging* (p.17).

Solomon has been particularly critical to psychological constructivism for, although being constructivist herself, she tends towards the social construction of knowledge in a Vygotskyan tradition. She supports that children's sense-making process of daily-life events is more social than personal (Solomon, 1993) and she questions the notion of 'children-as-scientists'. She further points out that constructivism failed to propose a particular pedagogical approach that would enable its principles to be realistically applied in the science classroom (Solomon, 1994). This thesis regards that this weakness has proved to be the greatest of the grand constructivist theory since it allowed for a theory-practice divide to emerge. It is for this reason that the next section takes on problems related to this divide. Before doing so, though, a further point needs to be made.

Having briefly presented an anthology of criticisms to constructivism it should be noted that in spite of the well-founded nature of such critique on ample argumentation, it has not yet managed to deprive constructivism from its 'grand theory' status. As Solomon (1994) suggests, there are two possibilities that could explain constructivism's survival as a theory:

*Either the decline of constructivism is so slow as to be imperceptible, or else the logical requirements of a theory in the social sciences are no longer as stringent as older philosophical requirements made them* (p.13).

Interesting as it might be, this is not among the central issues addressed by this thesis, which prefers to take a closer look at the actual problem involved in the 'doing' of constructivism.

1.2.4.1. The divide between constructivist theory and practice

Of the different grounds on which constructivism has been criticised this writer has chosen to focus on the apparent divide between constructivist theory and practice for it is the one problem that directly affects teachers, students and the teaching and learning process alike in the science classroom.

In presenting the virtues of constructivism Strike (1987) suggested that

*(including science) to learning cultural practices. Neither reduction seems adequate to describe children learning in school* (Bliss, 1995, p.157).
the claim that people are active in learning or knowledge construction is rather uninteresting. It is uninteresting because no one, beyond a few aberrant behaviorists, denies it (p.483).

A first conclusion from Strike’s statement is that constructivism is indeed enjoying a hegemonic position in science education. However, a closer look inside schools suggests that the extent to which the widespread acceptance of constructivism by science education academia managed to extend in schools, or among science teachers, is highly debatable. This brings to light an important divide between constructivist theory and practice, pinpointing what is probably the most serious problem currently faced by those involved at the frontline of education, that is teachers in classrooms.

Arguing in favour of constructivism and making a case for the principles it represents is by far an easier task than applying these principles in the classroom. Being constructivist in practice means that the teacher has to make pupils' existing understanding of the phenomena to be taught explicit, and help them to construct new meaning from that point onwards. The personal and highly subjective nature of such a process, though, makes the implementation of true constructivism highly problematic in classes of 20-30 pupils where the pupils share different 'starting points' of understanding, have different experiences, and demonstrate different abilities to construct knowledge at different rates. Whether it is possible for a single teacher to understand to sufficient depth the understanding and sense-making mechanisms brought into a class of thirty pupils, in order to provide appropriate stimuli for fruitful (re)construction of new meaning, is an issue open to discussion.

Research evidence (Jofili and Watts, 1995) suggests that a serious obstacle to the application of constructivist principles and methodologies in class is the teachers' fear of losing control of the class and of using new approaches. It is often, therefore, the case that

Even while teachers may have some appreciation of constructivist principles, these seldom find their way into the broad sweep of classroom practice (...) When the prior knowledge of the pupil differs from the teacher’s explanation, it is all too often solemnly ignored without any real attempt to use it (Jofili et al., 1999, p.7).

Taking into account further motivational, socio-cultural and behavioural factors, makes true application of constructivist process in schools something of a utopia. This thesis not only acknowledges the existence and the problematic nature of such a divide, it consciously takes this into consideration in the design of the research and the implementation of the experimental approach suggested, as the discussion in the methodology chapter will show.

It is no overstatement to say that the practical problems of the constructivist perspective
directly emerge from the perspective itself. Following the fundamental principle of constructivism, when teachers or researchers attempt to understand children’s understandings they are themselves involved in a process of construing children’s constructions since no direct access to the construct system of another is possible. One must therefore always construe another’s constructs based on experiential reality and usually ‘on flimsy evidence’ (Geelan, 1997) hence bringing to the forefront the importance of subjective interpretation, since to understand the world of meaning one must interpret it (Schwandt, 1998).

A radical view of constructivism in essence denies the feasibility of constructivist teaching (Glasersfeld von, 1984). Even the Vygotskian perspective, which acknowledges the social role of more knowledgeable individuals in one’s learning would only allow the teacher to ‘scaffold’ learning. The emerging question, therefore, is what is the role of the teacher and of scientifically orthodox knowledge in a constructivist classroom? This writer regards the role of the teacher as one of a) identifying students’ ‘starting points’ (first at the class level and then for individual students) and b) offering appropriate stimuli and opportunities for learners to gradually construct an understanding of the specific science concepts studied. This description of the teacher’s role clearly presupposes a central role for learners in the learning process. In acknowledging such role for the students, this writer shares Gunstone’s views (1995) with regards to both teachers’ and students’ contribution in constructivist teaching

There is a widespread tendency for those involved in education to see student centred as the opposite of teacher controlled. This I reject totally – it has no rational basis (...) I am arguing student centred learning of a form which requires strong teacher control. However, it is subtle teacher control that allows for flexibility in engaging students in the learning process (p.18).

The role of the teacher is, therefore, perceived by this writer to be one of facilitator of knowledge construction, not by offering ready made scientifically orthodox knowledge, but by providing an environment that will encourage and facilitate the active mental and physical involvement of learners in the learning process.

The issues raised up to this point are only a small sample of the concerns expressed within the literature indicating that the constructivist coin indeed has two sides. Their discussion has served to both maintain fairness in presenting a philosophy that admittedly bears a number of drawbacks, and in keeping the full picture in mind when attempting to bring theory to life. By and large this thesis maintains a constructivist framework with the limitations that this has to offer.

Having broadly presented the underlying principles, the main directions and some of the
pitfalls associated with the constructivist process of learning and understanding, follows a more focused insight into the nature of CCL - the approach where the actual application of constructivism is brought to light.

1.3. Conceptual Change Learning – The working framework

*Conceptual change learning* (CCL) has been a predominant trend in science education over the last two decades based on the foundations of constructivist learning and an epistemological view of the nature of science. In relation to constructivism CCL can be thought of as an explicit attempt to apply its principles in the science classroom, in the hope that the ‘new’ approach would solve the long identified problem of students’ poor understanding of science following school instruction.

CCL theorists endorse the claim that knowledge is personally and socially constructed (Driver, 1989); learners are seen as responsible for their own learning which can only take place if they themselves construct new understanding on previous experience. During conceptual change, learners may reconsider the appropriateness of their current understanding and may adjust, modify, extend or reject existing concepts.

Although the term ‘conceptual change’ has dominated relevant literature numerous terms related to CCL are also evident, such as ‘knowledge restructuring’ (Carey, 1985) and ‘principle change’ or ‘belief change’ (White and Gunstone, 1989). Most of these terms usually carry the implication that individuals’ particular conceptual structures are replaced by more sophisticated ones that can account for phenomena where previous conceptions failed to do so. In recent years, though, most scholars (e.g. Gunstone 1994) regard both replacement and addition of new ideas as valid cases of conceptual change. Once again a plethora of terms is used to describe this process ranging from ‘conceptual capture’ (Hewson, 1981) and ‘assimilation’ (Posner et al., 1982) to ‘conceptual exchange’ (Hewson, 1981) and ‘accommodation’ (Posner et al., 1982). ‘Conceptual refinement’, ‘incorporation’ or ‘extension’, are terms also in effect (Tytler and White, 1996).

1.3.1. The content and nature of CCL

In discussing the nature of any theory a first question to be addressed should be one of establishing compatibility between the underpinning framework and its object of study.
Going back to the broader philosophical views regarding scientific knowledge Carr et al. (1994) point out that

*If science is not a set of truths which exists independently of people, then in the construction of this structured complex of ideas there will often need to be changes made to ideas* (p.157).

This successful marriage of the subjective philosophy of scientific knowledge with the personal process of constructing scientific knowledge, suggests that CCL is all too compatible with contemporary views about science as an object of study.

Important as such compatibility might be, it should be acknowledged at this early stage of the discussion that CCL has not only inherited the previously discussed practical problems associated with constructivism, but it also suffers one further important flaw. Interestingly, if one considers separately each of the words from the term *conceptual change learning*, the conclusion will soon be reached that there are serious objections among different scholars regarding what is a *concept*, what is accepted as *change*, and what *learning* really means. The problem, therefore, is one of debate within the literature regarding the meaning of fundamental terms of the theory. Before taking the discussion any further it is important to look briefly into such points of conflict in order to make the meaning of the terms used by this thesis explicit.

1.3.1.1. Some definitions

What is a concept? - Concepts versus conceptions

Although psychologists suggest that *concepts foster cognitive economy by dividing the world in manageable units* (Atkinson et al., 1999) similar economy is certainly not reached when it comes to the meaning of the term itself. A first problem with the word *concept* is the duality in its meaning. As White and Gunstone (1989) suggest, the notion *concept* has at least two commonly used meanings that should be distinguished as these inevitably affect the meaning given to *conceptual change*.

*One use (of the term) ... is the recognition of members of a class. Under this use, we say that someone has the concept of 'test tube' if the person identifies objects correctly as test tubes or as not test tubes. This is a clear-cut skill, that the person either has or has not, and is readily acquired by generalizing from a range of objects. The person may not be able to define or even describe a test tube, but can tell one when he or she sees it. Bruner et al (1956) and Gagne (1965) use the word concept in this sense. A different usage is for concept to refer to all the knowledge a person has about a term. Thus a person might know that test tubes are made of glass, come in a range of sizes, stand in a rack, have stoppers, and are used to hold chemicals. There might also be images, visual ones of the appearance or haptic ones of the feel of a test tube being shaken in the hand, and episodes of experience, both generalised ones of boiling solution in test tubes, 'popping' hydrogen, or of pouring*
in and out of test tubes, and specific ones of a particular event in which, say, an accident led to a burn or a cut, or perhaps some remarkable reaction was observed. This collection of propositions, images and episodes, together with the skill of recognizing test tubes and the motor skills of using test tubes in various ways, is the person’s concept of 'test tube' (White and Gunstone, 1989, p.578).

White and Gunstone (1989), therefore, regard concepts as 'the collection of elements of knowledge a person has about a given term' (p.578). Elsewhere, White and Gunstone (1992) define understanding of a concept as the set of propositions, strings, images, episodes, and intellectual and motor skills that the person associates with the concept. Rather than elaborating on each of the terms used by White and Gunstone (1992), the intention of this writer is to highlight the complexity and multiplicity of different types of knowledge constituting one's understanding of a concept.

In a similar way Watts (1983) refers to ambiguity of the word concept. It is a word, he says, that

... can apply with equal authority to describe both the individual personal knowledge structures of the human mind and to the general categories of public disciplines. It is the way in which the interaction (emphasis in original) of these two meanings is discussed that indicates the orientation of a particular study. Largely, the bulk of research work into concepts and concept development sees the concept itself as fairly immutable and focuses instead upon how people perform as they fail (or manage) to 'acquire' it (p. 1.10).

The fact that the debate has concentrated on the meaning of the term ‘concept’ does not by itself suggest that the choice of the specific word as the object of CCL has enjoyed consensus within the literature. White (1994), for instance, distinguishes between ‘conceptual’ and ‘conceptional’ change. This distinction is based on the definition given to ‘concept’ and ‘conception’; the former is viewed as that set of knowledge the person associates with the concepts’ name, while the latter is a more complex system of explanation. He suggests that ‘major shifts (in learning) that typically involve detailed explanations of phenomena, may better be called conceptional change’ (p.118) rather than the most commonly used ‘conceptual change’. Conception could mean the learner’s representation of either a single phenomenon or a number of closely related phenomena under a common heading (e.g. ‘reproduction’) (White, 1994).

Although White’s (1994) remark that ‘conceptional change’ might be a better term is fully acknowledged by this writer, in order to avoid confusion in the discussion, this thesis makes use of the most commonly used term in the literature, that of ‘conceptual change’ which appears in most of the quotes and references made. At the same time both terms conception
and *concept* are used throughout the thesis. The former is used to denote a personal construct of the individual learner as a result of subjective sense-making, while the latter is used to refer to the ideas currently accepted by the scientific community as orthodox science. In the course of the research, for instance, the researcher was teaching *concepts* such as electric current or conductivity, while the children were constructing their own personal *conceptions* of these phenomena.

'Misconceptions', 'alternative frameworks' or 'children's science'?
The discussion regarding the meaning of the word 'concept' or 'conception' inevitably relates to a similar debate regarding the appropriate term for referring to children's explanatory structures prior to classroom instruction. The terms most widely used in the literature are 'misconceptions' (Helm, 1980), 'children's science' (Tasker, 1980; Gilbert, Osborne and Fensham, 1982), 'alternative frameworks' (Driver and Easley, 1978; Driver et al., 1995), 'alternative conceptions' (Gilbert and Watts, 1983) and 'pre-conceptions' (Thijs and Van den Berg, 1995).

Debate over the appropriateness of each of these terms has been both intense and interesting over the years, attempting to make a case in favour of the 'best' term for depicting children's ideas. Typical of this debate has been the disagreement between the 'alternative frameworks' camp and the 'misconceptions' advocates, at the core of which was the belief of the former that the use of the term 'misconceptions' was erroneous due to the *a priori* disregard of children's ideas as being simply wrong.

Even in those cases where the same term was used by different scholars discussions were once again triggered regarding the meaning attributed to the term and its implications. In the case of the widely used 'alternative frameworks', for instance, Driver used the term to refer to features of an individual's mental organisation that was used for conceptualising one's experience of the physical world (Driver and Easley, 1978). For Gilbert and Watts (1983), on the other hand, the term was used to highlight commonalities in the cognitive structure of many individuals, presenting a framework as *'a composite picture based upon ideas shared by a number of pupils'* (Watts, Gilbert and Pope, 1982, p.15).

Others have used different terms to represent how children make sense of physical phenomena. Vosniadou and Ioannides (1998), for example, identify what they call 'synthetic models' i.e. models constructed by children in their attempt to reconcile the scientific information they receive with presuppositions and beliefs supported by their everyday

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experience. The taught scientific notion of a spherical earth, for instance, seen in relation to the everyday experience of a flat earth (supported by observation), can lead to a ‘flattened sphere’ model. Pintrich, Marx and Boyle (1993), on the other hand, regard ideas as competing for the same conceptual niche resulting in a ‘survival-of-the-fittest ideas and concepts’ (p.172). The idea that wins, they say, will most likely be the one that resolves anomalies.

In spite of the chasm between the underpinning philosophies of different camps it is generally agreed that students’ ideas prior to instruction are important and cannot be ignored. It is further widely agreed that the fact that some students fail to align their views with those of orthodox curricular science does not the least mean that they are of lower intelligence to the ones that do so. Rather the reason for not making such a change could be that their existing perspectives fulfil their everyday life needs and they have no reason to seek for new explanations (Zylbersztajn, 1983).

Having raised the debate regarding the status and the nature of children’s pre-existing ideas this thesis adopts both the terminology and the philosophy associated with Driver’s ‘alternative framework’ camp. This is a choice believed by this researcher to be more congruent to the constructivist philosophy portrayed by this thesis, which considers children’s ideas within the context and the conditions under which they were individually constructed, rather than their dismissal as wrong. In the context of this thesis, therefore, children’s ideas are taken as the starting point for further learning based on conceptual change.

What is ‘change’?

A third fundamental problem within the CCL framework is the one associated with the term ‘change’ which is again characterised by duality in meaning. As Chi, Slotta and de Leeuw (1994) point out

...the term ‘conceptual change’ unfortunately can refer to both the processes of change as well as the resulting change (p.28).

The duality in meaning of ‘change’ is a common theme for a number of scholars. Hewson and Hewson (1991) are being particularly successful in making the distinction, offering a third potential meaning of the word

When thinking of conceptual change it is helpful to recognize that the same word ‘change’ is used in different ways. One might talk, as in the fairy tale, of a frog changing into a prince when the princess kisses the frog. In this case, there is only one entity before and a different one after; the frog is no more after the change, there
is only a prince. Here change means extinction of the former state. A second example might be Jane’s savings account. Her money earns interest and the balance grows; she spends money and the balance falls. Here change means an increase or decrease in the amount of something. A third example might be an election for political office with the incumbent being beaten by the challenger: there has been a change of mayor. Both people continue to live in the city, but only one person is mayor. The incumbent loses status, while the challenger gains it. In this case, there is no extinction; change means an exchange of one entity by another (p.61).

This thesis regards that Hewson and Hewson’s (1991) third example is the most appropriate for representing the process of conceptual change. By reconstructing one’s existing understanding to reach a more scientifically orthodox concept, the former is not ‘deleted’ in some magic way rather it is adjusted to account for more complex phenomena where the previously held understanding failed to do so. Once the learner has constructed the new conception the old one does not necessarily cease to exist, it thereafter enjoys a lower status than before. This is congruent to Strike and Posner’s (1992) notion of ‘conceptual ecology’ and of Taber’s (1997) notion of a ‘conceptual toolbox’, which allows the co-existence of different conceptions (scientific or alternative) and selective use by the learner depending on the requirements of each setting. The term ‘conceptual change’ will therefore be used in this sense throughout this thesis, always referring to the process of learning and not its outcome.

What constitutes ‘learning’? – The notion of understanding.

Due to the central role of understanding in the processes and approaches advocated by this thesis it is considered necessary to make the meaning attributed to the term explicit. In order to describe the process of understanding this thesis makes use of an analogy in which understanding is a process similar to constructing a jigsaw puzzle. Understanding something is regarded by this writer as finding a place for a new piece of information on the individual’s conceptual puzzle that fits with existing pieces in the specific area being tackled. Achieving this is a result that brings satisfaction, makes sense, and calls for a further step forward in the case of both learners and jigsaw constructors.

The process described is neither flawless nor can it guarantee that the result achieved is the ‘correct’ one. This is so because, just like in the case of the jigsaw puzzle, the ‘shape’ of the new piece of information may fit but the ‘picture’ on it may not be exactly the right one. This discrepancy may escape one’s attention until a later stage is reached when new pieces come to join the last piece (mis)placed into the jigsaw. The arrangement clearly resembles construction of human understanding, for the learner appears to be happy with the
equilibrium achieved with the latest piece of knowledge integrated in his or her conceptual puzzle, until new units of information come in that do not fit with the former.

This point of the analogy also helps in explaining the existence of alternative frameworks and the persistence of such structures. A new piece of knowledge or information makes perfect sense to the individual only because it is viewed (perceived) within a very limited conceptual area that is being served by the arrangement. As a result, different people may hold considerably different understandings about the same phenomenon, which, none the less, make sense to each one of them and keep them content. One can therefore talk of ‘individual understanding’ and ‘scientific understanding’. Key features of ‘scientific understanding’ are that it covers a broader area, takes into consideration a number of inter-affected variables and has a ‘top-view’ perception of the phenomenon studied, contrary to ‘individual understanding’ that is based primarily on personal experience and constructs that relate to a narrow conceptual area.

When a new piece of information that ‘comes in’ does not fit, the learner has to broaden the perspective of the learned area. One has to take into consideration more information and more established structures from the existing conceptual puzzle if s/he is to comprehend where exactly the problem with the new piece of knowledge lies. This means tackling a broader conceptual area that will eventually result in better understanding. ‘Better’ or deeper understanding, therefore, means being able to house the new piece of knowledge in as large a conceptual area as possible. Returning to the puzzle analogy, only when one ‘steps back’ and takes a look at the adjacent areas or, better, at the whole picture, will s/he be able to tell whether the construction of the jigsaw puzzle is progressing in the right direction or not. In the case of human understanding such ‘stepping back’ will enable the individual to either appreciate new learning within a system of inter-related frameworks, or acknowledge that his/her current understanding has very narrow limits and does not account for different contexts.

Unfortunately the jigsaw analogy suffers a number of flaws that restrict to some extent the accuracy with which it depicts human learning. For example, all knowledge does not arrive in similar pieces or chunks, which need only to be slotted in the right place as in the case of the jigsaw puzzle. Moreover, in a jigsaw there is only one correct place for each piece in order to form the correct picture and rearranging the pieces or using them in different configurations is not possible. Also, pieces are not interchangeable between two similar, yet different jigsaws, something that conflicts with the potential of using knowledge across different
contexts or in considerably different ways. By referring to these flaws the intention is to show that this writer is aware of the existence of these, and possibly other, limitations associated with the analogy, yet expresses the belief that they do not deprive the analogy from the important role it plays within this section.

A last point to make at this stage is that learning and understanding belong to the category of ‘mysterious’ processes that cannot be traced or pinpointed in any direct manners other than the observation of their outcomes. According to Taber and Watts (1996), as students learn more about science then the range of their concepts increases, the level of sophistication of their concepts deepens, and better integration of their existing concepts with each other takes place. They therefore suggest that developments in students’ understanding can be analysed by: a) looking for the appearance of ‘new’ concepts that were not previously used by the learner; b) observing how concepts are defined, explained and developed over a period of time; c) noting how different concepts are related to each other by the learner (Taber and Watts, 1996).

Useful as these guidelines might be, it should be noted that they are restricted to the observable outcomes or ‘symptoms’ of the processes taking place at each moment. How conceptual change is performed; when is the best time for teachers to initiate change; what really goes on in the learner’s mind, and what mechanisms are involved in this process remain largely unanswered questions.

1.3.2. Models of CCL

A basic feature of CCL-centred research of the last two decades has been the development of various models of learning, some derived from epistemological literatures (e.g. Posner, Strike, Hewson and Gertzog, 1982) and others from cognitive psychology (e.g. Osborne and Wittrock, 1983). In spite of differences in emphasis or rationale of various CCL models they all share a Piagetian, or very similar, framework. The difference, as Pintrich, Marx and Boyle (1993) suggest, is that contrary to Piaget’s more global formal structures and operations, CCL models take a more domain-specific view of individuals’ conceptions or schemata.

Posner et al. (1982) proposed the ‘conceptual change model’ (CCM) which proved highly influential in science education as it provided the theoretical framework for a number of studies. The model considers the pre-conditions needed for conceptions to change in order to lead to ‘accommodation’ (substantial conceptual change) or ‘assimilation’ (cases where a
major conceptual revision is not necessary) (Strike and Posner, 1985). According to the model, the construction of a new scientific conception will take place only if the learner regards the new conception as superior or more sophisticated when compared to the one s/he already holds. This decision means that the status of the existing conception is lowered, to the benefit of the new concept - which is placed higher in the learner’s conceptual hierarchy. The decision to change (or not) existing conceptions is, according to the CCM, based on the following four conditions: new conceptions must be *intelligible, plausible and fruitful* to the learner, while establishing *dissatisfaction* with existing (mis)conceptions. These four conditions for conceptual change to occur have enjoyed considerable consensus within the literature, yet the same cannot be said for the *nature* of conceptual change as proposed by the model.

The second important frame of the model is what Strike and Posner (1985) call *conceptual ecology*. This provides the context for conceptual change, which is viewed as a competition between learners’ old and new conceptions for a certain conceptual niche, based on the perceived status of competing conceptions. This framework of conceptual ecology provides the cognitive resources for the learner to judge the status of a conception and the niche to be occupied by the conception with the higher status.

It has being suggested that, in practising CCL, the focus of teachers’ efforts has been on the notion of intelligibility, with too little thought given to plausibility, fruitfulness or even dissatisfaction with existing conceptions (White and Gunstone, 1989). This is believed by this researcher to be one of the reasons why the CCM did not prove to be panacea for science education. It should be acknowledged, though, that Strike and Posner (1992) made it clear that their model did not provide a detailed account of learning that could be directly applied to the science classroom. Instead they saw themselves as

*...describing the ‘hard core’ of a research programme that could be extended in profitable directions by further work (p.150).*

Although Posner’s *et al.* (1982) CCM does not provide the focus of this thesis, it does hold an important place both for substantiating the theoretical framework of the thesis and the design and implementation of this research. In doing so, this writer shares the scepticism raised over recent years regarding the absence of the affective dimension from the Strike and Posner model (Treagust, 1996; Watts, 1998), an issue of broader applications to CCL as raised earlier. Treagust (1996), for instance, has pointed out that emphasis of the CCM is fully on the intellectual and the cognitive, totally ignoring the affective. As a response to this
weakness the multi-dimensional framework for conceptual change suggested by Treagust (1996) incorporates an epistemological, ontological and social-affective dimension, hence placing emphasis not only on what the learner already knows, but also on what the learner feels about this knowledge. Critique of the CCM has eventually led to the revision of the model (Hewson and Hewson, 1991; Strike and Posner, 1992). In their more recent papers Strike and Posner (1992) acknowledged that

*A wider range of factors needs to be taken into account in attempting to describe a learner’s conceptual ecology. Motives and goals and the institutional and social sources of them need to be considered. The idea of a conceptual ecology thus needs to be larger than the epistemological factors suggested by the history and philosophy of science* (p.162).

Other models have also been proposed yet none has been as widely welcomed as the CCM. Each of these models placed its own emphasis on different aspects of the learning process and conditions for successful CCL to take place. Gunstone (1991), for example, highlights the importance of recognition, evaluation and reconstruction on behalf of the learner

*Conceptual change can be seen in terms of recognizing, evaluating, reconstructing: the individual needs to recognize the existence and nature of their current conceptions, the individual decides whether or not to evaluate the utility and worth of these conceptions, and the individual decides whether or not to reconstruct these conceptions* (p.129).

Elsewhere Gunstone and Northfield (1994) draw close parallels to the Posner et al. (1982) model

*Dissatisfaction implies recognition, evaluation requires at least plausibility, and fruitfulness is an extremely helpful way to consider approaches to making the demanding task of reconstruction one which is personally valuable to the learner* (p.525).

1.3.3. The process of CCL – Practical issues

The widespread acceptance of the principles of CCL and more specifically the view that knowledge is personally and socially constructed have generated a number of implications for science education. Driver (1989), for instance, has listed in the past the following six implications:

1. Learners are not viewed as passive recipients, but as purposive and ultimately responsible for their own learning;
2. Learning is seen as involving a change in the learner’s conceptions;
3. Personal knowledge is not taken to be ‘objective’ but is personally and socially constructed;
4. Science as public knowledge is a product of human corporate endeavours, and this should be reflected in the knowledge construction process undertaken in the classroom;

5. Teaching is not the ‘transmission’ of knowledge but the negotiation of meaning;

6. Curriculum is not that which is to be learned. It is a programme of learning tasks, materials, and resources, which enable students to reconstruct their models of the world to be closer to those of school science.

These implications, that radically move away from traditional theories of learning, inevitably triggered the rise of new methodologies and considerable practical changes in the science classroom. The question therefore to be addressed next is ‘what should a CCL-based lesson look like?’

Most CCL-based teaching practices share the view that

If students come to lessons with ideas about their world which already make sense to them, then teaching needs to interact with these ideas, first by encouraging their declaration and then by promoting consideration of whether other ideas make better sense (Carr et al., 1994, p.150).

Within this line of thought, a typical CCL teaching sequence is the one suggested by Nussbaum and Novick (1981): the teacher a) makes children’s alternative frameworks explicit to them, b) presents evidence that does not fit and so induces dissatisfaction, and c) presents the new framework, based on formal science, and explains how it can account for the previous anomaly. Although this approach was proposed nearly two decades ago it is still widely used in different variations and serves as a general methodological framework for new research.

Nussbaum and Novick’s (1981) sequence clearly suggests that CCL is a ‘linear’ relationship moving from the simple to the complex, a view that is also shared by a number of other scholars. Taber and Watts (1997), for instance, acknowledge such a fairly linear process of alteration from one framework of ideas to the next ‘en route towards scientific orthodoxy’ (p.10). They further point out that progress towards more complex ideas can be achieved both through a gradual evolution of frameworks and through more sudden ‘revolutions’ in thinking when radical changes are made. According to Driver et al. (1995) progression from children’s science to the scientific or the curriculum point of view may involve intermediate conceptions, following a course of ‘conceptual trajectories’ which they define as

a sequence of conceptualizations which portray significant steps in the way knowledge within the given domain is represented (p.168).

Pines and West (1986), on the other hand, described three routes along which learners’
understanding can proceed. The first is ‘conceptual development’ which involves the formation of new patterns and relationships within already known structures. The second is ‘conceptual resolution’ where there are relatively minor differences between the learner’s and teacher’s perspectives which can be rather easily straightened out by means of good teaching. The third is ‘conceptual exchange’ where there are major fundamental differences between the taught view and the view held by the learner.

Although apparently different, the above examples are clearly not in conflict to each other, rather they put emphasis on different dimensions of the CCL process. Debate, however, has proved more intense regarding the point when this process should be considered successful or not. Shayer (1978), for instance, refers to large proportions of the student population that fail to master basic concepts, suggesting that their partial understanding can be as useful as a series of excursions half-way up the cliffs surrounding what would be interesting territory, if it were ever reached. Watts (1983), on the other hand, clearly disagrees with this view that regards anything less than a whole concept as useless. He argues that treating concepts as having a binary mode, one of either ‘having’ or ‘not having’ a concept, is essentially a gross oversimplification.

Irrespective of the revolutionary (or not) nature of the change process, there is considerable consensus in the literature suggesting that teachers should:

- make sure that the pupils’ original ideas are not treated as wrong, but merely as ideas of limited application
- show that the new ideas based on formal science work where their ideas worked
- show that the new ideas work where their ideas did not
- point out the differences between these situations (Hashweh, 1986).

Albeit attributing children’s ideas a central role in the CCL process, it is widely acknowledged that the role of the teacher remains crucial in skilfully initiating and maintaining this process. The demands of the approach can further be pinpointed as another significant factor that has contributed to the not so widespread application of the approach in the science classroom, in spite of the remarkable research interest.

1.3.3.1. Problems with CCL

The process described so far is certainly not problem-free and success can easily be hindered due to a number of reasons. Tytler and White (1996), for example, identified epistemological beliefs, lack of domain-specific knowledge, specific problems associated with applying conceptions to new phenomena, and past histories of conceptual application as potential
barriers to conceptual change. Other factors affecting the conceptual change process and its success are individual beliefs, classroom contexts, the nature of the interactions between teacher and students (Pintrich, Marx and Boyle, 1993), the teacher’s familiarity with the approach and the all too familiar to teachers time and curricula constraints.

A further problem that can restrict success relates to an important paradox within the process of CCL as identified by Pintrich, Marx and Boyle (1993)

Current conceptions held by the learner can result in problems resulting from discrepancies between experience and current beliefs, but current conceptions also provide a framework for judging the validity and adequacy of solutions to these problems (...) Thus a paradox exists for the learner; on the one hand, current conceptions potentially constitute momentum that resists conceptual change, but they also provide frameworks that the learner can use to interpret and understand new, potentially conflicting information (p.170).

The broader CCL framework did not manage to avoid criticism, typical of which was reference to the complete lack of the affective dimension from its theoretical founding. Clearly, emphasis of CCL research was on identifying, listing and analysing children’s theories and explanatory models without considering that the content of such theories and models is strongly influenced by personal, social, motivational and historical factors. The existence and persistence of students’ misconceptions in science offers ample evidence in this direction. It is under this light that scholars like Pintrich, Marx and Boyle (1993) call for ‘an integration of motivational constructs and an attention to classroom contextual factors... ’ (p.174) in CCL.

Watts and Bentley (1987) recognise that the active role that is expected of the pupils makes considerable demands on them. They find themselves having to reveal their thinking while at the same time having to be open minded enough to change that thinking. This requires a highly supportive classroom environment where pupils’ ideas are accepted by the teacher and the risk of other pupils ridiculing one’s thinking is eliminated.

To recapitulate, therefore, is to say that problems associated with the conduct of CCL relate both to practical constraints and to gaps or inconsistencies from within its fundamental assumptions. In order to minimise the experience of such problems during the course of this research, a further insight into the way the research set out to pursue conceptual change is needed.
1.3.3.2. Cognitive conflict—The 'how?' of the research

Addressing the question of how to promote conceptual change Scott, Asoko and Driver (1991) identify two main groupings of strategies. On the one hand are strategies that are based upon cognitive conflict and the resolution of conflicting perspectives and, on the other, strategies that build on learners' existing ideas and gradually extend to new domains (e.g. through metaphor or analogy). Each of the two groupings is based on different emphases on where responsibility for promoting conceptual change may lie. In the first case, of central importance is the learners' active part in recognising their knowledge while, in the second case, emphasis is placed on the design of appropriate interventions by teachers rather than the role of accommodation by learners.

Without excluding selective use of the latter this thesis advocates use of the cognitive conflict approach as a process that

'loosens' an existing cognitive structure, making it more amenable to restructuring at a higher level on another occasion (Adey, Shayer and Yates, 1989a, p.241).

This writer regards cognitive conflict as the situation when the learner comes across new information or new viewpoints regarding a phenomenon, consideration of which makes the explanation or theory held for that specific phenomenon seem inadequate or incomplete. This is so because new information conflicts and challenges one's existing explanatory framework, revealing the inadequacy of the latter for explaining fully the phenomenon studied and creating a state of psychological 'dissonance' (Nussbaum and Novick, 1982a). By saying that one's current understanding is challenged, this writer shares the same meaning as the one reflected in Schwandt's (1998) words, who follows Guba and Lincoln (1989) in their elaboration of the properties of constructions

One's constructions are challenged when one becomes aware that new information conflicts with the held construction or when one senses a lack of intellectual sophistication needed to make sense of new information (Schwandt, 1998, p.229).

Arguments in favour of the cognitive conflict approach can be drawn from cognitive psychology suggesting that children's existing ideas can act as 'interference', which is a factor impairing retrieval from long-term memory. If, for example, the student associates the concept of electric current flow with a 'unipolar' model (Osborne and Freyberg, 1985) while the teacher proposes the 'scientific' model, when the student is later required to retrieve what s/he knows about current flow the former association can interfere and make it difficult to retrieve the latter. This researcher argues that making explicit that the former model is insufficient for explaining the phenomenon studied by means of creating cognitive conflict, is a tactic that helps to minimise the occurrence of such interference.
In addition to the above arguments, the choice of the cognitive conflict approach is made for two further reasons. First, this thesis regards cognitive conflict to be a process that makes emerging concepts (that resolve the conflict) more salient (Watts and Alsop, 1997) and memorable to the learner, hence, it is argued, more durable. Second, building on and gradually extending pupils’ ideas to reach the scientific point of view is an endeavour that runs the risk of reinforcing pupils’ initial misconceptions (especially if, by the end of the lesson, the pupils do not manage to move on to the scientific conception, but can only remember that the teacher was actually ‘building on their ideas’). This by no means suggests that children’s existing ideas are to be humiliated as ‘wrong’, rather the objective is to emphasise the need to bring these ideas to light, comparing them with the ones of orthodox science and establishing the latter’s advantage in explaining more fully the phenomenon studied.

Presenting experimental evidence that does not agree with the pupils’ predictions based on their alternative explanatory frameworks, is believed by some to be the most powerful way of introducing cognitive conflict in the science teaching context (Postlethwaite, 1993). Karmiloff-Smith (1984), on the other hand, argues that conceptual change derives first from practical success after which the learner tries to comprehend how that success was achieved. In either approach, it is important that the pupils do not simply experience the dismissal of their existing theories or explanatory frameworks, but are offered a new or fuller framework that can explain a broader range of phenomena. Furthermore, both correct and incorrect responses should receive due attention in such a way that pupils not only learn to discriminate the two, but further understand the relationship between them (Case, 1975).

It has also been suggested that the conflict situation must be carefully chosen by the teacher (a) to be within a rather familiar context to the students and (b) to make a real cognitive demand on the students, but not such that would be incomprehensible (Adey and Shayer, 1994). Failure to carefully control the components of the conflict can result in some pupils being totally unaware of such a conflict, hence ruling out the chance of accommodation (Adey and Shayer, 1993).

Being an integrated part of the learning process through which the learner constructs his/her own understanding, cognitive conflict is inevitably equally personal and subjective for different individuals. Consequently, what might appear as sufficient evidence for challenging a learner’s understanding and causing cognitive conflict, might not be enough reason for a
different learner to reconsider his/her knowledge. In challenging, therefore, an alternative explanatory framework by providing evidence of suggesting a different viewpoint that is not accounted for by that framework, it is the teacher’s responsibility to provide as many different examples as possible to cover a greater range of stimuli that would eventually cause cognitive conflict. This is an approach that takes into consideration the subjective nature of both learning and cognitive conflict and it is adopted as a central characteristic of the teaching involved in the research presented by this thesis.

In some cases cognitive conflict fails to cause conceptual change or even fails to sufficiently establish itself as a ‘conflict’ deserving to be considered by the learner. The reason for this could lie in the strong belief of the learner in the framework held to that moment; a framework that sufficiently served in explaining the phenomenon under study and one that was probably reinforced by the learner’s experience from within his/her social surroundings. On the other hand, the new point of view or evidence recommended by the teacher may be considered by the learner as trivial, irrelevant or inaccurate, therefore being ignored or overlooked and failing to establish cognitive conflict. Similarly, Arnold and Millar (1987) warn regarding the use of cognitive conflict, saying that such conflict may prove insufficient to cause reconceptualization,

...and may by itself produce suppression or misinterpretation of evidence to fit existing theories (in other words, the observation is theory-laden). The need for conceptual change if the conflict is to be resolved may have to be explicitly stated and encouraged, and the scientific perspective specifically introduced as a more powerful and fruitful alternative before accommodation will occur (p.558).

This thesis has taken these ‘health warnings’ regarding the use of cognitive conflict seriously, and considered them in the conduct of teaching involved in the research. The discussion now shifts to looking at issues covered by CCL research, listing the areas in which sufficient answers were given, pinpointing problems or dimensions that were not sufficiently addressed and defining the focus of the present thesis.

1.4. CCL research and the focus of this thesis

1.4.1. Contemporary CCL research and under-explored areas

CCL research has made a valuable contribution to science education over the years producing a vast as well as immensely interesting literature (Carmichael et al., 1990; Duit, 1991; 1993). The main theme of CCL research has been an unprecedented interest in children’s ideas and
the understanding they bring into class, a trend that has resulted in studying numerous subject areas of physics (e.g. Nicholls, 1992; Vosniadou and Ioannides, 1998) and to a lesser degree of biology (e.g. Beckwith, 1996) and chemistry (e.g. Taber and Watts, 1997). The key-role of the teacher during the process of constructing meaning within the science classroom has led to putting teachers alike under the focus of research, often showing numerous similarities between pupils’ and teachers’ alternative conceptions of science (e.g. Kruger, Summers and Palucio, 1990).

A number of reasons have been offered for the start and rapid growth of research in the field of students’ conceptions, predominantly in a social context. Duit (1989), for instance, proposed the following: a) dissatisfaction among science educators with curriculum development through the sixties and the early seventies; b) a turn in psychology to ‘cognitive science’ (science educators at that time were looking for theoretical foundations for learning science, while cognitive psychologists were looking for learning domains which were not too narrow to investigate); and c) the constructivist view which resulted in placing the ideas of the ‘students’ conceptions movement’ within a framework of contemporary philosophical thinking.

The richness in quantity and diversity of CCL research has not been enough to avoid leaving under-explored areas. Thomas et al. (1997), for example, point out that conceptual change has been studied extensively in relation to students’ ideas with considerably less investigation on conceptual change as this relates to students’ knowledge of learning processes. Looking at this from a ‘reverse’ perspective one will also see that in those cases where knowledge of learning processes was investigated, this was treated as a skill per se rather than in direct relation to students’ conceptions, and learning by conceptual change. This is a major issue for the present study as will be shown in defining the focus of this thesis. Other under-explored areas have also been identified. Vosniadou and Ioannides (1998), for example, suggested that the fact that little attention was paid to the development of cognitive flexibility and metaconceptual awareness is one of the limitations of conceptual change research.

With the foundations of CCL set in the 1980s and early 1990s, contemporary research builds upon different aspects or extensions of CCL, typical of which are studies in transfer of science process skills (Toh and Woolnough, 1994), consistency of learners’ alternative frameworks (Palmer, 1993) or scientific conceptions (Tytler, 1994), cognitive acceleration (Adey and Shayer, 1994), and metacognition (Gunstone, 1994; Watts, 1998). However, most of the work available to date has selectively dealt with studying children’s prior conceptions.
or related problems in the learning process, and with designing approaches that would facilitate better learning through conceptual change. Very little interest has been exhibited in what happens after learning has taken place.

1.4.2. Focus of this thesis

This thesis does not intend to elaborate on a critical analysis of CCL literature since the scope is rather to identify and put forward important under-explored aspects of CCL. Before doing so, though, two comments are due. First, contrary to the majority of reported research that has selectively focused on secondary school populations, this thesis advocates greater attention to primary school children. Research findings do suggest that approaches based on the CCL model can have positive outcomes with young children in the primary school (Swanson, 1990). The appropriateness of introducing CCL to primary school students can also be indirectly derived from the reactions of secondary students, who voiced concern regarding changes of their learning processes ‘at such a late’ and ‘important stage’ of their education, when CCL was proposed to them (Thomas et al., 1997). ‘The sooner, the better’ may therefore be applicable here. Second, without claiming defect in Driver’s (1989) implications of CCL as reported earlier (1.3.3), this thesis argues that it is time science education moved on. Having entered the twenty-first century it is widely accepted that individuals cannot possibly acquire all existing knowledge, hence ability to generate and apply meaning to new contexts becomes increasingly important. The vision, therefore, of science educators should be one of enabling students not only to personally construct their own meanings but, equally important, to have the flexibility to use their knowledge in a number of different contexts over a long period of time.

This thesis supports that, from the academic perspective of science education, both discussion and research have matured and need to shift into meta-constructivist dimensions. Effort should be put in applying CCL and constructivist principles in practice but this should not be done in the static way of the past. A step further is needed with due consideration being placed on meta-CCL issues. In order to make both the term meta-CCL and the area of particular interest to this thesis explicit, reference has to be made to different periods of CCL research as shown in Figure 1.1.
Periods of CCL research and areas addressed

<table>
<thead>
<tr>
<th>'Early-CCL'</th>
<th>'Main-CCL'</th>
<th>'Meta-CCL'</th>
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<tbody>
<tr>
<td>e.g. What ideas do children bring to science lessons?</td>
<td>e.g. What is the nature of CCL? What processes are involved in CCL? What are the conditions for CCL to take place? Are conceptions consistently applied?</td>
<td>e.g. What happens after CCL has taken place? How durable new conceptions are? Can they be utilised in different contexts? What effect does metacognition have on new conceptions?</td>
</tr>
<tr>
<td>What is the nature of children's ideas? How should these ideas be treated?</td>
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Figure 1.1

The period of early-CCL research refers to the era of identifying, describing and analysing children's understanding. Although knowledge obtained during this period cannot really be differentiated from CCL since children's existing ideas form the very object of change, the divide helps in pointing out that such knowledge has provided the foundations on which CCL could be based. It is also emphasised that although the three periods appear in the chronological order in which they emerged (moving from left to right), this does not suggest that thematic overlap did not occur.

Main-CCL represents a period of interest into the nature and the mechanisms of conceptual change. Questions such as the mapping of what and how it changes, identifying the essential conditions for change to occur, and devising teaching approaches that would be compatible with the principles of CCL are typical examples of main-CCL research concerns.

Last, meta-CCL comprises issues looking at aspects of the learning process once conceptual change has been achieved. The research questions of the present thesis were inspired from this exact area focusing on four important directions:

a) What happens to recently constructed conceptions of science when no further instruction or interaction takes place? (This does not imply that the learner can possibly be isolated from external stimuli and new information that relates to the taught concepts; rather what is meant is that no further explicit instruction is given),

b) How durable are learners' conceptions of science?

c) How utilisable are learners' constructed conceptions in contexts other than the ones in which learning took place?

d) What action can be taken in order to enhance b) and c)? (i.e. prolong chronological durability and increase ability to utilise in different contexts).
The section that follows gives this writer's views on the first question of what follows the construction of meaning by learners. The approach is of course explicitly theoretical in nature, incorporating in the discussion the model of concept-life and decay (CLD) introduced in this thesis. The model should be treated as an attempt to represent basic aspects of the mechanisms of learning, remembering and forgetting, making extensive use of an analogy from the world of physics. Although verification of the model is not one of the primary objectives of this study, since the mechanisms involved are abstract and sufficient evidence cannot be derived, reference to the model's assumptions will be made where appropriate during the analysis and discussion of the results of this research in Chapters 6 and 7. The remaining questions that relate to the three core notions of this study, namely durability, the role of context and metacognition, are thoroughly discussed in subsequent chapters.

1.5. Model of Concept-Life and Decay (CLD)

The model of concept-life and decay (CLD) offers a theoretical framework that describes the processes of constructing and deconstructing scientific conceptions by learners, portraying a CCL philosophy. The CLD model can be viewed as an extension to existing CCL models such as the Strike and Posner (1985, 1992) model. It shares a similar constructivist philosophy and acknowledges the use of these models in describing the conditions necessary for conceptual change to take place (intelligibility, plausibility, fruitfulness and dissatisfaction). As discussed earlier, these models portray aspects of what was called by this writer main-CCL research. The contribution the CLD model anticipates making is one of highlighting meta-CCL phases of the process of learning in an attempt to make the learning process itself more successful and more lasting. In doing so, the CLD model does not anticipate prescribing 'checklists' or 'recipes' in the way of the Strike and Posner model regarding the conditions for CCL to take place, rather it sets out to offer a means of modeling the complex processes of learning through a different lens.

The CLD model is based on an analogy of the way radioactive elements behave hence the adoption of the term 'decay'. The term is thought to be appropriate not least because radioactive decay is a complex process with some of its mechanisms still unclear to the scientific community, just like the process of human learning and forgetting is still covered with a veil of mystery for educationalists and cognitive scientists. The following sections
draw parallels between radioactivity and human learning to substantiate the analogy; and discuss the rationale behind the construction of the model.

1.5.1. Drawing parallels in the analogy between radioactivity and human learning

In order for an analogy to deserve attention it has to be in a position to display at least some similarities between the original phenomenon and the phenomenon under study. The parallels that can be drawn between radioactive decay and the process of human learning are numerous.

The uniqueness of human learning, for one, resembles the way in which radioactive elements behave in uniquely different ways. According to the constructivist philosophy learners construct meaning in very individualized manners. They have their own learning styles, their own preferred learning techniques and their own personal abilities. They exhibit different rates of constructing or ‘aborting’ knowledge and they react to learning stimuli in different manners. On top of this, most of the mechanisms of human learning are, to date, unclear to social scientists, resembling scientists’ partial knowledge of some of the processes of radioactivity.

Considering the effect of the two processes on their objects of activity, namely radioactive elements and conceptions, helps in identifying further parallels between the two processes. By ‘losing’ parts of themselves over time existing conceptions in essence become new conceptions, just as in the case of radioactive elements changing because of the emission of particles and the loss of parts of the nucleus. It is further suggested that similar to the three types of particles (α, β, γ) being emitted or ‘lost’ by radioactive elements there are three types or categories of knowledge being ‘lost’ over time from conceptions held by a learner. The three categories are related to:

a) Ability to recall information related to held conceptions.

b) Ability to explain, justify and elaborate on aspects of held conceptions.

c) Ability to apply and utilise learned concepts in different contexts.

Reference to the three categories at this point is restricted to highlighting the links between radioactive decay and the CLD model. Fuller discussion will follow during the analysis of the data collected since this categorization relates to the underpinning philosophy of both means of collection and interpretation of data.
This researcher acknowledges an important difference in the analogy between what is 'emitted' or 'lost' during the two processes of decay. In the case of radioactivity, no material is lost since emitted electrons, for example, may recombine with other ions to become new elements and therefore continue to exist in a different state. In the case of forgetting, though, it is widely acknowledged that although some pieces of information -often trivial- can be stored in long-term memory for remarkably long periods, the vast majority of information items in short-term memory are lost on fast and continuous basis without ever been retrieved again. Such knowledge, in a sense, ceases to exist, something that does not apply for particles emitted during radioactive decay. Having highlighted this difference, what is of particular importance for the analogy to hold is that, in both the emission (of radioactivity) and the forgetting (of conceptions), the result is that particles and pieces of information are no longer part of the initial radioactive element or working conception respectively. In other words, the similarity on which the analogy stands lies in the fact that following decay (radioactive and conceptual) elements of X are no longer part of it. Put very simply, the analogy should be based on the fact that Y separates from X and not on what happens to Y once separated. As will become clear in the following chapters, the focus of this thesis is to delay the point of separation of pieces of knowledge held by the learner by increasing the durability of learners' conceptions.

1.5.2. Key-elements of the CLD model

The basic assumption of the CLD model is that in general conceptions held by an individual have their own concept-life. This is the time period between initial construction of a conception and the point when this begins to gradually lose its constituent parts (e.g. propositions, strings, images, episodes, according to White and Gunstone, 1992) or the learner fails to access this information. During concept-life the conception bears all information that initially contributed to its construction and it is a period during which further refinement and consolidation of learned concepts can take place provided the learner wishes to do so (e.g. finds further learning fruitful). This is a period that varies for different individuals as well as for different conceptions ranging from a few hours to many years if appropriately reinforced. Defining the period of concept-life, therefore, is highly arbitrary since this is not a period with fixed ends, as is further discussed later.

After this period of construction starts a process of conceptual decay when different elements of the conception held by the learner are gradually lost. At the same time, it is possible that although no knowledge is lost the learner cannot access this knowledge. Conceptual decay,
therefore, can be attributed to both loss of elements of knowledge and to loss of access to this knowledge. The process described can extend over a long period (years maybe) without necessarily reaching a point when the conception is completely ‘forgotten’. Figure 1.2 presents a summary of basic notions incorporated in the CLD model that should help make explicit the way this writer perceives the mechanisms discussed.

The CLD model suggests that conceptual decay takes place because conceptions are in an unstable state, just like radioactive decay takes place when an unstable nucleus disintegrates to acquire a more stable state. Conceptions, on the other hand, that are well embedded in the learner’s conceptual repertoire do not easily experience conceptual decay, and when they do this happens at slow rates. This view of conceptual decay is congruent to Strike and Posner’s (1992) ‘conceptual ecology’ and the attributing of a certain status to existing and new conceptions. The higher the status of the conception, the slower the process of conceptual decay, whilst for conceptions of low status the process of decay is more rapid. It is further suggested that ‘unstable’ conceptions are more likely to be less intelligible, plausible and fruitful to the learner than ‘stable’ (either scientific or alternative) conceptions.

In using the term conceptual decay, this researcher ascribes similar meaning as the one employed by Ausubel (1968) in his assimilation theory for ‘obliterative subsumption’, according to which a new concept is obliteratively subsumed under more general existing concepts in cognitive structure (Novak, 1998). In doing so, the subsuming (existing) concept becomes modified by the information borne by the new concept, which is gradually subsumed with time and ceases to exist as such. In making the connection between ‘obliterative subsumption’ and conceptual decay, emphasis is placed by this writer on the common assumption that both ‘obliterative subsumption’ and conceptual decay follow meaningful learning that provides enhancement of cognitive structure, differentiating, that is, from forgetting of rote learning.

Of particular importance to the CLD model is that, once the process of conceptual decay starts, any intervention for further conceptual development cannot be as successful as it would be during the period of concept life due to the loss of (or access to) some elements of related knowledge. It becomes apparent that this loss creates some gaps in the learner’s understanding which have to be filled before attempting any further development, a technique commonly used in schools through revision of learned material before further instruction.
Following construction and a period of *concept-life*

Conception A

begins to experience *conceptual decay*.

This can be attributed to:

| Knowledge that can not be retrieved | Loss of elements of knowledge | Loss of access to elements of knowledge | Knowledge that can potentially be retrieved |

resulting in:

Conception B

Which is less inclusive, less advanced and probably a previously held alternative conception

*Figure 1.2 Notions and relationships of the CLD model*
The importance of concept-life is therefore explicit. If concept-life is not long enough in order to facilitate appropriate intervention then further development of the concept is radically restricted (if any) since it will take place during the period of conceptual decay.

The CLD model further assumes that similar to radioactivity that virtually never drops to zero, with the exception of cases of learners suffering amnesia, individuals do not normally forget absolutely everything they learned about a certain concept, even after considerable time has elapsed. Supportive of this claim is the common experience that although people appear not to remember a certain concept taught some years ago, the mere sound of a relevant name or term can trigger memories from the trivial to the very important. Further discussion on issues of memory and forgetting is taken up in the next chapter that looks into the notion of durability.

A last point to be acknowledged is that the continuous construction of new knowledge is, of course, a factor that complicates the process of conceptual decay, since new conceptions might in effect reinforce or further weaken existing conceptions. Including this dimension in the analogy behind the CLD model would have led to a level of complexity that would hinder discussion, therefore it is consciously avoided. This said, it is not suggested that the analogy is free from any other important or less so points of conflict between the two processes of decay.

1.5.3. Points of conflict
As stated in the Introduction to this thesis, this writer strongly supports that a fundamental principle in the use of analogies is that no analogy is flawless nor can it fully represent every single element of the phenomenon under study — only the phenomenon replicating itself could do that. There are, therefore, a number of points on which the CLD model does not meet the corresponding processes of radioactive decay.

One such point is related to the fact that radioactive nuclei disintegrate spontaneously and the process cannot be speeded up or slowed down. Contrary to this, the main claim of the model is that conceptual decay can be slowed down, something that is among the fundamental assumptions of this thesis. A second point of conflict between the model and radioactive decay is that, in the case of the latter, radioactivity cannot be ‘reversed’ or ‘built up’ within an element. Elements posses radioactivity as part of their characteristics and they are involved in a ‘one-way’ process of ‘losing’ their radioactivity with time. In other words, they behave in
an irreversible manner. Quite the opposite exists in CLD where human learning
interchangeably behaves in a twofold way, both constructing and ‘aborting’ knowledge if this
is of no use for a period of time. A third inconsistency of the model is that the radioactivity
being ‘lost’ is emitted to the surrounding environment, hence portraying an ‘inside-out’
process taking place. In the case of conceptual decay, though, the process is one of ‘inside-in’
since ‘lost’ or ‘aborted’ knowledge mysteriously ‘disappears’ from one’s working memory,
often with the potential to be later retrieved if the right stimuli are offered.

These points of conflict in the analogy between the CLD model and the phenomenon of
radioactive decay are certainly not trivial and probably not the only ones that can be
discussed. However, they are raised in order to emphasize that these are consciously
overlooked, stressing that an analogy-based model can be sufficiently valid by selectively
focusing on the elements that successfully fulfill the analogy.

1.5.4. Conclusion to the model

A number of links were drawn between the two types of decay that, as this thesis suggests,
justify the viability of the CLD model. In doing so, two important points should be kept in
mind: a) both radioactive and conceptual decay are complex processes still obscured by
mysterious mechanisms for which definite answers or claims are not possible; and b) the
parallels between the two phenomena should not be judged on a strict one-to-one basis but
should be seen under the selective philosophy that should accompany the use of any analogy.

Conceptual decay takes place in an unspecified manner over time and reflects the personal
lack of stability of conceptions held by the learner. The target of the experimental approach
proposed by this thesis is to increase the concept-life of taught material by means of
metacognitive instruction. This reflects two main objectives: first, achieving longer durability
of taught concepts; second, offering longer opportunity for more advanced concepts to be
constructed. Lastly, it is emphasized that the CLD model provides a general theoretical
background to this thesis and serves in representing how the mechanisms of learning,
remembering and forgetting are perceived by this writer. Any attempt to identify elements of
this model in the conduct or the results of this research, although justified, should not be
made with the belief that the research intended to verify the theoretical model in any way.

Before concluding this chapter reference is made to the topic of electricity, which provides
the content area in which this research is accommodated. In doing so, the choice of the
specific topic by this researcher is justified and CCL research in the same area is briefly discussed with an emphasis on students’ alternative conceptions of electricity.

1.6. Research on children’s ideas of electricity

The study of electricity offers an area that is welcomed by children with enthusiasm mainly because of the practical activities involved and because it is an area that is related to everyday life, making the study of it meaningful and purposeful for the children. It is also a subject that presents considerable difficulties in comprehending the science involved, therefore providing a research area that allows for richness in outcomes due to the complex concepts and relationships it entails. Electricity is also a topic considered by a number of teachers to be hard to teach, something that adds to the importance of any contribution made to this area by this research. This attitude on behalf of the teachers can have a positive impact on practical aspects of this research, in the sense that many teachers would be happy to hand over their class to someone else who would undertake the teaching of the specific unit.

Research into children’s conceptions of electricity is impressively extensive and covers different levels of complexity (e.g. Shipstone, 1984, 1985; Osborne and Freyberg, 1985; Duit et al., 1991). Methodologies used by such studies have varied considerably, usually being imposed by the age of the participants and the amount of prior knowledge they held about electricity. In studies with young children who have experienced no formal teaching of electricity, the procedure usually involved giving the children some simple material, like a dry cell, a couple of wires and a light bulb and then asking them to light the bulb. Having done so, the children were then interviewed, asked to explain what they did, what they were thinking of, and how they could explain what happened. The outcomes of these studies suggest that children’s early ideas about electricity generally indicate some sort of a source-consumer relationship in which the battery gives something to the bulb (Driver et al., 1994).

In their effort to describe the science behind the process of lighting a bulb children make use of a number of ‘mini-theories’ or explanatory models. Osborne and Freyberg (1985) in New Zealand, identified four explanatory models usually used by children, which were also found by other researchers in different countries (e.g. Psillos, Koumaras and Tiberghien, 1988; Driver et al., 1994). These are briefly described in Figure 1.3 as reference is made to them.
again in proceeding chapters that deal with the analysis of data and the discussion of the outcomes of this study.

The ‘unipolar model’.
According to this model only one wire in a circuit is considered to be active and there is flow of current from the positive terminal of the battery to the bulb. The second wire is seen as being ‘extra’ or with no important role in lighting the bulb.

The ‘clashing currents model’
This model suggests that current flows from both terminals of the battery to the bulb where it meets and produces energy that lights the bulb up.

The ‘current consumed model’
According to this model current is ‘used up’ by the bulb, hence resulting in less current in the wire returning to the battery, and suggesting a time sequence of events. Shipstone (1984) calls this a ‘sequence model’ while Osborne (1983) calls this an ‘attenuation model’.

The ‘scientists’ model’
This is the scientifically accepted model according to which current flows around the closed circuit and it is conserved. Any change introduced at any point of the circuit affects the whole system, therefore the circuit is seen as a system of interacting elements.

Figure 1.3 Children’s alternative explanatory frameworks of electricity

Notably, all alternative explanatory models are ‘sequential’ implying that current, electricity, energy, or ‘something else’ leaves the battery and travels around the circuit meeting wires and components in sequence. The battery is often considered by children to be a unipolar ‘giver’ of electricity, being a store of electricity or energy, and very little notion of voltage or potential difference is held. Most pupils think of current as synonymous with electricity and electrical energy (Driver et al., 1994).

According to Borges and Gilbert (1999), children’s understanding of simple electrical circuits improves with age and instruction, moving from simple intuitive mental models towards versions of the socially agreed model of ‘orthodox’ science. Children gradually come to acknowledge the need for a closed circuit if current is to flow in it, and the bi-polarity of the battery and other circuit elements (Osborne, 1983; Psillos et al., 1987; Cosgrove, 1995). Other aspects of their understanding, on the other hand, such as the ones related to conservation of current, are more resistant to change. Notably, when research techniques similar to the ones described earlier were used with older students, even at university level,
their attempts to light the bulb and the explanations they were giving were very similar to the ones given by primary school students (Fredette and Lochhead, 1980), something that is indicative of the persistence of some alternative ideas associated with electricity. Problems with the durability of scientifically correct conceptions of electricity constructed by students were also reported. Osborne (1983), for instance, found that in a small group of 11-year-olds, 86 per cent held the scientific model following a critical lesson in which current measurements were taken on either side of a bulb, but that only 47 per cent still held similar understandings after one year.

There are two main problems with teaching electricity that can considerably hinder the process of learning. The first problem is that electricity is, by and large, an abstract entity, since only its effects can be observed and studied. As Black and Solomon (1987) point out:

*Lamps light and ammeter needles move, but the current is only to be thought of by a creative effort of the pupil’s own imagination* (p.250).

This is one reason why children’s explanations of electricity entail strong anthropomorphic features that help them visualise the phenomenon, and the reasoning on which some researchers have used anthropomorphic representations to facilitate teaching of basic concepts of electricity (van Valkenburgh, 1974; Hartel, 1982). As noted earlier, models, analogies and metaphors have been long and widely used in the teaching of science in an effort to make abstract, remote or invisible phenomena and ideas accessible to young learners. In the case of electricity, and electric current in a circuit, in particular, a plethora of such analogies have been recruited over the years (Stocklmayer and Treagust, 1994; Georghiades, 1999b) offering valuable teaching tools for tackling an admittedly difficult topic.

The second problem with electricity as a science topic is the strength with which prior conceptions or alternative frameworks of electricity are maintained by pupils. Being part of everyday life, children are brought up exposed to numerous concepts and ideas associated with electricity. ‘Short-circuit’, ‘blown-out fuse’, ‘power failure’, ‘electric shock’, ‘insulators’ and ‘switch’ are only a few examples of terms that nearly everybody uses in everyday situations. Nevertheless, the meaning attached to these terms can diverge dramatically from the scientific point of view, and the meanings resulting from such divergence are usually the ones to which the children are exposed from a very young age. Reinforced by observation that tends to ‘verify’ rather than contradict these ideas, makes their change a hard task to accomplish. The language used at home and its idioms can also
play an important role in establishing alternative conceptions, an issue that is discussed further during the analysis of the results in Chapter 6.

1.7. Summary

This first chapter set the background to this thesis by discussing the broad theoretical framework of conceptual change learning (CCL). Constructivism was presented as the underpinning philosophy and an insight was attempted into the nature of CCL and the mechanisms involved during learning and forgetting. CCL literature was briefly reviewed highlighting under-explored areas and making the focus of this thesis explicit. In doing so the model of concept life and decay (CLD) was presented listing a number of important assumptions made by this writer. The last section of this chapter summarised outcomes of research on children's ideas of electricity, which is the subject-unit accommodating the research presented by this thesis.

The second chapter discusses the notion of durability of learners' conceptions within the CCL framework just drawn.
Chapter 1 - Conceptual Change Learning

**Constructivism**
- History of constructivism
  - Content and nature of constructivism
  - Constructivist teaching – Practical issues
  - Critique of constructivism

**CCL**
- Content and nature of CCL
- Definitions
  - Concepts v Conceptions
  - Misconceptions v alternative frameworks
  - What is 'change'?
  - Learning and Understanding

- Models of CCL
- The process of CCL – Practical issues
  - Problems with CCL
  - Cognitive conflict

- Contemporary CCL research and under-explored areas
  - Early-CCL
  - Main-CCL
  - Meta-CCL

- CCL and the focus of this thesis
- Focus of this thesis

- Model of Concept-Life & Decay (CLD)
- Research on children’s ideas of electricity

Figure 1.4 Graphic summary of Chapter 1
CHAPTER 2 - DURABILITY OF PUPILS’ CONCEPTIONS

2.1. Introduction to Chapter 2
2.2. Importance of maintaining durability of conceptions
2.3. Psycho-cognitive dimensions of durability
   2.3.1. Memory and forgetting – Links to the CLD model
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2.6. Summary
2.1. Introduction to Chapter 2

With rare exceptions (...) the goals of training are long-term goals. We would like the knowledge and skills acquired during training to be durable, not only in the sense of surviving from the end of training to a later time when that knowledge or skill is demanded in a real-world setting, but also in the sense of surviving periods of disuse in the posttraining environment itself (Bjork, 1996, p.186).

Oxymoron as it might seem to investigate how durable pupils’ newly constructed conceptions are within a framework of conceptual change, this thesis assumes that there is ample ground for doing so. The common phenomenon of pupils forgetting what they learned in very short time after initial instruction (Hagerman, 1966; Novak, 1998) offers sufficient evidence for the existence of an important problem related to the durability of pupils’ conceptions of scientific phenomena, and imposes the need for investigating this area.

This is the main theme discussed in this second chapter. The importance of maintaining durability of pupils’ newly constructed conceptions within a CCL background is argued; durability is contrasted to the notions of persistence and consistency of conceptions; and an outlook of the mechanisms involved in memory and forgetting is briefly attempted. Links to the previously discussed notions of concept-life and conceptual decay are also drawn. This chapter concludes by making reference to some methodological dimensions of the research with respect to the durability of pupils’ conceptions in electricity.

2.2. Importance of maintaining durability of conceptions

The ancient Greeks used to characterise the notion of time as ‘pandamator’, which meant ‘tamer of all’. By doing so they emphasised the belief that everything is under the powerful impact of time and that cannot be beaten. To speak of durability, therefore, is an undertaking that can prove futile and meaningless unless the boundaries in which durability is sought are defined and the significance for such a relativistic claim is made explicit.

In the context of organised systems of education, durability is among the qualities that ideally should characterise all taught knowledge, if teaching and learning are to be acknowledged as purposeful endeavours. The reasoning behind such a claim is that education aims to prepare the citizens of tomorrow who will use the skills and knowledge accumulated over their
school lives in real-life settings. In order for knowledge to be potentially used, it has to be durable.

Following an extensive review of related studies, the term 'durability of conceptions' does not appear to have been previously used in the literature. This thesis defines durability of conceptions as that which answers the question 'How long does a workable conception remain in effect within the learner's cognitive repertoire?' What might at first sound as a rhetorical question (one that could easily reach an answer by testing taught material after a certain amount of time has elapsed since learning took place), becomes an issue of high significance within the broader framework of this thesis. Putting aside its value as a positive feature of learning, the notion of durability is regarded by this writer to be of utmost importance to learning by conceptual change, primarily because of the structuring of the learning process. Simply considering that the success of conceptual change learning is largely determined by existing (mis)conceptions (e.g. their nature, strength, persistence) then it becomes apparent that the durability of these conceptions will have an impact on the whole process.

In making this claim, this thesis demonstrates the following reasoning. Conceptual change, by definition requires the existence of 'Conception A' in order to construct 'Conception B' by means of changing the former. In order to do so, it becomes apparent that 'Conception A' should have a long enough concept-life (introduced in Chapter 1) such that will allow 'Conception B' to be constructed upon it or to evolve from it given that appropriate interaction takes place. It is therefore argued that if CCL is a chain-process of constructing new conceptions on pre-existing ones, then the durability of new conceptions each time should be seen as a prerequisite for effective learning. Failure, for instance, to establish scientific 'Conception C' on a previously constructed 'Conception B' may be because 'Conception B' was not durable enough and the learner exhibited regression (conceptual decay) to initial 'Conception A' -probably an alternative framework- before any further conceptual interaction took place (Figure 2.1).

What is therefore argued is that durability is a feature of conceptions with a key functional role to play, often determining the success or failure of the whole process of learning through conceptual change. Put differently, durability is considered by this writer to be sine qua non for conceptions, if CCL is to be an on-going process characterised by progressively moving to higher levels of learning and understanding.
Figure 2.1. The process of conceptual change
In advocating the high significance of durability this thesis does not claim that prolonged durability can compensate for quality or depth of understanding of conceptions. What it does suggest, though, is that durability can be a *precondition* for quality and depth of understanding to develop, for a shortly abandoned conception (that consequently demonstrates very short *concept-life*) is denied the chance for developing such features.

By saying so, this writer does not assume that durability is a feature of conceptions that exists in some general or objective way, rather it is based on a judgement made each time further conceptual change is sought. If, for example, the process of *conceptual decay* commences before any attempt is made towards more advanced conceptions then it can be said that sufficient durability has not been demonstrated.

Due to the apparent dependence of the notion of durability of pupils' conceptions on functions such as *memory* and *forgetting* the discussion cannot ignore the psycho-cognitive dimension of durability. The following section takes this path of inquiry.

### 2.3. Psycho-cognitive dimensions of durability

The notion of durability of conceptions is heavily rooted in the field of cognitive psychology being tightly linked with *memory* and *forgetting*, and to a lesser degree with theories of consciousness and sub-consciousness. Numerous studies that take an interest in these areas of psychology are currently available in the literature, their outcomes being extremely diverse in nature. This section presents such studies as part of the theoretical framework of this chapter rather than as objects for extensive elaboration in their own right.

#### 2.3.1. Memory and forgetting — Links to the CLD model

Human memory and its functions have been extensively studied over recent years resulting in the revealing and describing (in some cases less so) of complex and somewhat mysterious mechanisms. Drawing from the vast literature in this area, contemporary psychology makes at least two important and widely accepted distinctions with regards to memory, which are briefly discussed in relation to the interests of this thesis.

The first point is that memory is characterised by the three stages of *encoding*, *storage* and *retrieval*, often paralleled with the processes involved in storing a computer file on disk.
These three stages of memory are thought by this researcher to be important for, as the presentation of the research design in a proceeding chapter will show, they refer to significant turning points of the research presented by this thesis. An explicit attempt is made to influence the process of encoding during learning by means of metacognitive activities that are thought to make links and relationships apparent and facilitate deeper understanding. This course of action is based on the belief that such intervention makes storage more lasting by offering meaningful representations of taught concepts and by facilitating more conscious learning. During retrieval, on the other hand, contextual considerations are heavily taken into account as they provide one of the main research directions of this thesis. For example, taught concepts are tested in a variety of contexts using ‘parallel’ exercises that refer to the same concept accommodated in considerably different settings.

The second point that enjoys considerable consensus is that memory can be divided into short-term (or working) for storing information for short periods of time, and long-term for storing information for longer periods, both terms emerging from William James’ (1890) notions of ‘primary’ and ‘secondary’ memory. The longitudinal design of the research presented by this thesis, extending over a ten-month period, clearly directs interest into long-term memory. The use of terms such as ‘memory’, ‘remembering’ and ‘forgetting’ will therefore refer to long-term memory and the mechanisms associated with it.

Referring to the long-term store as of ‘supposedly unlimited capacity’ Butler and McManus (1998) point out that

... information in the long-term store need never be lost if only one knew how to find it. Forgetting would occur because similar memories become confused, and interfere with each other when we try to recall them. So, unless we have the mind of a mnemonicist, one birthday party becomes confused with another and what we remember in the end is something about the significance of birthdays rather than exactly what happened when we were 5 or 10 or 15. General meanings are more important than details unless something marks those details for us (a 21st birthday or a surprise party) (p.39).

This thesis assumes important implications for classroom practice emerging from such a standpoint, for it primarily suggests that investigating ways of ‘marking’ the learning of concepts should become a priority in the teaching of science. In favour of this comes the all too common experience of people tending to recall some – possibly trivial – piece of knowledge after many years, only because that knowledge was constructed under unusual or striking circumstances. This is an argument that is taken on in Chapter 4 metacognition being the ‘marking activity’ employed by this researcher.
Other dimensions of human memory like, for instance, the fact that different types of memories and different structures of the brain are responsible for the storing of different kinds of information (e.g. facts against skills) are also widely acknowledged by psychologists (Baddeley, 1990) yet their heavy reliance on biological perspectives places them beyond the domain of this thesis. What is of interest to this thesis, as will emerge in the following chapters, are views such as Novak’s (1998) interpretation of Ausubel's theory, according to which

\[ \text{variation in amount of recall depends primarily on the degree of meaningfulness associated with the learning process (p.60).} \]

The second area of interest to this section is the one of forgetting. Two main theories for explaining forgetting are currently available, both originating from Ebbinghaus (1913). The first is the spontaneous decay theory according to which memory deteriorates with time regardless of other output. Thorndike (1914) revised the decay theory suggesting that memory traces decay when they are not used. The second theory, on the other hand, that of interference suggests that memory is actively disrupted by the impact of other input during the time between initial storage and retrieval. To date it is often impossible to know whether forgetting from long-term memory is caused by loss during the process of storage or due to failure in the stage of retrieval. Psychologists also assume that many cases of forgetting can be the result of loss of access to the information learned, rather than the loss of the information itself, a point that was already accounted for in discussing the CLD model in Chapter 1.

Following the work of Ebbinghaus (1913) it is widely acknowledged that newly learned material is initially forgotten at rapid rates and that forgetting becomes far more gradual at longer retention intervals (Groome et al., 1999). This is reflected in the well-known curve produced by Ebbinghaus in which forgetting of lists of words initially learned to mastery appears to take place in an exponential way (Figure 2.2).

This thesis shares the view that Ebbinghaus’ curve may be less universal than is often assumed (Baddeley, 1990) and not applicable in all learning situations since its generation was based on very different (primarily more artificial) circumstances than the ones in which learning takes place in schools. One important difference between Ebbinghaus’ curve and the rate at which conceptions experience decay lies in that, because conceptions are more meaningful entities (even when partly or wrongly understood) than unrelated words or
numbers, forgetting does not take place as quickly as in the latter case. Conceptions are not lists of isolated words or numbers rather they comprise mental constructions of related pieces of information put together in an intelligible, plausible and fruitful way. Consequently, once conceptions are constructed, it seems reasonable to assume that they are not as rapidly forgotten as a list of unrelated words and numbers because of the impact of meaning as a unifying agent. Research from both fields of psychology (Craik and Tulving, 1975; Bradshaw and Anderson, 1982) and education (Ausubel, 1968; Novak, 1998) provide ample evidence to support this claim.

![Figure 2.2. Ebbinghaus' curve of forgetting](image)

Having discussed a number of important dimensions of the notion of durability of pupils' conceptions and presented aspects of how its nature is perceived by this writer, the next section reports how similar issues were treated by science education literature.

2.4. CCL research with a time dimension

2.4.1. Brief review of related studies

It is inevitable that this section starts by pointing out that research with an interest in durability of pupils' conceptions is among the least available to date within science education. Discussion, therefore, will have to be based on related areas or areas that partly share a similar interest.

The Cognitive Acceleration through Science Education (CASE) project is one of the research efforts that included a time dimension. The project is discussed in some detail in Chapter 4 that deals with the notion of metacognition. Of interest to this chapter is the fact that CASE
has investigated long-term effects of programmes extending to two and three years after initial intervention (Adey, Shayer and Yates, 1991). In doing so CASE focused (among other things) on how permanent the effects of the intervention programme were on *children's ability to think and learn*, general thinking skills being at the core of its underpinning philosophy. The target area was once again (general) *skills* rather than (specific) *conceptions*. Conceptions themselves were apparently treated as an integrated part of the whole procedure and not as *the* area under investigation, hence clearly differentiating from the issues addressed by this thesis. The outcomes of the project were encouraging, presenting evidence of both short-term and long-term improvement in children's ability to think and learn.

Other studies on conceptual change that investigated students' conceptions on a long-term basis are also available but they are very few in number (e.g. Engel-Clough *et al.*, 1987; Novak and Musonda, 1991). The study of coherence and persistence of students' preconceptions (Licht and Thijs, 1990) and the conditions for permanent effect of intervention programmes on the way students process fresh learning and approach problem solving (e.g. Feuerstein *et al.*, 1980) are examples of the focus of such research. No research reports were traced by this writer in which the central question was how durable or how long lasting are children's newly constructed conceptions, something that makes research of this aspect of CCL even more challenging.

Of particular interest to this thesis is the fact that some scholars are beginning to assume links between durability of learning and engagement in metacognitive thinking (Hacker, Dunlosky and Graesser, 1998), which is precisely what this thesis is advocating. The connection between the two areas is discussed in detail in Chapter 4, which deals more fully with the notion of metacognition. Discussion at this stage will concentrate on making explicit how this writer perceives durability of conceptions and how its nature is contrasted to related notions such as *consistency* and *persistence*.

### 2.4.2. Durability versus consistency and persistence of conceptions

A common theme of CCL literature which includes a time dimension is the frequent reference to two areas closely related to durability, namely the notions of *consistency* and *persistence* of pupils' conceptions. The literature more often than not treats the two as a single feature of conceptions, a practice that is not followed by this writer who assumes different characteristics for the two phenomena. Before, however, differentiating between the two notions of consistency and persistence, distinction between consistency and persistence
on one hand, and durability on the other, is called for. As defined earlier, durability is thought by this writer to refer to the question: “How long does a workable conception remain in effect within the learner’s cognitive repertoire?” whereas consistency and persistence are related by this writer to the question “How often is a conception used when resembling contexts are encountered?” High consistency or persistent use of a particular conception suggests that this is strongly embedded in the person’s conceptual repertoire, something that need not necessarily be true for a conception (inactively) present for a long time. This difference in essence is precisely why this thesis treats research on consistency and persistence of conceptions as ‘related’ research and not as identifying with the notion of durability.

Looking at the second distinction, that between consistency and persistence of conceptions, this is based on the impact or the contribution made to the CCL process by each of the two, this being either of a positive or negative texture. Although persistence of a conception naturally denotes durability, it is this writer’s belief that this has a rather negative sense due to the fact that persistence in the use of a certain (alternative or scientific) conception can act as impediment to further conceptual change. In other words, persistence is taken to denote the insisting on using a certain conception, hence indicating resistance to change. Seen in relation to the subjective and fallible nature of science advocated by contemporary philosophers of science (e.g. Matthews, 1994), the persistence of existing ideas is a feature of learning that easily falls beyond ‘good’ science practice. Consistency, on the other hand, has a more positive tone referring to one’s tendency to systematically use a conception that is judged to be appropriate in a number of circumstances. Consistency is considered by this writer to be more than the result of luck or coincidence, rather it involves decision-making on behalf of the learner that leads to the choice to (consistently) use a certain conception, or not.

The perceived difference between consistency and persistence is admittedly a very thin one and this writer cannot speculate that the use of the two terms by other scholars was accompanied by the assumptions put forward here. In spite, therefore, of this writer’s declared belief for the need of distinguishing between the two, the following section presents related research under one heading due to the interchangeable use of the two terms within the literature.
2.4.3. Research with an interest in consistency or persistence of conceptions

The majority of the literature that investigates CCL from a time perspective deals with the notion of consistency focusing on the consistency of children’s use of both science conceptions (e.g. Tytler, 1994) and alternative frameworks (e.g. Palmer, 1993). Engel-Clough and Driver (1986), for instance, studied consistency in the use of students’ conceptual frameworks across different task contexts. In doing so, they employed a longitudinal element in their study by examining secondary school students’ conceptual frameworks two years after their initial investigation. They found, among others, that alternative ideas are not as consistently used by students as are ‘scientific’ responses, an outcome that is particularly hopeful in suggesting that once a correct scientific explanation is learned in one context it is likely that it will be used in others. They also presented some evidence that students’ alternative frameworks associated to ideas that could be informed by experiential knowledge are more persistent than others.

In a study of primary school children’s explanations of phenomena concerning air pressure Tytler (1994) found considerable fluidity in their use of conceptions, suggesting that young children, in particular, are opportunistic in applying a range of ideas to different tasks. He further concluded that the notion of consistency is somewhat problematic due to the multifaceted character of learners’ thinking about phenomena and the operation of contextual cues and cultural understandings regarding the appropriateness of a conception under particular circumstances.

Referring to low levels of concept consistency among students Palmer (1993) suggests that their failure to achieve complete consistency is not just a feature of alternative conceptions, rather

…it may be rooted in a general inability to apply ideas consistently across different contexts, even when these contexts are closely related... (p.230).

Palmer (1993) identifies further problems of conflicting evidence from studies in the field. He points out that Vosniadou and Brewer (1992) studied conceptions of the Earth’s shape, identifying ‘consistent concepts for the great majority of the children’, whereas Summers and Kruger (1992) traced inconsistencies in their learners’ descriptions of energy and Engel-Clough and Driver (1986) reported that ‘students were using different alternative frameworks in response to parallel questions’ on pressure, heat and inheritance. The matter becomes even more interesting, yet complicated, when considering cases of conceptions that are not
mutually incompatible hence using them in parallel does not denote inconsistency (Tytler, 1994).

In spite of the persistent and recurring nature of pupils' alternative frameworks reported by a number of scholars (e.g. Gunstone et al., 1981; Gauld, 1986), the notion of consistency is strongly questioned by others in a holistic manner, suggesting that most students are unable to consistently apply either the alternative or the correct scientific conception (e.g. Palmer, 1993). A potential explanation of these findings may be accommodated within the notion of durability of conceptions; that is, scientific or alternative conceptions may not be used consistently in resembling contexts because by the time the learner is expected to refer back to them, these have already experienced conceptual decay. In evaluating, therefore, the two notions in terms of research priority, this thesis ascribes greater importance to durability of conceptions. Even more so, in the case of primary school children where of greater importance is not how consistently a child applies a certain conception of science, rather how long that conception remains in effect, in order to enable further change towards more sophisticated concepts in the future.

The negative sense attributed to persistence of conceptions earlier in this section, is partly justified by the fact that an important outcome of CCL research with a time dimension is one of persistence of pupils' alternative conceptions or preconceptions, rather than for the 'scientific' conceptions that pupils frequently appear to adopt in class. The literature is rich of examples of studies reporting similar outcomes hence making the notion of durability increasingly interesting and important.

In a study by Gunstone et al. (1981) with 12- and 13-year-old pupils, the main effort was to change children's initial beliefs about force and motion which were largely pre-Galilean. The pupils believed that if things are to be kept moving then a force is needed, and that speed is proportional to force. After working with the pupils for eight weeks the researchers observed that the experiences they had offered the pupils throughout the period brought them to revise their views into line with the Newtonian system. However, when the researchers decided to do one final probe of the pupils' beliefs they found, to their surprise, that the initial pre-Galilean beliefs were still there. The Newtonian statements that appeared in all previous probes were of very temporary nature.

In another study by Gauld (1986) with upper secondary school students the subject was 'electric current in a simple circuit'. When the students were asked about the current on each
side of the bulb, Gauld found that, along with the scientists' belief that the current is the same in both wires flowing round the circuit, there were a number of alternative conceptions or misconceptions among the students. Having identified these initial beliefs the researcher proceeded to use ammeters on each side of the bulb, something that demonstrated that current was the same on both sides. Any belief, therefore, other than the 'scientific' was proved to be wrong. However, three months after the demonstration, Gauld returned to the same students and asked them again about the electric current in the wires. Most of the students had reverted to their original beliefs while some of them even claimed that what they were supporting had been proved to be correct by their measurements three months ago! What had actually happened was that these students changed their memories of the observation in order to match their beliefs, exhibiting 'confirmatory bias' (seeing what one expects to see) (Hennessy, 1993). As White and Gunstone (1989) put it 'Beliefs conquer memories' (p. 580).

In general, the literature has indirectly identified a number of factors affecting or determining the potential durability of taught scientific concepts. These factors include students' existing conceptions, the time interval between teaching and testing, and the context(s) within which the concept is taught and tested (Dawson and Lyndon, 1997). Of particular interest to this thesis is the fact that research has shown that the number of students who give correct answers to physics questions declines significantly as students become more and more remote from their school science learning (Viennot, 1978), therefore substantiating the claim that

Lapse of time will select preferentially for the life-world structure of meaning if there is no further reinforcement of symbolic knowledge (Solomon, 1983, p.53).

This stance represents a major challenge to this thesis, for part of its objectives is to delay regression to life-world meanings, by influencing initial construction of conceptions by means of metacognitive instruction.

Having briefly looked at the notions of consistency and persistence of students' conceptions, the two will be brought up again during the analysis of data in Chapter 6. The next section serves in sharpening the focus of this thesis with regard to durability of pupils' conceptions and discusses briefly some methodological dimensions of this research.
2.5. Focus of this thesis and some methodological issues

The notion of durability of conceptions is overtly multidimensional and can be tackled from a number of different angles. Cognitive psychology, learners' biological maturation and theories of learning are only a few of the theoretical frameworks that could serve as a perspective for discussing and researching this area. The need therefore for clearly defining the interest and the research focus of this thesis is evident.

The first point to make explicit is that the research presented by this thesis does not attempt to measure how durable specific conceptions are nor to analyse in detail aspects of durability *per se*. Such an attempt would inevitably be highly problematic and of limited validity due to lack of appropriate means for such measurement and the great number of methodological threats accompanying an endeavor in this direction. The scope of the research is primarily comparative. It sets out to examine any impact of the proposed experimental approach (discussed in subsequent chapters) against more traditional methodologies by looking at observable outcomes, namely retention of conceptions over a period of time. The attempt behind this is one of prolonging durability or delaying conceptual decay to alternative life-world explanations. Comparisons with regards to durability between different conceptions taught within the same subject-unit are also possible, but only as a 'secondary' outcome of this research.

An important assumption of this thesis is that deeper insight into the issues of durability and consistency (or persistence) is tightly linked to ability to use conceptions in different contexts. What appears to be consistent or inconsistent is largely defined by the process of decision making in using constructed conceptions. "Does situation B resemble situation A?" "Will conception X serve effectively in situation B like it did for situation A?" Answers to this kind of questions will specify whether the conception being considered will be used or not. Therefore, if the same conception is employed in a series of similar or related settings, then one can talk of a durable and consistent conception. If, on the other hand, for similar settings the learner refers to a series of different conceptions, the problem of a conception exhibiting short durability, or a conception which albeit durable is characterised by inconsistency then arises. In both cases, the key activity is the attempt to apply or utilise conceptions, demonstrating that durability shares important links with the other broad problem area of this thesis, that of using newly constructed conceptions in different contexts.
Last, although methodological issues are thoroughly covered in Chapter 5 a word is thought necessary at this stage on practical aspects of this study that relate to durability. This thesis is largely akin to the decay theory of forgetting (Ebbinghaus, 1913) that shares a similar terminology with the CLD model presented in Chapter 1. This choice does not suggest that interference between teaching and follow-up testings during the period of this research is altogether excluded. It is, however, this writer’s belief that since no other topic related to current electricity is required by the science curriculum for Year 5 to be taught to the classes participating in this research, such action of interference is largely diminished.

In order to bring its objectives to life the research presented by this thesis employed a longitudinal design with three follow-up testings over the period of one school year, making use of written tests and repeated interviewing. The reasoning behind the selection of the ‘three time’ instances for testing how durable pupils’ conceptions proved to be, the research tools used and the exact course of action taken is thoroughly described in the methodology chapter (Chapter 5). The point made here is that in order to test the notion of durability of conceptions this thesis makes use of both qualitative and quantitative measures. The first of these measurements look at the question of ‘what is durable?’ with an interest in the ‘depth’ of durable conceptions, whereas the second consider the question ‘to what extent are conceptions durable?’ focusing on the ‘how much’. In order to investigate the latter this research makes use of written tests by which means this researcher can describe the extent to which constructed conceptions prove durable or not. Repeated interviews with the students are employed for examining the former, in order to identify the conceptions held by the students (either ‘scientific’ or ‘alternative’) and follow these conceptions in the three rounds of interviews to study how these change over time. A more detailed account of the blend of qualitative and quantitative measures for analysing and describing durability is given in the methodology chapter.

2.6. Summary

The discussion on durability of pupils’ newly constructed conceptions of science has aimed to highlight the importance of durability as a positive feature of conceptual change learning and to make clear how the focus of this thesis differentiates from questions already covered by existing literature. Reference was made to examples from the limited literature on durability, along with discussion of the closely related notions of consistency and persistence.
of conceptions, clearly distinguishing between the two. Durability of conceptions was discussed in relation to psychological functions such as memory and forgetting, and the focus of this research with respect to durability was defined. Brief reference to practical dimensions of the research with regards to durability of conceptions was also made.

Chapter 3 looks into the second of the two major directions of this research, that of ability to utilise conceptions across different contexts.
Figure 2.3 Graphic summary of Chapter 2
CHAPTER 3 - CONTEXTUAL USE OF NEWLY CONSTRUCTED CONCEPTIONS

3.1. Introduction to Chapter 3
3.2. Importance of ability to use knowledge in different contexts
   3.2.1. The debate over transfer
3.3. Importance of context
   3.3.1. Situated cognition
3.4. Practical aspects of the research with a 'context' dimension
3.5. Summary
3.1. Introduction to Chapter 3

The literature on conceptual change tends to operate on the underlying assumption that a conception, once gained, is applied across contexts... (Tytler, 1994, p.338).

This chapter looks at pupils’ ability to make use of newly constructed conceptions of science in contexts other than the ones in which learning took place. It considers context as an important aspect of human learning; discusses the existing debate over the feasibility of transfer of learning; and presents briefly the views advocated by those who write of situated cognition that assume a determinant role for context in the learning process. Some practical aspects of the research presented by this thesis are then described in order to inform the reader of how ‘context’ is treated within this thesis.

3.2. Importance of ability to use knowledge in different contexts

Context is placed under scrutiny in this chapter based on the belief that an erroneous oversimplification currently prevails in the CCL literature, which assumes that learners unproblematically manage contextual use of conceptions once constructed. The problem with such an assumption is that CCL theorists do not furnish sufficient evidence to show that students hold consistent views across a range of phenomena (Tytler, 1994). In other words, what might be regarded as a successfully constructed conception, being the outcome of a process of conceptual change, is not followed up by CCL research in order to establish whether it can also serve the needs of the learner in different contexts or under different circumstances. One explanation for this omission is that it is the result of a tendency to see the CCL process in terms of theory replacement that focuses on purely structural elements of thinking (Tytler and White, 1996).

One of this writer’s core assumptions, already discussed in the Introduction to this thesis, is that the process of CCL should not be considered completed as soon as the learner presents evidence of having constructed new conception(s), but should be further investigated to see if newly constructed conception(s) can successfully be utilised in new settings. The importance of demonstrating such ability is regarded by many scholars as an indispensable feature of learning and understanding. Brown (1987), for instance, argued that

... a learner can be said to understand a particular activity if he or she can use it appropriately and discuss its use (p.65),
and Billett (1996) has suggested that
For knowledge to be robust it should be applicable in novel circumstances (p.269).

In a similar vein Dawson and Lyndon (1997) have emphasised that
What we are looking for when we attempt to teach a new scientific interpretation is that learners will generalise its use to other events which are, to a greater or lesser extent, different from the context in which it was taught... (p.159).

Taking a different perspective, van der Meer and Mastik (1993) suggest that learning consists of two elements: acquiring knowledge, insight and skills on the one hand, and application in other settings, on the other. They further make the point that
...neither symbolic interaction nor experiences as such suffice to constitute learning. 'Learning' presupposes reproduction of behaviour or application of insights and reasoning in 'new' or 'other' settings (van der Meer and Mastik, 1993, p.78).

This is a position that is fully adopted by this thesis.

The importance of ability to use knowledge can be made explicit if one considers that a widely accepted objective of schooling and education is to prepare students for life and work within a social group. In the absence of learners’ ability to make use of the knowledge, skills and attitudes acquired within schooling, both to different contexts within the school domain and to different contexts within the wider social framework, education would have no real meaning.

This thesis further argues that failure to accommodate and use conceptions in more than one context does not simply indicate a defect in the learner’s ability to use newly constructed knowledge, rather it reveals a deeper problem that pinpoints the process of CCL. Inability to make use of a scientific conception possibly indicates that conceptual change has taken place at a ‘low level’, in such a way that the new conception is intelligible, plausible and fruitful (Strike and Posner, 1985) only within the specific setting in which the change has taken place. This outcome is obviously not a satisfactory one since it leads CCL to a form of conceptual correlation; a process, that is, in which the learner correlates specific scientific conceptions with specific contexts within which the former can be applicable. The notion of generalisability that is widely regarded as a major quality of effective learning is apparently absent from such a setting. Consequently, this thesis suggests that effective CCL cannot be considered achieved unless ability is established to use new conceptions to different contexts. The need, therefore, for discussing the role of context in demonstrating such ability, becomes apparent. Before doing so, reference is made to the closely related debate over the feasibility of transfer of knowledge.
3.2.1. The debate over transfer

Transfer of learning (learning referring to both content knowledge and skills) is an area that has managed to attract intense interest from researchers in education, mainly due to the high status attributed to the act of demonstrating such ability on behalf of the learners'. 'Transfer' (Perkins and Salomon, 1989; Watts, 1991; Toh and Woolnough, 1994); 'extension' (Tytler and White, 1996); 'analogical problem solving' (Gick and Holyoak, 1980); 'bridging' (Adey and Shayer, 1994); 'generality of application' (Bailey, 1984); and 'meta-competence' (Fleming, 1991) are only some of the terms used in the literature to denote an attempt for relocating learning in different contexts. Each of these terms carries its own assumptions and philosophical framework. At the core of their difference lies the definition they assume for 'context', an undertaking that, as will be discussed in this chapter, can prove highly problematic and controversial.

Typical of the perceived importance of ability to make use of constructed knowledge is the fact that numerous projects included strong elements of transfer in their design. In Feuerstein’s et al. (1980) ‘Instrumental Enrichment’, for example, transfer is a predominant aspect of working and pupils are encouraged to imagine how the strategies they use for solving problems might be used in other learning contexts. Such research projects have been the source of valuable information on the notion of transfer. It has been demonstrated, for instance, that there exist specific factors affecting how well individuals manage to transfer appropriate learning (Watts, 1991); that transfer requires conscious effort by both teacher and learner (Adey and Shayer, 1993); and that it is equally important that it is explicitly taught by the teacher (Toh and Woolnough, 1994). The importance of distance between the two contexts has also been under scrutiny (Toh and Woolnough, 1994).

Of particular interest to this thesis is the fact that the bulk of research with such ‘post-learning’ interest was undertaken on transfer of science process skills (Donelly and Welford, 1989; Toh and Woolnough, 1994) with too little attention paid to transfer of pupils’ conceptions of science. Work currently available on transfer of conceptions is sparse, fragmented and usually highly selective, like, for instance, the work by Seddon and Waweru (1987) on the transferability of scientific concepts between different languages for multilingual students. It is therefore strongly argued that ability to utilise conceptions in different contexts deserves equal attention. In favour of this standpoint come findings of the Assessment of Performance Unit (APU) in the U.K., which as mentioned earlier showed that pupils’ performance was low when they were required to apply concepts in contexts other
The literature on transfer currently suffers two important flaws. First is the divide between advocates of transfer who call for methodologies that will teach or enhance ability to transfer skills and knowledge (e.g. McKeachie, 1987; Salomon and Globerson, 1987; Adey and Shayer, 1993), and those who explicitly question the potential of 'true' transfer taking place (e.g. Ceci and Ruiz, 1993; Detterman, 1993). Typical of the existing fierce debate in the literature and the authoritative approach of some of the latter, are the views of Detterman (1993) who confidently states that

...cases of transfer are probably rarer than volcanic eruption and large earthquakes (p.2).

Second, even among scholars who acknowledge the potentials or the feasibility of transfer remains the problem of defining transfer, or rather recognising transfer when this takes place. In conducting the debate, discussions revolve round different problematic dimensions of transfer such as, for example, defining the difference between transfer and application (e.g. Georghiades, 2000) and establishing similarity (or lack of it) between contexts (e.g. Salomon and Perkins, 1989).

This thesis explicitly places itself in the group of transfer advocates, something that should justify the inclusion of a section on transfer in this chapter. However, in view of the obscured scenery within the literature it chooses to focus on the role of different contexts with regards to learners' attempt to make use of constructed conceptions, and not to use the terminology associated with transfer, application, or any other of the previously listed approaches. Having said so, the reader is free to make his/her own judgements whether what are to be reported are cases of transfer or not. The next section looks at the importance of context in constructing and using knowledge, briefly discussing the prevailing positions in the literature.

3.3. Importance of context

The role of context in constructing meaning is a common theme for discussion in the literature related to this work (e.g. Rogoff, 1984; Engel-Clough and Driver, 1986; Adey, 1997). Dey's (1993) humorous example makes the point very explicitly
Communication errors can occur when a 'wrong' context is assumed, sometimes with humorous results. Take the exhortation: 'leave your clothes here and spend the afternoon having a good time' – which appeared on a sign in a laundry in Rome. Without knowledge of the context, we might mistakenly infer that we are being exhorted to strip off and 'have a good time'. However, knowing the context obliges us to infer a rather more pedestrian meaning! (Dey, 1993, p.33).

Forcing the discussion back to a more scholarly tone, Rogoff (1984) has argued that

_Thinking is intricately interwoven with the context of the problem to be solved. The context includes the problem's physical and conceptual structure as well as the purpose of the activity and the social milieu in which it is embedded_ (p.2).

Due to this interweaving of thinking and context others have come to regard that knowing is not an invariant property of an individual, rather it is a property that is relative to situations (Greeno et al., 1993).

Typical of the importance attributed to contextual dimensions of learning within the field of education is the fact that recent critiques of traditional long-established theories, like those of Piaget, are based on contextual grounds. Bidell and Fischer (1992), for instance, assume that the greatest mistake of Piaget's theory of stages was that he maintained a context-neutral conception of human abilities, seldom drawing a sharp distinction between his constructivist framework and his structuralist stage theory (for detailed discussion, see Demetriou, Shayer and Efklides, 1992).

To date there is considerable research evidence suggesting that the context or phenomenal setting of a task or problem can influence an individual's performance (e.g. Donaldson, 1978; Engel-Clough and Driver, 1986; Nunes et al., 1993). It is widely acknowledged, for instance, that perceived similarity, or the lack of it, between new and old tasks is a critical factor in the transfer of training (Gick and Holyoak, 1983). What is not quite clear, though, is how such influence really acts, for, the role of familiar context is characterised by conflicting evidence within the literature.

On one hand, there is work showing that familiar contexts help with the comprehension of the problems at hand and facilitate better performance. Donaldson (1978), for instance, has shown through her experiments that although three to four year old children face considerable difficulties with the procedures of a problem task they are given, when the same problem is presented in a familiar and realistic setting this results in dramatic improvement in performance. Numerous studies, on the other hand, have shown that learners are more likely to make use of scientific principles if questions are set in obviously 'scientific contexts' and
that deliberately setting problems in familiar contexts resulted in children reverting to familiar everyday systems of explanation, abandoning learnt symbolic knowledge (Solomon, 1983; Bliss *et al*., 1988; Murphy, 1989).

An explanation to such conflicting evidence can be accommodated in Rogoff’s (1984) view that

*The person’s interpretation of the context in any particular activity may be important in facilitating or blocking the application of skills developed in one context to a new one* (p.2).

The direct link drawn by Rogoff (1984) between the importance of context, on one hand, and ability to utilise knowledge, on the other, is of particular significance to this thesis. In a similar vein Boaler (1993) remarked that contexts can serve either to disguise or confuse a process with which students are familiar and confident, or to provide a familiar metaphor. In a nutshell, ‘*Contexts have the power to form a barrier or bridge to understanding...*’ (Boaler, 1993, p.370).

Cognitive psychology suggests that successful retrieval from long-term memory is highly associated with both the context in which encoding (learning) took place and the context in which retrieval (application) of learned items is attempted. Ideally when the contexts of encoding and retrieval are the same, facts or episodes are easier to remember (Estes, 1972). Unfortunately it is common experience that the contexts of organised schooling are rarely encountered in everyday life, therefore making the need of overcoming such contextual obstacles evident.

Many scholars from both the field of education (e.g. Toh and Woolnough, 1994; Watts, 1991) and psychology (Atkinson *et al*., 1999) acknowledge the importance of ‘distance’ between different contexts if new knowledge is to be used successfully elsewhere. The point that enjoys considerable consensus is that the greater the distance between the context in which learning takes place and the one in which new knowledge is to be used, the less likely is that such transition will take place successfully (Murphy and Schofield, 1984; Engel-Clough and Driver, 1986; Toh and Woolnough, 1994). Palmer (1993), on the other hand, reported a more catholic problem of students not recognising the similarities between contexts even when the contexts were closely related.

An important point that was made earlier is that the definition of ‘context’ can prove highly controversial. Context can range from the setting of a story in a textbook or the circumstances...
under which a problem seeks a solution, to the broader school or social environment of the pupils. One can easily question, for example, whether ‘context’ refers to the physical surroundings of the learning arrangement (e.g. the laboratory or the school’s pond); the topic or the broader subject studied, or the specific example used at the moment? This is a question that can apparently be re-stated in numerous variations and becomes even harder to tackle when the task is one of deciding whether two contexts are ‘the same’ or not. The literature has, to date, failed to reach consensus with regards to responses to these questions. As Salomon and Perkins (1989) point out, there is no hard criterion for reaching a definite answer

*We draw such lines according to our intuitions, which differ somewhat from person to person. Sometimes what one person calls transfer, perceiving the contexts in question as ‘different’, another may call mere learning, perceiving the contexts in question as ‘the same’* (p.115).

A number of scholars have at times attempted to address such contextual considerations. Looking at problem solving in science Watts (1994) listed four different types of contexts for problems, namely a) school textbook science, b) real concrete application, c) everyday, personal, or social, and d) symbolic abstract problems. Solomon (1983) on the other hand, spoke of two broad domains of knowledge, the school-based symbolic knowledge and the life-world knowledge domain, a distinction that is clearly underpinned by assuming different contexts. Valid as any such classification might be, it is unfortunately insufficient for answering the question of how context is truly defined, a response that heavily relies on one’s criteria in attempting to do so. The highly subjective nature of the notion of context seems to validate the view that context is ‘essentially a mental phenomenon’ not available to other people (Edwards and Mercer, 1987). This writer’s criteria for treating the notion of context are listed in a proceeding section, where the different contexts used in this research are clearly described in an attempt to make these available to the reader.

Although failing to convincingly address the central question regarding context, related research has enabled important insights into context-affected dimensions of the learning process in science. Contextual features of the tasks, for instance, were found to influence consistency of use of conceptions, suggesting that students sometimes use different frameworks when dealing with parallel questions (Engel-Clough and Driver, 1986). Gender related trends in respect to context were identified in research by the APU suggesting that certain contexts favour boys’ learning and others that of girls (e.g. see Murphy, 1990; Boaler, 1993). Boaler (1993) also presented research evidence suggesting that children from a learning environment characterised by the complete integration of process and content
performed better than children from an environment that concentrated mainly on content, when encountering mathematical problems in different contexts. These examples of research outcomes with regards to context are of course neither exhaustive nor necessarily the most important within the literature, their scope being to give a taste of the diversity in focus of related research.

To conclude on the importance of context in the learning process is to acknowledge that

There is currently a powerful body of opinion in education which maintains that the context in which a learning activity is set is so important that it completely over-rides any effect of either the logical structure of the task or the particular general ability of individuals (Adey, 1997, p.51).

This view of context is passionately advocated by writers in what might be called the ‘situated cognition’ camp, setting a trend that has given a new dimension to contextual aspects of human learning. Situated cognition is discussed in the following section.

3.3.1. Situated Cognition

Interest in situated cognition (or situated learning) resides in concerns regarding paucity of the transfer of knowledge appropriated within schools to situations and circumstances outside schools (Billet, 1996). The situated cognition camp regards knowledge as not an abstract entity that is independent of situations, rather that it assumes that the context of learning can have a significant effect on the learning outcome to such extent that the setting and conditions under which learning takes place form an inseparable dimension of the knowledge acquired. It approaches learning as an active, constructive process, its main focus being ‘on the interactions between people and the historically and culturally constituted contexts in which they are embedded...’ (Gruber et al., 1995, p.170). Advocates of situated cognition believe that it offers a new dimension to theories of learning. Henessy (1993), for instance, argues that

The relatively new theoretical framework which characterises ‘everyday’ or ‘situated’ cognition considerably widens our view of cognitive models of problem solving (a) to recognise the critical role of the social and physical circumstances in which actions are situated, when interpreting those actions (Suchman, 1987), and (b) to encompass thinking as a part of culturally organised activity which is carried out within a community of practitioners (p.2).

In spite of great diversification in their theorising, situationists formulate their theories with the basic assumption that there is indivisibility between cognition and culture, with the unit of analysis that is commonly grounded on the amalgamation of person, activity and setting, and with the core supposition that knowledge is actively constructed rather than passively absorbed by an intelligent agent (Gruber et al., 1995, p.178).
According to Lave (1988) an individual's performance is so determined by the current context every time, that there can be no such thing as 'general ability'. This has been illustrated by studies of the performance of individuals on ratio problems in 'authentic' shopping situations where individuals had to perform 'best-buy' estimates, and when similar ratio problems were set in a formal paper and pencil test. Although both tasks dealt with exactly the same number ratios, performance for the 'authentic' settings was significantly higher than the one for 'formal arithmetic' task (see Lave, 1988). Equally interesting findings relating to context and cognition, come from the work of Nunes, Schliemann and Carraher (1993) who studied schooled and unschooled children and adults in Brazil. They reported, for instance, that children selling cigarettes on the streets are consistently accurate in their arithmetical calculations but fail to solve basically the same problems when these are presented as formal school-mathematics tasks. Interestingly, and taking as axiomatic that 'all learning is situated', some situationists admit that

the nature of the situation and circumstances in which knowledge is appropriated is influential in determining the likely prospect of subsequent redeployment to other situations and settings (Billet, 1996, p.263).

With regard to learning by conceptual change, the situated cognition view suggests that use of co-existing alternative models may be appropriate when different contexts are encountered. Consequently, learning is seen as a process of distinguishing when particular conceptions are appropriate rather than one of exchanging prior conceptions for ones closer to scientific orthodoxy (Solomon, 1983; Hennessy, 1993). Hennessy has (1993) further argued that (a) contexts in science problems need to be made far more authentic in the children's eyes, than they generally are in school science, and (b) that since children's alternative conceptions arise out of social construction, far greater attention should be paid to children's preconceptions before attempting to teach them 'orthodox' science.

The situated cognition perspective has not only enjoyed passionate support by its advocates but has also been the target of fierce critique and dismissal by its critics. Adey (1997), for instance, suggests that the situated cognition camp has failed to show that all conceptual difficulties can be accounted for by simply changing the context.

Were that to be the case, says Adey, then Bruner's famous dictum could be modified to: 'Anything can be taught to anyone at any age, provided you get the context right'. Teachers in millions of classrooms all over the world would consider that to be an absurd proposition (p. 59).

Referring to the need for authentic contexts Adey (1997) questions 'what counts as authentic' and points out that any simplification of a context to suit young children is an immediate
reduction of authenticity. He further argues that insisting on ‘authentic’ experience is a denial of transfer possibilities which is the base on which the whole educational enterprise is predicated.

If everything worth learning were to be introduced individually in its own context, Adey says, then either the curriculum would become impossibly overcrowded, or the range of skills and understanding considered important in an educated person would have to be severely restricted (Adey, 1997, p. 54).

Although discussion could surround arguments and counter-arguments over the paucity of situated learning, this would make no further contribution in the direction of interest to this thesis. Links to the situated cognition perspective will be drawn again in one of the proceeding chapters, during discussion of the notion of metacognition. At this stage, having presented the main positions of the situated cognition camp that has, admittedly, maintained considerable influence on contemporary literature, the point to make is that this thesis does not portray a situationist outlook. Rather it argues in the same vein as Perkins and Salomon (1989) that

...the approach that now seems warranted calls for the intimate intermingling of generality and context-specificity in instruction. (...) We believe that this direction in education is promising and provocative: It gets beyond educating memories to educating minds, which is what education should be about (p. 24).

To make explicit how this claim is dealt with in practice, reference is made to some important practical dimensions of the research presented by this thesis.

3.4. Practical aspects of the research with a ‘context’ dimension

A distinctive feature of the literature on contextual dimensions of learning, discussed earlier, is that no agreed measures for defining ‘context’ have been reached to date, resulting in some obscurity in the field as to how different scholars perceive or treat context in their work. It is therefore necessary to present the meaning attributed to ‘context’ by this thesis and to discuss in detail the ways in which different contexts used in the course of this research differ from each other.

The tests designed for assessing taught concepts during the follow-up phases of this research comprise three parts, each containing one type of exercise. Each of these three types of exercise was designed to correspond to a different type of context, therefore reference to ‘different types of exercises’ in the following pages instantly suggests the use of ‘different
contexts' and vice versa. To make the point clear, reference is made to Figure 3.1. The tests cover a number of taught concepts represented by 'Concept 1, 2, 3...' by means of three different types of exercises ('Type A, B, C'). Each concept is therefore tested three times by three different exercises, one of each type. (For example 'Concept 2' is tested by exercises A2, B2, and C2). This arrangement enabled this researcher to assess both overall performance on taught concepts and the ability to make use of these concepts in contexts of progressive complexity. The focus, therefore, is clearly on the vertical dimension of Figure 3.1 comparing across different types of exercise.

![Figure 3.1 Test design](image)

The contexts used in the three types of exercise do not simply differ in the specific problems they present or the descriptions they offer, rather they are different with respect to certain characteristics that are related to cognitive demands placed upon the learners. These characteristics are listed in Table 3.1.

**Part A – ‘Type A’ exercises**

- No ‘surrounding’ context other than the question itself
- No pictorial representation
- No reference to examples or arrangements used in class
- No need to ‘use’ knowledge rather merely report it
- No immediate need for reflective thinking

**Part B – ‘Type B’ exercises**

- ‘Familiar’ context given similar to the ones used during the teaching of the subject-unit
- Pictorial representation and material depicted similar to the arrangements and equipment used in class
- Justification of answer given is required. The pupil is not just reporting knowledge but an explanation is needed in relation to the given context
- Some need for reflective thinking

*CHAPTER 3 - Contextual use of newly constructed conceptions*
**Part C – ‘Type C’ exercises**

- Tasks given in ‘unfamiliar’ contexts in the sense that these are not contexts specifically used in class.
- Pictures used refer specifically to the context of the exercise and not to contexts similar to the ones in which learning took place.
- Pupils have to isolate the problem or the question from the broader setting, identify the piece of knowledge related to it and provide a response within this setting (i.e. relate to their reply to the initial question set by the task).
- Pupils have to justify their responses as in Type B exercises, but in this case they further have to justify their response in relation to the ‘unfamiliar’ context. (i.e. ‘adjust’ their knowledge to both solve and justify).
- Need for substantial reflective thinking.

**Table 3.1 Characteristics of the three types of exercise used**

The three types of exercise are considered by this researcher to be in hierarchical relationship to each other with regards to their difficulty and the cognitive demands they place upon the pupils, Type A being the easiest and Type C the most advanced. It is further acknowledged that a different categorisation of exercises and the use of different contexts might have been equally valid, this being the result of the (previously discussed) subjective interpretation of the notion of context.

The use of different types of exercise, each with a different contextual orientation, was a choice based on the repeatedly reported outcome within the literature that contextual features of the task seem to influence pupils’ performance – for instance, affecting consistency in the use of scientific conceptions (Tytler, 1994) or having a gender-related impact (Murphy, 1990). Boaler’s (1993) caution that

*...a context which may facilitate understanding and transferability for one student may inhibit understanding or cause a variance in procedure and performance for another (p.369)*

was seriously taken into consideration by this writer, along with Engel-Clough and Driver’s (1986) warning that in choosing the contexts to be used by the teacher or researcher one should bear in mind that ‘...tasks which may be similar to scientists may not appear that way to students’ (p.475).

An important point to be emphasised regarding the use of different types of exercise is that in doing so these maintain testing of the *same* piece of subject knowledge each time. This was a methodological choice determined by the fact that one of the objectives of the research was to examine pupils’ ability to use constructed knowledge in different contexts. Had the subject knowledge tested differed along with the context, this would result in simultaneously having...
two dependent variables, hence disabling the study of either. Having said so, it is noted that
the extent to which the three types of exercises test exactly the same concept in each case is
inevitably subject to some variation and to the judgement of the reader. In order to illustrate
how this is treated by this research Figure 3.2 presents an example of three exercises used to
test the same concept in different contexts.

Exercise 1 - Type A
1. Fill in the gaps:
   ‘Insulators .................. electrons and therefore .................. electric current to
   pass through them’.
2. Name two conductors and two insulators that you know:
   Conductors a) .................. b) ..................
   Insulators a) .................. b) ..................

Exercise 2 - Type B
This is a device made by Year 5 pupils in their Design and Technology class. After they fixed
the wires on the wooden board, the children realised that the wires were not long enough to
form a complete circuit. The only materials they have are the ones shown in the list below.
Which of these materials can they temporarily use in order to bridge gap AB and see whether
their device works?
Write ‘YES’ next to the materials they can use and ‘NO’ next to the materials which are not
suitable for this purpose.

Piece of wood .........
Cotton wool .......
Thin copper tube ......
Plastic ruler ......
Piece of iron bar ......
Pencil ......
Strip of thick paper ......
Strip of cloth ......
Exercise 3 - Type C

Irene wants to get a new screwdriver as a present for her father who is an electrician. She can choose between the two screwdrivers shown below. Which one do you think she should choose? Explain why?

Price £3.00

Screwdriver with high quality metal handle

Price £3.00

Screwdriver with plastic handle

Answer: ........................................................................................................
........................................................................................................

Figure 3.2. Example of three exercises testing the concept of 'conductors and insulators'

Another important methodological choice of this research is to avoid helping the pupils during administration of the tests to identify links between taught material and the questions or problems at hand. In following this approach, this researcher takes into consideration Detterman’s (1993) warning that

*When subjects are told that previous material may be useful in the solution of a new problem, it hardly seems reasonable to refer to the solution of the new problem as the result of transfer* (p.11);

transfer taken by this writer to refer to using taught material in different contexts. The other pole is also evident within the literature suggesting that

*In the absence of demonstrations that Strategy X works equally well for Task B as for Task A and equally well in Domain D as in Domain C (but perhaps not so well for other tasks or domains), strategies are welded to the original instructional setting* (Brown, Bransford, Ferrara and Campione, 1983) (Garner and Alexander, 1989, p.149).
This researcher chooses to take the risk of not offering such demonstrations when asking the pupils to take the tests, allowing the claim that any successful identification of such links will be the students' own 'discovery'. Further discussion on methodological aspects of the context dimension of this research follows in Chapter 5.

3.5. Summary

This chapter discussed issues relating to pupils' ability to use newly constructed conceptions in different contexts. The importance of such ability was described and the role of context was discussed both in constructing meaning and in using it. Reference to writers in the situated cognition camp was made and the way different contexts are incorporated within this research was presented.

In conclusion, this writer assumes that an important point regarding learners' ability to make use of knowledge is that

*The hallmark of the expert is the ability not only to use ... ideas but also to recognize the situation-specific rules that govern their application, and the interrelationships between them* (Tytler, 1994, p.346).

It is a strong claim of this thesis that metacognition, the focus of the following chapter, is acting towards this direction.
Chapter 3 - Contextual use of newly constructed conceptions

- Importance of ability to use knowledge in different contexts
  - In relation to the scopes of education
  - In relation to CCL
  - Debate over transfer

- Importance of context in learning
  - Definition of context
  - Situated cognition

- Practical aspects of the research with a 'context' dimension
  - Test design
    - Type A exercises
    - Type B exercises
    - Type C exercises

Figure 3.3 Graphic summary of Chapter 3
CHAPTER 4 – METACOGNITION

4.1. Introduction to Chapter 4
4.2. Historical review of metacognition
   4.2.1. Some definitions
   4.2.2. Importance and origins of metacognition
4.3. General thinking skills
   4.3.1. General thinking skills and metacognition
   4.3.2. Metacognition and young children – Implications from the teaching of general thinking skills
4.4. Features of the nature of metacognition
   4.4.1. Cognition versus metacognition
   4.4.2. Metacognition: A ‘blanket’ term?
   4.4.3. Identifying and measuring metacognition
4.5. Studies in the outcomes of metacognition
4.6. Metacognition and CCL – Drawing links
4.7. Metacognitive claims of this thesis
   4.7.1. Linking context, durability and metacognition
   4.7.2. General versus situated metacognition
   4.7.3. Situated metacognition and situated cognition
4.8. Summary
4.1. Introduction to Chapter 4

'...if somebody knows something, then he knows that he knows it, and at the same time he knows that he knows that he knows'. Spinoza, 1632-1677 (cited in Weinert, 1987)

Having identified the problem areas in preceding chapters the next reasonable step is to look for potential solutions. The proposal put forward by this thesis is that metacognitive instruction can have a positive impact in dealing with the problems of short durability of conceptions and inability to use these when encountering new contexts. Metacognition is widely believed to make students responsible for their learning hence more actively involved in the learning process, and there is growing literature advocating metacognition's positive impact on students' achievement (Brown, 1987; Garner and Alexander, 1989; Gunstone, 1991; Thomas et al., 1997; Hacker, Dunlosky and Graesser, 1998). Although this writer is consciously aware of the limitations of higher-order thinking skills in primary school children and of the fact that very little work on metacognition has been undertaken with children of this age group, it is still his belief that metacognitive instruction can successfully be offered at this level, the minimum positive outcome being pupils becoming aware of their learning.

This chapter puts the notion of metacognition under scrutiny. It provides a brief historical review of its origins along with different definitions of the term, discusses the nature of metacognition and presents relevant research. Links are drawn between metacognition and the broader CCL background in order to describe more fully the focus of this thesis. Situated metacognition is then introduced as the main proposal put forward by this thesis and the reasoning behind it is thoroughly discussed.

4.2. Historical review of metacognition

4.2.1. Some definitions

The term 'metacognition' was introduced by John Flavell in the early nineteen-seventies based on the term 'metamemory' previously conceived by the same scholar (Flavell, 1971). Flavell (1979) regarded metacognition as referring to learners' knowledge of their own cognition, defining it as

'knowledge and cognition about cognitive phenomena' (p.906).
Flavell’s definition was followed by numerous others often portraying different emphases on (or different understanding of) mechanisms and processes associated with metacognition.

It is generally acknowledged within the literature that metacognition means ‘thinking about one’s own thinking’ (Adey and Shayer, 1994) or as referring to ‘cognitions about cognitions’ (Meichenbaum et al., 1985). Brown et al. (1983) define metacognition as referring to one’s knowledge and control of the domain of cognition. Meichenbaum et al. (1985) put it in a congruent way, viewing metacognition as the executive decision-making process in which the individual must both perform cognitive operations and oversee his or her progress. Another widely accepted view of metacognition is one that relates metacognitive activity to students’ knowledge, awareness and control of the processes by which they learn (Brown, 1987; Garner and Alexander, 1989; Gunstone, 1991; Thomas et al., 1997). Recognising, evaluating and, where needed, reconstructing existing ideas are considered to be characteristics of the metacognitive learner (Gunstone, 1991).

Instead of adopting the term ‘metacognition’ others have used the terms ‘metalearning’ (White and Gunstone, 1989) or ‘deutero-learning’ (Bateson, 1983) while Salomon and Globerson (1987) used the term ‘mindfulness’ to describe an awareness of problems, situations, and ways of thinking and talking about them.

The number of definitions, terms and analyses of what metacognition stands for has been the cause for some confusion in the literature. Weinert (1987), for instance, speaks of a ‘vague’ and ‘imprecise’ working definition of metacognition. Adey and Shayer (1994), on the other hand, refer to confusion among science educators over not only the meaning of the term ‘metacognition’ but also its actual recognition. This point is taken further in the discussion in the proceeding section on the nature of metacognition.

Since the introduction of the term by Flavell ‘metas’ (e.g. metalistening, metacommunication, metapersuasion) have proliferated in the literature (Kluwe, 1987). Watts (1998), for instance, argued that very close to the notion of metacognition stands ‘meta-affection’ that focuses on the affective dimension of learning, defining this as ‘the conscious awareness, monitoring, regulation and evaluation of intra-personal and interpersonal affective activity’ (p.8). Interestingly, all processes referred to in the definition of ‘meta-affection’ are either initiated or controlled by cognitive mechanisms, suggesting the strong dependence of anything ‘meta’ on cognitive functions.
4.2.2. Importance and origins of metacognition

The importance of metacognition as higher order thinking activity is for many scholars self-evident. Karmiloff-Smith (1991), for instance, believes that it is the ability to become conscious of thought processes (that is being reflective) that drastically differentiates human learning from animal learning. Nelson and Narens (1996), on the other hand, identify the importance of metacognition in its potential to act as a bridge between different areas such as decision-making and memory; learning and motivation; and learning and cognitive development. A number of scholars alike ascribe a significant role to metacognition with regards to problem solving and, more specifically, in relation to an individual's ability to identify, represent, plan and evaluate within a given problem (Davidson, Deuser and Sternberg, 1996). Gardner (1991), for instance, regards the difference between good and poor problem solvers to often lie in the formers' ability to think about their problem-solving activities. Others ascribe an explicitly educational flavour to the importance of metacognition suggesting that it can have a positive impact on students' learning (Hacker, Dunlosky and Graesser, 1998). The connection is very clearly made by Gunstone (1994)

There are a number of very commonly occurring poor learning tendencies exhibited by learners (Baird, 1984; 1986). These are superficial attention, impulsive attention, non-retrieval of relevant ideas and beliefs already held, staying stuck (i.e. one problem or error leads to no further progress) premature closure, ineffective 'unlearning', and lack of reflective thinking. These poor learning tendencies represent inadequate metacognition and are major barriers to learning (p.135).

Relating metacognition to developing one's self-knowledge and ability to 'learn how to learn' resulted in awarding metacognition a high status as a learning feature, especially in view of a rapidly-changing technological world, when not only it is impossible for individuals to acquire all existing knowledge, but it is also difficult to predict what knowledge will be essential or useful for the future (Blagg et al., 1998; Georghiades, 1999a).

The subsequent calling for inclusion of metacognition in the development of school curricula, therefore, seems fully justified. Flavell (1987) proposed that good schools should be 'hotbeds of metacognitive development' because of the opportunities they offer for self-conscious learning. Similarly Paris and Winograd (1990) have argued that

students can enhance their learning by becoming aware of their own thinking as they read, write, and solve problems in school. Teachers can promote this awareness directly by informing students about effective problem-solving strategies and discussing cognitive and motivational characteristics of thinking (p.15).

Clearly sharing this view, Gunstone and Northfield (1994) took a step further and argued in favour of a central position of metacognitive instruction within teacher education. Action in
this direction is congruent with the views of Borkowski and Muthukrishna (1992) who have argued that metacognitive theory has

considerable potential for aiding teachers as they strive to construct classroom environments that focus on strategic learning that is both flexible and creative (p.479).

The common denominator to stands advocating the importance of metacognitive activity within educational contexts has been the placing of metacognition high on research agendas.

Reasons for the growing interest in metacognition over the past three decades relate not only to the anticipated improvement in learning outcomes through interventions that aim at developing students’ metacognition (White, 1986), but also to the broader rise in interest in cognitive theories of learning (Brown, 1994). However, as Brown (1987) points out in an excellent review of the origins of metacognition, 'processes metacognitive' have been recognised and advocated by educational psychologists (e.g. Dewey, 1910; Thorndike, 1914) well before the emergence of the term 'metacognition', especially in the area of reading and writing. John Locke, for instance, used the term 'reflection' to refer to the 'perception of the state of our own minds' or 'the notice which the mind takes of its own operations' (Locke, 1924). A few years later, the importance of the concept of reflected abstraction to human intelligence was discussed by Piaget (1976) who pointed out the need for making cognitions statable and available to consciousness, at which point they can be worked on and further extended (Campione, 1987). 'Introspection', a technique used by early psychologists to find answers to psychological questions was also a first sign of interest in metacognitive processes. The definition of 'introspection' as 'the reflection on one's own conscious experience' (Butler and McManus, 1998, p.4) makes such connection all too obvious.

In searching for the origins of metacognition others go far beyond the twentieth century. As Spearman (1923) points out

Such a cognizing of cognition itself was already announced by Plato. Aristotle likewise posited a separate power whereby, over and above actually seeing and hearing, the psyche becomes aware of doing so. Later authors, as Strato, Galen Alexander of Aphrodias, and in particular Plotinus, amplified the doctrine, designating the processes of cognizing one's own cognition by several specific names. Much later, especial stress was laid on this power of 'reflection', as it was now called by Locke (p.52-53).

Hard as it might be to pinpoint the exact origins of metacognition, it is by far easier to reach agreement over the fact that recent interest in metacognition has resulted in the reawakening of interest in the role of consciousness, awareness or understanding in thinking and problem-solving (Campione, 1987).
Following a review of the many different historical roots from which metacognition has developed Brown (1987) warned that

... metacognition is not only a monster of obscure parentage, but a many-headed monster at that (p.105).

The acknowledged complexity of the notion of metacognition is also successfully reflected in Flavell's (1987) remark that although

...metacognition is usually defined as knowledge and cognition about cognitive objects, that is, about anything cognitive (...) the concept could reasonably be broadened to include anything psychological, rather than just anything cognitive (p.21).

In his attempt to identify where metacognition fits in 'psychological space' Flavell (1987) suggested that concepts that may be related to metacognition include executive processes; formal operations; consciousness; social cognition; self-efficacy; self-regulation; reflective self-awareness; and the concept of psychological self or psychological subject. The diversity of perceived meaning and the multidimensional nature of metacognition are therefore without question, a conclusion that, as a proceeding section will show, was reached by numerous studies in the past. Before discussing further aspects of the nature of metacognition, it is important to address briefly the area of general thinking skills, which shares important links with the one of metacognition.

4.3. General thinking skills

Emphasis on the teaching of general thinking skills was a prevailing feature of western educational systems of the post-Sputnik era viewed by politicians, policy makers and academics as the way ahead for reforming and boosting the failing education of that time. Typical of the importance attributed to developing ability to think is the statement made by the Educational Policies Commission (EPC) in the United States in 1961, assuming that

The purpose which runs through and strengthens all other educational purposes – the common thread of education – is the development of the ability to think. This is the central purpose to which the schools must be oriented... the development of every student's rational powers must be recognized as centrally important (EPC, 1961, p.xiv).

Interest in improving learners' thinking skills, however, goes back far beyond the 1960s, being interpreted by some as a response to the indoctrinating nature of much of organised schooling (Costello, 2000). Alfred Binet (1857-1911), for instance, who is most widely
known for devising the first mental tests, later to be known as IQ tests, believed that
children’s intellectual performance could be improved. He proposed a training system he
called ‘mental orthopaedics’ aiming towards strengthening a variety of thinking skills
including attention, memory, perception, invention, analysis, judgement and will.

In advocating the teaching of thinking skills most scholars assume the need of viewing such
an undertaking in a systematic way, that presupposes important structural changes of systems
of education. Nutbrown (1994), for instance, suggested the implementation of such changes
that will eventually lead to ‘a curriculum for thinking children’ (p.117). Similarly Fisher
(1998) refers to ‘a thinking curriculum’ that will place the development of thinking at the
heart of the educational process. Perkins (1993), on the other hand, argues that

To teach for thinking, it is not enough to teach skills and strategies. We need to
create a culture that ‘enculturates’ students into good thinking practices (p.98).

The strong and plausible theoretical arguments in favour of the teaching of general thinking
skills and the promising claims put forward by its advocates, resulted in the launch of a
plethora of projects in this direction. Feuerstein’s ‘Instrumental Enrichment’, ‘The Somerset
Thinking Skills Course’, Lipman’s ‘Philosophy for Children’, ‘Cognitive Acceleration
through Science Education’ (CASE), ‘Thinking through Geography’ and ‘Activating
Children’s Thinking Skills’ (ACTS), are only a few examples of such projects (see
McGuiness, 1999). Against this backdrop Fisher (1998) speaks of

a world-wide ‘philosophy for children’ movement, which uses philosophical enquiry
to enhance the thinking, learning and language skills of students of all ages and
abilities... (p.1).

The apparent trend of developing thinking skills that emerged in recent years has followed
mainly three different approaches:
1. Teaching general thinking skills
2. Teaching subject (or domain) specific thinking skills (e.g. in mathematics, science etc)
3. Teaching thinking skills across the curriculum, promoting thinking skills for all lessons.

In the case of the research presented in this thesis, metacognition is not taught as a general
thinking skill and, although practised within a specific science content, the intention is not to
present metacognitive activity as exclusively associated with the subject area tackled.
Furthermore, teaching metacognition ‘across the curriculum’, although not excluded as an
interesting direction for further research, is not among the objectives of this thesis. In view,
therefore, of the apparent relation of metacognition to the area of thinking skills, and the
differentiated focus characterising this thesis with regards to the majority of existing research
in the area of thinking skills, the perceived connection between the two and a first taste of the way this researcher treats the latter, have to be presented.

4.3.1. General thinking skills and metacognition

Following Vygotsky as 'one of the first to realize that conscious reflective control and deliberate mastery were essential factors in school learning' (p.13), Fisher (1998) makes the connection between general thinking skills and metacognition:

*If we can bring the process of thinking and learning to a conscious level, and help students to become more reflective, then we can help them to gain control or mastery over the organization of their learning. On this view effective learning is not just the manipulation of information so that it is integrated into an existing knowledge base, but also involves directing one's attention to what has been assimilated, understanding the relationship between the new information and what is already known, understanding the processes which facilitated this, and being aware when something new has actually been learned. It involves not only thinking, but a metacognitive process: thinking about thinking (p.14).*

Typical of the perceived connection between the study of thinking skills and metacognition is the fact that in a recent review of research into thinking skills commissioned by the Department for Education and Employment (DfEE) in the U.K., one of the key-conclusions was that a metacognitive perspective should be part of the general theoretical framework of similar research (McGuinness, 1999).

This researcher acknowledges a strong connection between the two areas based on the assumption that metacognition is a mental skill that entails a great deal of thinking. The approach employed by this researcher is one that assumes that metacognitive skills are thinking skills, potentially being a characteristic of the learner and requiring appropriate stimuli for their 'awakening' and gradual development. In other words, metacognition is not seen as something to be 'taught' to the learner in a 'outside-in' process, rather it is a skill that can be helped to develop in an 'inside-out' manner. In doing so, metacognition is not employed as a thinking skill in its own right, instead emphasis is put on its impact in achieving deeper understanding of taught material. This is not to be seen as reducing the importance of metacognition as a thinking skill, rather it is a result of the differentiated focus of this research. The exact way in which metacognition is treated by this researcher is made explicit later in this chapter when the metacognitive claims of this thesis are presented in detail.

The last point to make at this stage, with regards to the 'thinking skills movement' is that
there is growing literature advocating the introduction of children to philosophical and reflective thinking early in their lives (Lipman, 1985; Fisher, 1998; Costello, 2000), suggesting that the practice of advanced thinking skills is feasible with young children (Nutbrown, 1994). This is at the core of the discussion undertaken in the next section, being an issue of key importance to this study.

4.3.2. Metacognition and young children – Implications from the teaching of general thinking skills

The feasibility of research that incorporates metacognitive elements, designed with Year 5 (11-year-old) primary school pupils in mind, is a pragmatic issue of major concern for this thesis. This concern has emerged following the clash of opinion within the literature as to whether primary aged children can or cannot benefit from, or are even able to experience metacognitive activity. Brown (1987), for instance, has discussed that

For Piaget, reflected abstraction requires hypothesis testing and evaluation, and the ability to imagine possible worlds and their outcomes; therefore, it demands formal operational thought (Piaget, 1976). For others, earlier signs of emergence are possible; however, reflection is rarely attributed to the very young child or novice, regardless of how precocious they might be (Brown & DeLoache, 1978) (p.68).

Casting further doubt as to the ‘appropriateness’ of practising metacognition with children of young ages Adey, Shayer and Yates (1989a) offered evidence of eleven-year-old students not benefiting from a series of intervention lessons that incorporated metacognitive elements, positive outcomes being concentrated in older age groups.

As is usually the case, the other pole also exists in the literature with a number of scholars advocating such endeavour with young learners. Gunstone (1994), for instance, asserts that ‘...all students have metacognitive ideas and beliefs of some form’ (p.134) hence the use of the term ‘enhancing metacognition’ in his writings. Similar claims are often supported by evidence obtained from research with primary age children. One such example is Matthew Lipman’s ‘Philosophy for Children’, which was implemented with 5-16 year old children and has been successful in promoting metacognition (Lipman, 1982; 1985). Other researchers, like Rudd (1992), recorded signs of increased learning awareness even in cases of 8 and 9-year olds who produced complex and revealing concept maps about their learning.

In view of the limited work in metacognition with young children, arguments in favour of such an undertaking inevitably must come from the broader field of teaching general thinking skills where a number of projects like ‘Philosophy for Children’ (Lipman, 1982) and ‘Bright
Start' (Haywood, 1997) provide ample evidence in favour of an early start of systematic practice of thinking skills.

Based on the collective body of evidence, Novak (1998) has concluded that, by age 3, all normal children can think hypothetically and deductively in domains where they have acquired adequate conceptual frameworks, hence exhibiting such mental activity that falls within the Piagetian formal operational stage. In a similar vein Donaldson (1978) argued earlier that development relies more heavily on experience rather than age, and that appropriate interventions can help even young children to develop some of the metacognitive strategies of successful learning. Coles (1996) discussed that

...there is evidence that children can already engage in reasoned thinking prior to school through peer-group conversation (p.5), explaining that ...young children are able, in conversations with their peers, to question, make suggestions of a hypothetical nature, challenge, and so on (p.5).

The reason, Coles suggests, why such features are not evident in classroom talk is because adults are perceived by children to be more knowledgeable and thus less open to questions, challenges or suggestions.

Although Adey and Shayer (1994) are among those who appear sceptical about the potentials of metacognitive instruction to primary school children, their discussion manages to offer the other camp a strong argument in favour of an early involvement with metacognition. They specifically point out that

Cockroft (1982) wrote of the 'seven-year gap', as the difference between the most able (at the 90th percentile) and the least able children (at the 10th percentile) in the first year of secondary education (year 7 / grade 6). The CSMS data showed that the reality is more like a 12-year gap. In ordinary mixed-ability high schools, the most able 12 year-olds were operating at the level of average 18 year-olds or higher and the least able at the level of average 6 year-olds (Adey and Shayer, 1994, p.31).

A closer look at this range suggests that at least some of the children in primary school are able to cope with metacognitive instruction since they can reportedly operate at the level of 18-year-olds. It also indicates that even when dealing with more mature ages (i.e. secondary students) there will be students operating at levels resembling the ones of their primary peers hence setting the appointing of 'metacognitively appropriate' ages at question.

The problem with young ages did not escape Flavell's (1987) attention who related it to the important role metacognitive experiences play in everyday cognitive lives.

As one grows older, Flavell said, one learns how to interpret and respond appropriately to these experiences. The converse implication is that young children
may have such conscious experiences, but may not know how to interpret them very well; children simply may not know what these experiences mean and imply (p.24).

In response to Piaget's stage theory Flavell (1985) questioned the feasibility of identifying clear-cut stage-like 'cognitive metamorphoses' during childhood and adolescence and conversely suggested the existence of 'developmental trends' during these years. He identified

the developing sense of the self as an active cognitive agent and as the causal center of one's own cognitive activity and the increase in planfulness (Flavell, 1987, p.26)

as two changes in the development of children that could possibly contribute to the acquisition of metacognition.

This thesis suggests that the question at issue is not whether children have the potential to engage in metacognitive activities, rather it is one of finding the right ways and the right activities for initiating and enhancing such an activity. Following Flavell’s reasoning, and in view of ample evidence from the ‘thinking skills camp’ favouring the involvement of young children in reflective thinking, the scope should be one of helping children to interpret such metacognitive experiences, getting them to know what they mean and imply. Practical issues regarding the way metacognition is incorporated by this research are discussed in detail in Chapter 5, which is the methodology chapter. Having, in principle, demonstrated the feasibility of engaging young children in practising metacognition, which was a point of particular significance to this thesis, discussion will now move towards directions of more in-depth elaboration. The section that follows serves in getting to know the monster better.

4.4. Features of the nature of metacognition

Albeit fashionable as a research area and a promising teaching strategy in its own right, metacognition has proved to be a complex and often poorly understood notion (Brown, 1987). Typical of the problematic and undefined nature of metacognition is the fact that Flavell’s contribution to Weinert and Kluwe's (Eds) (1987) book ‘Metacognition, motivation, and understanding’ was titled ‘Speculations about the nature and development of metacognition’. This section looks at the nature of metacognition in an attempt to highlight some of its important and usually controversial aspects. In doing so, it reports from the literature and makes some of the stands and assumptions of this thesis explicit, the scope being to offer a general picture of the notion of metacognition rather than the detailed
elaboration of its problematic aspects.

4.4.1. Cognition versus metacognition

Any attempt to discuss the nature of metacognition is inevitably linked to the problem of distinguishing what is 'meta' and what is 'cognitive' (Brown, 1987). Weinert (1987) admitted that

*On the surface, it seems easy to distinguish between cognition and metacognition. Metacognitions are second-order cognitions: thoughts about thoughts, knowledge about knowledge, or reflections about actions. However, problems arise when one attempts to apply this general definition to specific instances. These problems concern whether metacognitive knowledge must be utilized, whether it must be conscious and verbalizable, and whether it must be generalized across situations* (p.8).

In the same vein a number of scholars suggested that it is difficult to separate metacognition from cognition (e.g. Wertsch, 1978; Garner and Alexander, 1989) while others argued for the importance of establishing the independence of metacognition from general aptitude (Swanson, 1990).

In an attempt to make such a distinction clear Flavell (1976) suggested that cognitive strategies *facilitate* learning and task completion whereas metacognitive strategies *monitor* the process. To use a clear-cut example by Flavell (1976), asking oneself questions about the chapter might function either to improve one's knowledge (a cognitive function) or to monitor it (a metacognitive function), hence demonstrating co-existence and interchangeability of cognitive and metacognitive functions.

In a similar line of thought Forrest-Pressley and Waller (1984) regarded cognition as referring to the actual processes and strategies used by the learner, whereas metacognition is referring to what a person knows about his or her cognitions and to the ability to control these cognitions. Watts (1998), on the other hand, views metacognition in a hierarchical relationship to cognition.

*...it is a metalanguage, he says, which permits the individual to talk about what's happening in their first level of feedback-governed learning. It represents second order change* (p.5).

This thesis regards that an essential characteristic of metacognition as 'metalanguage' (Watts, 1998) is that such 'talking about' should entail more than the simple description of previous thoughts or actions. Metacognitive reflection involves the critical revisiting of the learning process in the sense of noting important points of the procedures followed,
acknowledging mistakes made on the way, identifying relationships and tracing connections between initial understanding and learning outcome. This is a key characteristic to be included on the list of features distinguishing between cognitive and metacognitive activity, for, although it is possible for cognitive activity (and consequently learning) to take place without a critical stand on behalf of the learner, the practice of a critical metacognition is not possible. The point made, therefore, is that being critical is a characteristic that is sine qua non for metacognition.

Although distinctions between cognition and metacognition at a theoretical level are of secondary importance for the needs of the research presented by this thesis, such distinctions are primarily essential at a practical level. This is so because metacognition is a central variable in the design of this research, providing the basic difference in treatment between experimental and comparative group. It is therefore essential during the course of teaching to verify that metacognitive activity will indeed be taking place in the experimental group, if differences in later performance are to be confidently attributed to such activity. This is a judgement to be based on this researcher's interpretation of classroom activities and pupils' reactions at each time, trying to identify whether their behaviour entailed metacognitive elements or not. In doing so, different metacognitive activities will be offered, such that they will act in a complementary mode, attempting to provide pupils with considerably different opportunities for reflecting on their learning. In other words, in those cases that metacognitive activity might not be observed, or might not be very clear, a different metacognitive stimulus will be offered. A more formal or more detailed mode of identifying metacognition can result in a process of attempting to 'measure' metacognitive activity, something that would be incompatible with the objectives of the study, and highly questionable with regards to its feasibility.

To recapitulate on the distinction between cognition and metacognition is to say that this thesis shares the view that such a distinction is essential irrespective of whether metacognition is to be studied as a thinking skill per se or in relation to its impact on aspects of the learning process, the key characteristic for its recognition being the critical revisiting of one's learning. The research presented by this thesis relies on the judgement of this researcher to determine whether metacognitive activity is taking place or not. Evidence towards this direction will comprise children's oral and written responses to metacognitive stimuli. (Samples of such work can be found in Appendix IV). Detailed description of the different metacognitive activities employed follows in the methodology chapter.
4.4.2. Metacognition: A ‘blanket’ term?

A widely discussed feature of metacognition is the ‘blanket’ use of the term (Brown, 1987) suggesting that the term embraces more than it can unproblematically represent. Wellman (1981) has made a number of points regarding the multiple coverage of metacognition.

First, the concept encompasses an essential, central distinction. However, this distinction serves to anchor the concept not intentionally define it. Second, prototypic central instances of the concept are easily recognized. However, third, at the periphery agreement as to whether an activity is legitimately metacognitive breaks down; the definitional boundaries are truly fuzzy. Related to this, and fourth, different processes all of which partake of the original distinction may be related only loosely one to another. Thus the term metacognition or metamemory serves primarily to designate a complex of associated phenomena (p.3-4).

Returning to the definition by Flavell (1979) metacognition is knowledge that takes as its object or regulates any aspect of any cognitive endeavour. This view of metacognition denotes a fundamental duality in nature suggesting that the metacognitive learner is capable of both stating knowledge about cognition and regulating such knowledge. The fact that a single term was used to refer to both knowledge about cognition and regulation of cognition, is believed to have been the cause for confusion in the literature.

Discussing the first dimension of ‘knowledge about cognition’ Brown (1987) suggested that it is relatively stable, often statable and can be fallible. She acknowledged that this type of knowledge is assumed to be late developing and that it requires learners ‘stepping back’ and considering their own cognitive processes as objects of thought and reflection. ‘Regulation of cognitions’, on the other hand, said Brown (1987), comprises activities that are relatively unstable and age independent. She also pointed out that they are often not statable, arguing that knowing how to do something does not necessarily mean that the individual is consciously aware of the activities involved nor that these can be reported on to others.

Following a similar analytical approach Nelson and Narens (1990; 1996) proposed a theoretical mechanism to represent a metacognitive system consisting of two structures, an ‘object-level’ and a ‘meta-level’, the latter containing a model of the former. The mechanism incorporates two relations in terms of flow of information from one level to the other comprising ‘control’ and ‘monitoring’ functions. ‘Control’ which is the information flowing from the meta-level to the object-level affects the object-level processes by initiating, continuing or terminating an action. ‘Monitoring’ on the other hand lies on the assumption that the meta-level is informed by the object-level, a process that results in changing the state of the meta-level’s model.
Others like Paris and his colleagues (Paris and Jacobs, 1984; Cross and Paris, 1988) who studied metacognition in relation to the area of reading, delineated two broad categories of metacognition. The first, which they called 'self-appraisal', includes an understanding of factors that affect reading, how different reading strategies operate, and why and when one uses strategies. The second, 'self-management', includes planning, evaluation, and monitoring.

In an attempt to clarify some of the obscurity covering what metacognition stands for, Flavell (1987) proposed a taxonomic categorisation of the components of metacognition. In doing so he distinguished between a) 'metacognitive knowledge' and b) 'metacognitive experience'. 'Metacognitive knowledge' is that part of one's knowledge that refers to cognitive matters. It comprises knowledge of person variables (knowledge concerning what human beings are like as cognitive organisms), task variables (referring to knowledge about how the specific information encountered affects and constraints the way in which one deals with it) and strategy variables (knowledge about cognitive strategies or procedures for achieving various goals). 'Metacognitive experience', on the other hand, comprises conscious experiences that can be either cognitive or affective and are pertinent to an ongoing cognitive situation or endeavour. To use one of Flavell's (1987) examples,

\[
\text{if one suddenly has the anxious feeling that one is not understanding something and wants and needs to understand it, that feeling would be a metacognitive experience} \quad (p.24).
\]

Hertzog and Dixon (1996) referred to multiple types of metacognitions classifying these as 'stored' or 'concurrent'. 'Stored metacognitions' comprise representations or information held in permanent, long-term memory either in the form of knowledge or beliefs. 'Concurrent metacognitions', on the other hand, are the information generated by, and associated with the act of cognizing.

\[
\text{As such, Hertzog and Dixon (1996) say, they are directly related to the control processes associated with monitoring the current status of the cognitive system (Nelson & Narens, 1990), and they may be associated with conscious awareness of the content and processes of cognizing (Cavanaugh, 1989) (p.229).}
\]

Instead of referring to a taxonomy of metacognition Von Wright (1992) distinguished two levels of reflection. At the lower level the learner is capable of reflecting about many features of the world in the sense of considering and comparing them in her mind, and of reflecting upon her means of coping in familiar contexts. However...she is unlikely to be capable of reflecting about herself as the intentional subject of her own actions (p.60-61). At the higher level, though, he says that: Reflecting about one's own knowledge or intentions involves an element which is absent from reflections about the surrounding world. Self-reflection
presupposes, in the language of mental models, a ‘metamodel’: in order to reason about how I reason, I need access to a model of my reasoning performance (p.61).

Von Wright (1992) acknowledges that the distinction between these two levels of reflection was previously made by cognitive psychologists, such as Lev Vygotsky, who drew the line between ‘soznanie’ or consciousness, and ‘osoznanie’ or conscious awareness. The confounding of the two levels of reflection distinguished by Von Wright (1992) is regarded by some scholars (e.g. Adey and Shayer, 1994) as one of the origins of the existing confusion in the literature.

The above examples of attempts to analyse or classify the concept of metacognition are not the only ones available in the literature, yet they manage to present sufficiently the prevailing approach to talking about metacognition. This thesis regards that important as such analyses might be, an underlying unifying idea should oversee any classification scheme, acknowledging that

*Metacognitive knowledge, awareness and control are all* (this writer’s emphasis) *learning outcomes as well as fundamental influences on the extent of achievement of more usual learning goals* (Gunstone, 1994, p.134).

Equally important, it should be emphasised that

*learners do not have some genetically determined levels of metacognition. Rather, the nature of personal metacognition derives from learning from experience (vicarious or managed) and hence, metacognition can be enhanced by appropriately designed learning experiences* (Gunstone, 1994, p.134).

The rather holistic approach reflected in such a stand does not suggest that this thesis ignores the existence of a problematic divide associated with the concept of metacognition. At the same time, though, it is noted that no attempt is made towards identifying either dimension. This is so because the objective of the research presented is neither to promote nor to measure metacognition *per se*, rather it is to study the impact of metacognition on aspects of children’s learning. Identifying metacognitive elements in children’s reactions (following metacognitive instruction) will be sufficient in serving the needs of this study, without specifying whether the metacognitive activity demonstrated belonged to the ‘knowledge’ or the ‘regulating’ dimension of metacognition. This is an issue that brings the discussion to the question of identifying or measuring metacognitive activity.
4.4.3. Identifying and measuring metacognition

Close to the problem of sufficiently defining metacognition lies the difficulty of assessing students' metacognitive abilities or performance. This is a practical obstacle caused by the fact that metacognition is an inner awareness or process rather than an overt behaviour (White, 1986) and because individuals themselves are often not aware of these processes (Rowe, 1991). Adey and Shayer (1993) traced the problem of illustrating metacognitive elements of an intervention program to the fact that this is more a feature of the teacher's strategy than of the printed materials. The same problem seemed to be evident in the early years of employing 'introspection' by some psychologists, for, according to William James (who is one of the founders of modern psychology), attempting to grasp the mind through 'introspection' is like 'turning up the gas quickly enough to see how the darkness looks'.

Attempts towards identifying metacognitive activity can be based on the acknowledgement that metacognition as understanding of knowledge '...can be reflected in either effective use or overt description of the knowledge in question' (Brown, 1987, p.65). In other words, it is suggested that it is possible for metacognition to be detected if the learner is able to effectively use or overtly describe such understanding. Reasonable as this approach seems, it fails to provide an answer to the question of how to measure metacognition reliably.

In order to measure 'knowing about knowing' 'more accurately' it has been suggested (Ericsson and Simon, 1980; Garner and Alexander, 1989) that researchers should use multiple methods that do not share the same source of error. Garner and Alexander (1989) proposed three ways of finding out what children know about their cognitions: a) asking them, b) having them think aloud while performing a task, and c) asking them to teach a younger child a good solution for a problem. In making these suggestions Garner and Alexander (1989) did not fail to acknowledge a number of problems, including children's lack of verbal fluency or variation in adult-child use of language; young children's difficulty in discussing general cognitive events; and their tendency for describing specific just-experienced events.

Flavell (1987) predicted that 'in the future' methods for measuring and assessing metacognitive experience would develop. Almost fifteen years later, the existence and trustworthiness of such methods are highly questionable. In making this remark it has to be emphasised that this thesis does not set out to offer new tools for identifying, measuring or assessing metacognition. The scope of this section is rather to highlight the fact that, due to
lack of consensus in the literature regarding the recognition and measurement of metacognition in action, and the absence of reliable tools for this purpose, such a task is bound to be a problematic one dependent upon the subjective judgement of this researcher. In other words, making the problem of identifying metacognition explicit and showing that this is consciously taken into account by this researcher, was the main target set by this section. Having done so, the discussion will now change direction and look at metacognitive research available to date.

4.5. Studies in the outcomes of metacognition

Since the emergence of metacognition as a new notion, considerable research was conducted with metacognitive dimensions holding either a central or a secondary position (Baird, 1986a; Brown, 1987; White and Gunstone, 1989; and Adey and Shayer, 1994). The common denominator to most of these projects is the fact that they shared the same anticipation, one of improving learning outcomes as a result of the practice of metacognition.

This section presents an anthology of studies with an interest in metacognition. The fact that considerable and important research outcomes on metacognition initially emerged in areas other than that of science education, along with the fact that metacognitive research in relation to science education has not yet produced sufficient amounts of work, imposes the necessity for looking at both directions. Studies on metacognition within science education are hence examined alongside studies with a similar interest accommodated in different areas. In doing so aspects of the underpinning philosophy, the objectives and the methodology of these studies are selectively discussed in order to make similarities and differences with the present research explicit.

Over the years metacognition has been related to a number of general cognitive abilities and aptitudes such as intelligence (Borkowski, 1985), general aptitude (Swanson, 1990) and memory (Pressley, Borkowski and O'Sullivan, 1985), or more subject-specific areas such as mathematics (Schoenfeld, 1987) and reading (Cross and Paris, 1988). Of the above areas the one with the most profound connection to metacognition was the broad area of thinking skills that was discussed earlier, based on the belief that

...if higher level thinking is to be generalized, students must be encouraged to think about their own thinking (Adey, Shayer and Yates, 1991, p.2).
Most of these studies offered ample evidence of a positive impact of metacognitive activity on student thinking and learning (e.g. Nickerson et al., 1985; Perkins and Salomon, 1989), a conclusion that, as will be discussed later, was further supported by research reports from within science education.

Research in metacognition has covered mainly three components: a) knowledge about strategies, which refers to knowledge about when, where and why different strategies should be used; b) strategy use, referring to the children’s actual use of metacognitive strategies without instruction or prompts; and c) cognitive monitoring, which is a metacognitive acquisition procedure needed for evaluating and changing strategy use and for determining the limits of the knowledge (Chmiiliar, 1997). Among the conclusions reached by metacognitive research to date are that a) knowing about knowing develops, b) both children and adults often fail to monitor cognitions and c) some strategies are difficult to learn and easy to abandon (Garner and Alexander, 1989).

The fact that the link between metacognition and thinking skills encouraged application of the former to improve the latter has resulted in a number of researchers focusing on groups with learning difficulties. Feuerstein et al. (1980), for instance, worked with disadvantaged underachieving children in employing their Instrumental Enrichment, while Campione (1987) studied metacognition mainly in relation to students with learning problems and sometimes with mentally retarded children.

Others, on the other hand, focused on the importance of establishing the independence of metacognition from general aptitude. In one such study, Swanson (1990) investigated whether high levels of metacognitive knowledge about problem solving could compensate for overall aptitude. He found that highly metacognitive students outperformed less metacognitive students in problem solving regardless of their overall aptitude level. In fact he reported that high-metacognitive/low aptitude children performed significantly better than low-metacognitive children with higher overall aptitude scores. He hence concluded that high performance on the problem-solving tasks is more closely related to children’s performance on the metacognitive measures than on the overall aptitude measures. This was a position that was previously supported by other studies in the literature (e.g. Minsky and Papert, 1984; Slife et al., 1985). The focus on metacognition over recent decades has reportedly resulted in positive shifts in students’ learning outcomes (see Baird and Mitchell, 1987; Adey, Shayer and Yates, 1991; Shayer, 1991) hence justifying the view that
effective learners operate best when they have insights into their own strengths and weaknesses and access to their own repertoires of learning (Brown, 1994, p.9).

Interestingly, though, most of the work on metacognition was conducted in relation to students' perceptions and beliefs regarding learning and the learning processes (e.g. Thomas et al., 1997). Focusing on the impact of metacognitive activity on taught content and on students' conceptions, as is the focus of this thesis, was clearly overlooked.

Having broadly sketched the scenery of general metacognitive research, reference will now be made to two large-scale projects that were either partly or exclusively conducted within the field of science education. These projects were PEEL (Project to Enhance Effective Learning) in Australia and CASE (Cognitive Acceleration through Science Education) in the U.K.

PEEL

PEEL (Project to Enhance Effective Learning) which was a multiple-year cross-subject approach aimed at secondary school students' understanding and informed responsibility for their own learning (Gunstone, 1991), was one of the large-scale projects that included an extensive metacognitive dimension. Contrary to other studies in the field of science education (e.g. Adey, Shayer and Yates, 1989) the approach followed by PEEL did not include 'special' classes at 'special time' but was meant to pervade all the lessons students had. The project was not identified with one or two teachers only, but it engaged six faculties (English, History, Geography, Integrated Studies, Commerce and Science) therefore exposing targeted classes to as many PEEL teachers as possible. The project did not apply a set of pre-specified activities, rather the teachers were free to introduce any activities they felt that were serving the objectives of PEEL.

Typical of the work done within the project was the work by Baird (1986b) who investigated ways of improving the metalearning of students in the science classroom. He introduced a number of materials and procedures, such as a checklist of questions to be considered by the students in each lesson (e.g. 'What is the topic?' 'What do I know about it?' 'Why am I doing it?'), students' diaries for answering these questions and for evaluating their learning each lesson, frequent discussions of the purpose of learning, and interviews with teacher and students. Although Baird found that students had become more purposeful learners with greater understanding of content, he also concluded that any true progress was difficult if metalearning was limited to a single subject for a number of periods per week with one teacher only. This is a challenging outcome for the research presented by this thesis since
metaeognition is to be implemented in the science class only for a limited time-period. However, the fact that Baird’s (1986) work was on (generally) promoting more effective learning, rather than on the (more specific) impact of metalearning activities on pupils’ learning of science subject matter, denotes an important difference in essence that does not allow any direct comparisons to be made.

In evaluating the outcomes of PEEL Gunstone (1992) identified four emerging issues of considerable importance: a) Student views about learning, teaching and their role in the teaching process formed a substantial barrier to improved metacognition; b) affective issues were a significant part of student reactions to and valuing of PEEL; c) making PEEL fruitful to students was an ongoing problem; and d) teaching approaches which are constructivist and metacognitively-oriented depend on learners having trust in their teachers. In general, the outcomes of the project have been encouraging: metalearning can be promoted and will facilitate conceptual change even if it remains fragile and artificial until perceived by students as meeting their own short-term goals (White and Gunstone, 1989).

CASE

Equally significant research was presented by the Cognitive Acceleration through Science Education (CASE) Project in the UK. Its main aim was to explore an approach that hopes to improve pupils’ ability to learn under the widespread effort of ‘raising standards’, that is, of improving long-term achievement. Metacognition was one of the main pillars of the intervention programme employed (Adey and Shayer, 1994).

The project developed a set of materials comprising a teachers’ guide and pupils’ worksheets for 30 lessons titled ‘Thinking Science’ (Adey, Shayer and Yates, 1989b). The researchers used experimental ‘CASE classes’ and control classes working with Year 1 (aged 11+) and Year 2 (aged 12+) students in mixed comprehensive secondary schools. Instead of their normal science lesson CASE classes were given a ‘Thinking Science’ activity once every two weeks, while control classes continued with their normal science lessons. This arrangement lasted for a two-year period.

The CASE project provided very promising results in the form of long-term and general effect. Long-term because students who participated in the CASE groups presented better achievement 2 to 3 years after the intervention had ended, and general because better achievement was reported in widely different subjects (i.e. science, mathematics and English) (Adey, Shayer and Yates, 1989a). However, an important outcome of the CASE project was
that the younger age group (11+) have not benefited at all from the intervention lessons. Positive effect was concentrated in the groups starting at 12+. This is a truly challenging result as it may question the potentials, or even the suitability, of metacognitive activity for primary school children who form the age group under study here; the implication being that any metacognitive activity within the primary science class should primarily be adjusted to the age -hence abilities- of participating students.

The inevitable point to make about CASE is that albeit sharing some common elements with the present research, once again interest focused on the teaching of thinking skills rather than on their impact on students’ conceptions of scientific phenomena. A more detailed comparison regarding the methodologies of these studies in relation to the present research can be made by reference to Chapter 5, which is the methodology chapter.

Following the presentation of two projects that have employed metacognition in primarily educational settings, the following section discusses the links perceived by this researcher between metacognition and CCL, in his attempt to justify fully the employment of metacognition in the teaching of science. In doing so, he shares Nelson's (1998) views on the current state of metacognitive literature

While it would be incorrect to think that the theories of metacognition are currently so highly developed that the applications to education are straightforward, it would also be incorrect to assume that our current ideas about metacognition are so fragmented and poorly developed that any application to education would be premature (p.xi).

4.6. Metacognition and CCL – Drawing links

In spite of the established significance of metacognition as a mental activity in the process of learning, this thesis regards that it is important to demonstrate explicit links between metacognition and the field of CCL that serves as the theoretical background to this research. Such a connection will provide the context for the discussion of metacognition and will enable a more critical outlook of issues such as the nature of metacognition or its practical dimensions. Drawing these links is the main scope of this section. In doing so, frequent references to work by Richard Gunstone and his Australian colleagues are made. This is not to be seen as the unquestioned acceptance of the stands they present, rather it should be regarded as an inevitable consequence of the impact of their work on metacognition in the field of science education.
A fundamental assumption made by White and Gunstone (1989) is that

*If metalearning can be taught, then the problem of how to bring about conceptual change may be solved* (p.581).

Albeit possibly an oversimplification of the problems posed by CCL, the above statement cannot be taken as anything but a very explicit indication of the importance attributed by contemporary constructivist literature to the notion of metacognition. Placed within the broad constructivist framework, the present thesis wishes to highlight the links between CCL and metacognition, not least because of the initial growth of metacognitive studies in areas other than science education.

Although the term *‘metacognition’* was not explicitly used, links between metacognition and constructivist approaches were identified long ago. In Driver and Oldham’s (1986) stages of constructivist teaching practice, for instance, the final stage was one of *review* where students were asked to reflect on their learning and proceed to comparisons between their initial and their current understanding. Similarly, Novak and Gowin (1984), who also advocated constructivist approaches, have talked in the past of the need for the *‘learning-about-learning’* stage that should be part of all teaching. Instead of looking at the vast totality of the constructivist framework the present discussion will be limited to the relationship between CCL and metacognition.

The link between the two areas is often explicit basing such a connection on the definition given to metacognition by CCL theorists. Gunstone and Northfield (1994), for example, have used metacognition to mean

*...learners having an informed and self-directed approach to recognizing, evaluating and deciding whether or not to reconstruct* (p.526).

Linking this to their views on the nature of conceptual change (see Chapter 1) led them to the justified conclusion that *‘...metacognition and conceptual change are totally intertwined’* (p.526).

Fensham, Gunstone and White (1994), on the other hand, took a different route to establishing such a connection by referring to *‘good learning’* based on conceptual change. They suggested that good learning incorporates the linking of different concepts and good teaching promotes it. When students comprehend why links are important and actively seek them between topics and across subjects, even better learning follows. Such behaviour, they said, is a characteristic of metacognition.
White and Gunstone’s (1989) use of Strike and Posner’s (1985) terminology is another clear attempt to relate the two areas

... people will accept training in metacognition when they are dissatisfied with their present style of learning and find metacognition plausible, intelligible and fruitful. There is little difficulty over plausibility and intelligibility, but dissatisfaction and fruitfulness are difficult to arrange. Perhaps the fact that we said the same thing about conceptual change is a recognition that metalearning and conceptual change are closely connected (p.585).

By highlighting the fact that both dissatisfaction and fruitfulness are dependent upon the learner Gunstone (1994) assumed that this provides the link with metacognition. He further suggested that

...the development of more appropriate metacognition should itself be seen as conceptual change - change of ideas and beliefs about learning / teaching / appropriate roles / nature of science (p.136).

Further support in favour of the existence of strong links between the two areas lies with the views of Gunstone et al. (1992) who regard metacognitive comments of the students as evidence of conceptual change taking place. In doing so, they do not claim that such metacognitive insight is any guarantee of substantial understanding.

What is being argued is that metacognitive insights, in general, can be a better indicator than test performance of conceptual exchange. This is so because there is at least some greater likelihood of internal fruitfulness being seen if the conceptual exchange is accompanied by increased metacognitive awareness. The presence of such awareness indicates that genuine exchange, rather than rote acquisition of compartmentalized formal knowledge without abandoning conflict spontaneous knowledge (Pines and West, 1988), has been achieved (Gunstone et al., 1992, p.188).

The same connection was also made by Champagne et al. (1985) in a study that aimed to produce conceptual change in mechanics. One of the signs that conceptual change had taken place was assumed by the researchers to be the considerable increase in metacognition among the students.

Without disagreeing with the views of Gunstone et al. (1992) regarding the impact of metacognition on internal fruitfulness, this thesis does not follow the implied ‘metacognition-hence-conceptual change’ route, rather it emphasises the interweaving of metacognition within and during the CCL process. This is a choice based on the belief that through metacognitive activities key features of conceptual change learning like intelligibility, plausibility and fruitfulness of new concepts (Strike and Posner, 1985) are enhanced. Consequently, it is argued, metacognition should be regarded as an aid to CCL rather than as an outcome or evidence of the latter taking place. Further to Gunstone’s et al. (1992) concern that metacognitive insights offer no guarantee for increased understanding, this writer warns
that even in cases where such understanding is evident metacognition cannot possibly
determine that conceptual change has taken place in the *desired* direction. In cases, for
example, of conceptual exchange between two alternative frameworks (rather than the
exchange of an alternative for a ‘scientific’ explanatory framework) the question is whether
signs of metacognitive activity (albeit their significance as such) can be taken as serving the
objectives of school science. The point made, therefore, is that instead of viewing
metacognition as a form of indirect evidence of conceptual change, it is better seen as
enhancing conditions for learning through conceptual change to take place. Put differently, it
is possible to make the distinction between *plain* CCL and *metacognitively enhanced* CCL,
the claim being that the latter is more likely to result in better learning outcomes than the
former.

Last, a point ought to be made is that the perceived links between the two areas are not a
product of a purely theoretical position, rather that classroom experience suggests that the
connection is real and of great potential. This is very well reflected in the words of a teacher
who was given the chance to apply metacognitive teaching in his work

*I am aware that there has been work done previously on Children’s Science and
Metacognition in isolation from one another but, as ‘classroom’ teacher, I believe
that the two are so closely interrelated that to teach science by one method and not
the other would be in error. For example, the process by which the student tries to
identify what he/she believes about a situation, then aligns this idea with what is
taught, looks for abnormalities and then tries to investigate/modify the ideas so to
move towards a scientist’s view of a phenomenon requires active learning. Students
must be aware of their own learning processes in order to carry out this process,
which may lead to truer understanding. After a year with PEEL and more
involvement with Children’s Science, I am still of the opinion that they must be used
together in order to get maximum benefit to both student and teacher* (McMaster,

The fact, therefore, that classroom experience complements and supports the theoretical
considerations that advocate the linking of metacognition and the broader CCL area, is highly
acknowledged by this thesis, being in line with the practical orientation it projects.

4.7. Metacognitive claims of this thesis

4.7.1. **Linking context, durability and metacognition**

... *one way to become better at metacognition is to practice it; another way may be to
practice other things which are not metacognitive themselves but which indirectly
promote metacognitive activity* (Flavell, 1987, p.26).
Flavell’s acknowledgement of the potential for an indirect promotion of metacognition raises the question whether such an effect can be reversed. Put differently, if non-metacognitive activities can have a positive indirect impact on learners’ metacognitive abilities, then can it be assumed that the practice of metacognitive abilities can have a positive indirect impact on non-metacognitive aspects of one’s learning? Based on the discussion to follow, this thesis suggests that an affirmative response should be given to this question, the core idea being that metacognition can have a positive indirect impact on durability of learners’ conceptions and ability to utilise these in different contexts.

One of the points highlighted during the discussion of the nature of metacognition was the fact that the growing research interest in metacognition is partly attributed to the influential role this can play with regards to everyday classroom problems. One such important problem is that very often students do not know the purpose of instruction in class. Gunstone (1991) suggested that the most significant factor contributing to this problem is the transmissive view of learning and teaching held by teachers and learners, along with passive views of the role of learners in these processes. Metacognition as a process of reflecting upon, and taking action about one’s own learning appears as a potential solution to this problem.

In a similar vein, this thesis argues that positive impact of successful metacognitive instruction can be extended to students’ abilities to both make use of and to retain conceptions for longer time. The equation is as follows. By being reflective, by re-visiting the learning process, making comparisons between initial and current conceptions, being aware of and analysing difficulties, learners gradually maintain deeper understanding of learned material. Based on such deeper understanding, two further assertions can be made. First, it is more likely that the learner who holds better understanding of a certain concept will be able to identify the use and purpose of this knowledge, to handle learned material in different manners and to explore potential use of this material under a number of different circumstances. Put differently, maintaining better understanding sets the bases for successful use of constructed conceptions in different contexts. Second, better understanding suggests a) greater ability to utilise learned material in order to meet the learner’s needs, and b) greater confidence regarding learned material. Consequently, the more a newly-learned conception serves the needs of the learner the longer it will last; and the learner who is confident about what he or she knows will have no reason to regress to the safety of any personal alternative frameworks (Figure 4.1). It is therefore a core stand of this thesis that the perceived relationship between metacognition, on one hand, and chronological durability and ability to
METACOGNITIVE INSTRUCTION

Being reflective; revisiting the learning process; making comparisons between prior and current conceptions; being aware of, and analysing difficulties...

Enances

DEEPER UNDERSTANDING OF LEARNED MATERIAL
The learner who holds deeper understanding is more likely to:

Be able to...
Identify the use and purpose of learned material.
Handle learned material in different manners.
Explore potential use of learned material under different circumstances

Exhibit...
Greater ability to utilise learned material in order to meet his / her needs for longer time.
Greater confidence regarding learned material (hence less chance for regression).

therefore demonstrating

SUCCESSFUL USE OF CONCEPTIONS ACROSS CONTEXTS

LONGER DURABILITY OF CONCEPTIONS

Figure 4.1 Links between metacognition, durability and context
utilise conceptions, on the other, is explicit and justifies further cross-investigation of the three areas.

In substantiating its claims, this thesis regards that two important points advocated by cognitive psychologists regarding human memory are compatible with this stand for offering metacognitive instruction. First the dominant long-term memory representation for verbal material is primarily based on the perceived meaning of stored items rather than being purely acoustic or visual, and second, long-term memory can be improved by creating real or artificial links between stored items (Craik and Tulving, 1975; Bradshaw and Anderson, 1982). It is consequently argued that reflection triggered by metacognitive instruction achieves both the identification of connections and relationships between learned (stored) items and in effect the construction of fuller meaning based on the understanding of such links and interconnections. In Atkinson’s et al. (1999) words

The better we understand some material, the more connections we see between its parts. Because these connections can serve as retrieval links, the better we understand, the more we remember (p.267).

Similarly Novak (1998) ascribes meaningful learning a central role in his theory of education, explicitly arguing that

...learning by rote is ineffective for long-term retention and application of knowledge... (p.8).

In his interpretation of Ausubel’s assimilation theory Novak (1998) further acknowledges that metacognitive tools can facilitate long-term memory. The claim, therefore, of metacognitive activity having a positive impact on students’ long-term retention of learned material and their ability to use constructed knowledge under different circumstances, by means of facilitating deeper understanding, is believed to be both valid and justified.

To recapitulate, the central argument of this section is that if attention is paid during the process of constructing a conception then this will have the fundamentals to demonstrate longer concept-life and learners will more likely show increased ability to use this in different contexts. This can be achieved by means of applying metacognitive instruction, such that it enhances better learning or deeper understanding, hence constructing more meaningful and stable conceptions that can withstand conceptual decay for longer time. Put differently, metacognition is proposed as a means of decelerating conceptual decay once the conception is no longer being actively used, hence making a contribution towards longer-lasting learning.
4.7.2. General versus situated metacognition

In spite of positive outcomes of studies on general thinking skills being numerously reported in the literature, the area of teaching thinking skills is not one that is currently enjoying consensus. Quite the contrary, the effectiveness of directly teaching thinking skills has been questioned (Segal et al., 1985) and an increasing number of scholars assume a trend in the literature towards embedding instruction within specific areas of the curriculum, rather than isolating thinking skills as separate topics (Halpern, 1992; Henessy, 1993).

Such critics often question the assumptions made by advocates of the general thinking skills camp. Henessy (1993), for instance, has criticised the fact that

...many teachers and educators work on the unvalidated assumption that universal cognitive skills of thinking and problem solving can be taught (often independently of the acquisition of prior subject matter) and immediately and flexibly applied to a variety of contexts (e.g. Argles, 1988; Bonington, 1988; Wharry, 1988) (p.23).

Others like Perkins and Saloman (1989), who share a rather more moderate stand, suggested that

The approach that now seems warranted calls for the intimate intermingling of generality and context-specificity in instruction... (p.24). They moved a step further to forecast that ...wider-scale efforts to join subject-matter instruction and the teaching of thinking will be one of the exciting stories of the next decade of research and educational innovation (p.24).

The research questions discussed by this thesis are thought to relate finely with such joining of subject matter and thinking skills. However, the fact that previously used metacognitive approaches were based on the ‘general thinking skills’ philosophy makes them incompatible for use within the philosophical framework advocated here. The need, therefore, for use of a differentiated approach for offering metacognition becomes apparent, especially in view of voices in the literature speaking of problems and pitfalls in studies of metacognition that seem fraught with methodological and technical difficulties (Schwartz and Metcalfe, 1996).

This thesis introduces the notion of situated metacognition distinguishing it from general metacognition. General metacognition is the kind of metacognition practised in most of the studies that aimed towards improving children’s general thinking skills. Such improvement was often ‘context-free’ or rather accommodated in an artificial context unrelated to ongoing teaching, hence the anticipation of transfer of any improved cognitive ability to other contexts. Metacognition was explicitly taught and in most cases special time was allocated for this purpose. Situated metacognition, on the other hand, is defined in this thesis as metacognition practised in the current context of normal lessons and within the time...
allocated for the teaching of curriculum subject matter, aiming towards improving learners' performance in the specific content taught by facilitating better understanding. The core of the distinction between general and situated metacognition is presented in the comparison made in Table 4.1.

<table>
<thead>
<tr>
<th></th>
<th>General Metacognition</th>
<th>Situated Metacognition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall Objective</strong></td>
<td>To improve general thinking skills across contexts/ different contents</td>
<td>To facilitate better understanding of specific subject content</td>
</tr>
<tr>
<td><strong>Anticipated improvement</strong></td>
<td>Enhance ability to transfer thinking skills in different contexts</td>
<td>Enhance performance in taught content. (e.g. longer durability and ability to utilise in different contexts)</td>
</tr>
<tr>
<td><strong>Context / Content</strong></td>
<td>General or ‘neutral’ Not related to subject taught</td>
<td>Specific Within subject taught</td>
</tr>
<tr>
<td><strong>Mode of instruction</strong></td>
<td>Explicitly taught</td>
<td>'Blended’ with normal classroom activities</td>
</tr>
<tr>
<td><strong>Time of intervention</strong></td>
<td>Specially allocated time</td>
<td>Normal teaching time</td>
</tr>
</tbody>
</table>

Table 4.1. Comparative summary of differences between general and situated metacognition

The fact that situated metacognition is not aiming directly towards the improvement of general thinking skills should not be seen as a criterion for placing it at a hierarchically lower position to that of general metacognition. Put differently, situated metacognition is not to be regarded as an inferior ‘variety’ of metacognition rather, it is argued, it is one that portrays a more ‘grounded’ approach with differentiated focus. In essence it is an explicit attempt to achieve a balance between subject matter knowledge and strategies for effective learning in the way advocated by Henessy (1993). The intention is to use metacognitive activity to facilitate conscious learning and awareness of how learners’ understanding progresses in order to achieve better understanding of taught material. The effect therefore of situated metacognition is traced in the learner’s performance in the content along which metacognition was employed, rather than in the form of improving one’s general thinking skills.
The choice to apply *situated metacognition* in a way that promotes the blend of content and reflection of the learning process is supported by strong arguments in the literature and research evidence in favour of such integration. Gunstone and Northfield (1994), for instance, suggested that the development of metacognitive skills and knowledge should not be separated from real learning tasks, a point that is all too congruent to the stands advocated by *situated metacognition*. Elsewhere, Gunstone (1994) has argued for the importance of specific science content in the enhancement of metacognition basing his claim on work with science graduates in a one-year pre-service high school science teacher education programme. Boaler (1993) presented research outcomes according to which children from a learning environment characterised by the complete integration of process and content performed better than children from an environment that concentrated mainly on content, when encountering mathematical problems in different contexts. Referring to work designed to test the effect of content instruction and general strategy instruction, Garner and Alexander (1989) reported that students who are weak in both content and strategy knowledge do not benefit from either form of instruction. One of the explanations they gave to this finding is that 'strategy instruction may only work for students who have a certain amount of certain kinds of content knowledge' (p.151) hence offering further argumentation in favour of blending content with process.

On top of the above arguments this thesis suggests that an added benefit of *situated metacognition* is that it can portray a dual positive outcome, both short- and long-term. Short-term because the positive impact of metacognitive activity is reflected on students' understanding of taught material, hence maintaining better performance in the subject-area covered. Long-term impact, on the other hand, stems from accumulated experience of metacognitive activity to be gained by the students, if *situated metacognition* is employed systematically throughout their school year(s). In other words, by applying *situated metacognition* both content knowledge is reinforced by becoming more conscious during its construction, and the learner’s thinking skills are gradually improved through their ‘enculturation’ (Perkins, 1993) in metacognition.

4.7.3. *Situated metacognition and situated cognition*

*Situated metacognition* apparently shares some similarity in terminology to the situated cognition (or situated learning) movement (Lave 1988; Rogoff, 1990) previously discussed in Chapter 3. Although the underpinning philosophy and the claims of the situated camp are not adopted by this thesis, some common ground between situated cognition and *situated
metacognition is acknowledged, mainly with regards to the importance of specific context (and content) for the learning process.

In spite of the high significance attributed to the role of context this thesis does not share the view that all learning is situated, nor that it can only be of use within the context in which learning took place. Quite the contrary, it argues that learning and experience acquired by the learner through situated metacognition can be of use in later encountered settings. The core claim of the situated metacognition perspective is that instead of teaching metacognition as a general thinking skill in a ‘neutral’ or unrelated context with the anticipation that metacognitive ability will later be applied in the context and content of school science, the advocated approach is one of offering metacognitive instruction within the science class context, explicitly using metacognition as a teaching tool for better learning and deeper understanding, aiming towards an immediate positive impact. The use of metacognition in its situated form is hence made more specific, more explicit and more direct than the one advocated by the general thinking skills approach. In effect, the stand advocated by this thesis moves between the two poles of situated learning and the teaching of general thinking skills. In order to make the perceived relationship explicit reference is made to Figure 4.2.

**Figure 4.2. The relationship between situated cognition, general thinking skills and situated metacognition**
In both cases the connection is twofold; one of situated metacognition being influenced in its underpinning rationale by the philosophies of the two camps, and one of situated metacognition having an impact in the direction advocated by each of the two traditions. Drawing from the situated cognition perspective situated metacognition acknowledges the importance of specific context in the learning process. At the same time, though, it is influenced by the general thinking skills tradition, with regards to the importance of metacognition as a general thinking skill. In terms of anticipated results from the practice of situated metacognition, a direct and immediate positive impact is claimed in the direction of the specific science content within which situated metacognition is offered, and an indirect and gradual positive impact on students’ metacognitive skills. More details on the way situated metacognition is offered within this research by means of the metacognitive instances approach is given in the methodology chapter (Chapter 5).

In closing this chapter two important points regarding the way metacognition is perceived by this writer should be brought to mind again. First, this thesis clearly distinguishes itself from work on metacognition that aimed towards ‘improving children’s ability to think’ (Adey, Shayer and Yates, 1991). The focus here is not on improving general thinking skills but on examining the impact of metacognition on more specific aspects of CCL, namely durability and ability to utilise recently constructed conceptions. Second, it is emphasised that the notion of metacognition holds an important but not necessarily the central role in the current study, which focuses primarily on durability of conceptions and the role of different contexts in using these conceptions. Metacognition should be examined in terms of the impact it has on these two aspects of CCL while bearing always in mind that

*Metacognitive tools are helpful, but they are neither a 'sure cure' nor a 'quick fix'*


4.8. Summary

This chapter discussed the notion of metacognition as a growing trend in the field of science education. It presented numerous definitions of the term and offered a brief historical review of its origins and of relevant studies. This was followed by a section on general thinking skills that highlighted important links to metacognition, and the feasibility of practising metacognition with young children was placed under scrutiny. Aspects of the nature of metacognition were discussed in an attempt to highlight some of its important yet
problematic dimensions and links were drawn between metacognition and CCL in order to substantiate the core objectives of the research. Last, the notion of situated metacognition was introduced and discussed in relation to the area of situated cognition. Practical aspects of the way metacognition is incorporated by this research are left for discussion in Chapter 5, which is the methodology chapter.
Figure 4.3 Graphic summary of Chapter 4
CHAPTER 5 - RESEARCH METHODOLOGY

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5.6. Summary
5.1. Introduction to Chapter 5

Trouble awaits those unwary souls who believe that research flows smoothly and naturally from questions to answers via a well organised data collection system (Hodgson and Rollnick, 1989, p.3)

This fifth chapter addresses methodological issues. It presents the philosophical framework within which methodological choices were made by this researcher; it describes in detail the design of the study; and presents the data-gathering tools employed. The metacognitive instances approach is described and examples of its application are given. Justification and elaboration of a number of methodological decisions is also provided, along with description of steps taken for authenticating both the approach and the specific methods used. In doing so, links with the philosophical assumptions underpinning this research are drawn.

5.2. Setting the framework - Establishing research awareness

One of the key issues addressed in the Introduction to this thesis was that this study claims a 'theory driven status' (Novak, 1998) in the sense that it ascribes great importance to substantiating methodological and other choices, by basing these on solid theoretical grounds. Before, therefore, looking into the design of this research and the specific research methods used, it is important that this thesis demonstrates sufficient research awareness as a prerequisite to taking informed action. In order to define research awareness an analytical approach is followed attributing to this thesis both a first and a second order of research awareness (Figure 5.1).

First order research awareness comprises a philosophical framework of purpose. It is the set of ideas underpinning this study, or the views of this researcher regarding the nature of the endeavour and the purposes it is to serve. Such a framework will operate as a reference point for judging the effort in bringing the research objectives to life, and in putting second order research awareness in a philosophical context. Second order research awareness, on the other hand, comprises a number of answers to questions related to pragmatic issues such as the research design, methods employed, and decisions made throughout the course of the enquiry. By being able to answer these questions the researcher demonstrates detailed knowledge of how the research develops from idea to flesh and bones and, at the same time, exhibits openness to scrutiny. The discussion that follows pursues these two dimensions of research awareness.
Figure 5.1 First and second order research awareness

5.2.1. First order research awareness - The philosophy behind the research

A doctoral thesis or research report is a means of presenting and disseminating a new piece of knowledge, therefore making a contribution to academia. An important aspect of such a contribution, though, is for the researcher to have clear views about the nature of the knowledge that is being sought, and eventually presented, and about the nature of the concluding claims accompanying such an endeavour.

A first point to make in this direction is to say that this thesis moves away from positivistic stands, or epistemological approaches, and poses a subjective outlook of knowledge. It does not seek to discover ‘facts’ nor to provide ‘evidence’ that will establish arguments in a definitive way. In spite of employing an experimental approach, traditionally thought to be the option of positive-oriented research, this thesis largely depends on several subjective...
interpretations on behalf of this researcher. Such interpretations had to take place both during the design of the research and during the analysis of data. For example, in designing tests for assessing the outcomes of teaching involved in this research, a great deal of judgement of what constitutes ‘different types of contexts’ was involved. Similarly, during the analysis of data this researcher has to be interpretative in judging the level of understanding demonstrated by the pupils interviewed and in marking answers to questions seeking justification of previously expressed views. Although every effort has been made to substantiate personal judgements by being consistent in the application of criteria and by authenticating the choices made - as will be presented later in this chapter - this thesis can by no means put forward claims for ‘objective truths’. The knowledge, therefore, to be extracted from this thesis should be treated as a ‘snapshot’ of what in reality is a set of complex processes, activities and relationships.

A further prerequisite for establishing research awareness is being aware of the context in which the research is placed. For the present study the context is clearly educational, hence attention should be placed on educational research as the broad field of action. In order to develop this line of thought, a definition of educational research is needed. According to Powney and Watts (1987) educational research is

*The systematic, empirical and critical inquiry into matters which directly or indirectly concern the learning and teaching of children and adults* (p.3).

This thesis makes use of this definition because it regards the three characteristics assigned to educational research to be of high significance. It further argues that these characteristics should be considered by researchers before the implementation of the research design, because the subjective way in which these are interpreted will define, to a great extent, the nature of the research awareness being established.

By ‘systematic’ this researcher argues that educational research should not be a ‘single-shot’ attempt. All learning processes, mechanisms of understanding, classroom behaviours, or school relationships, to mention but a few of the directions of educational research, are not static phenomena to be observed in a single instance. Research should, therefore, be spread over a considerable time period, be repeated on a number of occasions and be dealt with from different angles if it is to sufficiently provide information on the complex phenomena it investigates. Being systematic is also taken to suggest that the research should be based on in-depth theoretical and practical preparation, by identifying and practising suitable research methods, which should then be used in a consistent way rather than by relying on impulsive ideas generated ‘on the spot’. For educational research to be ‘empirical’ is to be interpreted as the arrangement in which the researcher truly ‘experiences’ the research. This requires the
researcher’s direct involvement in the field, the gathering of first-hand data and the accumulation of further impressions that the plain administration of a questionnaire or test would most probably fail to yield. Lastly, being ‘critical’ (or better ‘self-critical’) is probably the most important characteristic of educational research due to the need for judgmental decisions at all phases of the research. For example, the researcher should be critical of the significance of the research questions formulated; the feasibility of the proposed design; the appropriateness and effectiveness of the approaches used; the information obtained by the participants; the concluding claims put forward along with the analysis that generated them; and eventually the degree of fulfilment of the initial purpose of the research.

In order for this last judgement to be possible it becomes apparent, from the very initial stages of conceiving a problem or question that is worth being researched, the researcher should have a philosophical framework of purpose in which to accommodate the research. This should be the driving philosophy, or the mission statement, of the research later translated into research objectives. The framework of purpose differs from research objectives in two main respects. First, the framework of purpose is used as a broader notion than research objectives in the sense that it does not focus on the content of the research rather it comprises aspects of the researcher’s philosophical views and principles regarding the purpose of the research. Second, the nature, the complexity and the feasibility of the research objectives will largely be specified by the framework of purpose that the researcher has either consciously or subconsciously, adopted.

As a starting point for defining such a framework this thesis builds upon the view that regards educational studies as a 'practical science' (Langeveld, 1965). Educational researchers do not want to know facts and to be able to understand relations just for the sake of knowledge per se; they want to do so in order to be able to take some action and in order to act better than they did before. In judging the success of educational research in achieving this objective (i.e. of bringing better practice in schools) Shayer (1992) is not simply being critical but he speaks of a scandal

*The scandal of the intervention study literature, he says, is the lack of good evidence showing improved school achievement as a result of intervention* (p.115).

Similarly, the Teacher Training Agency (TTA) has recently reported that

*To date the UK’s new Teacher Training Agency has been able to identify only a small if significant body of research findings directly focused on classroom practice and enhancing it; more is needed* (TTA, 1996, p.1).

One of the challenges of contemporary educational research, therefore, should be one of providing answers to important research questions that could then realistically be put in
practical use. It is precisely this philosophy that lies behind the objectives of the present study.

This leads the discussion to the issue of distance between educational research and educational practice or, put differently, of the feasibility and applicability of research-based claims to everyday classroom practice. It appears that such distance is currently more of a gap for, as Brown (1994) pointed out in her presidential address to the American Educational Research Association, advances in learning theories of the past century did not find their ways into schools. The need, therefore, for designing educational research with schools and classrooms in mind is evident.

According to Shayer (1992) if one has a promising model from which practice can be derived then there are two questions that need to be answered.

1. What effects and what size effects are achievable using this model? and,
2. To what extent can this model be internalised and successfully used by teachers other than those closely involved with its development? (p.112).

Clear responses to these questions are thought to be an essential aspect of establishing research awareness since the answers given will inevitably reflect on the design of the research. Practical aspects such as sampling, sophistication of materials used, time demands of the research and constraints by existing teaching and institutional structures are only a few of the factors that should specify both the feasibility of the research, and its proximity to classroom practice.

With these thoughts in mind, the main objective set by this researcher was to design research that would be as close to everyday classroom practice as possible. This meant that the whole design had to be realistic, following a ‘down-to-earth’ approach. The intention was to avoid finishing with a highly experimental approach, applying radically innovative techniques and using expensive or sophisticated material, in an ideal setting of advantageous schools with no particular limitations on time, or curriculum constraints. Clearly such a setting has little to do with the reality of the majority of contemporary schooling hence the purpose of such research would instantly be undermined.

To recapitulate on the three directions of first order research awareness is to say that the philosophical framework of this thesis comprises a subjective outlook of knowledge, aiming towards improved classroom practice, facilitated by the outcomes of feasible research design. The discussion that follows addresses issues of second order research awareness.
5.2.2. Second order research awareness - Pragmatic dimensions of the research

Second order research awareness moves on more pragmatic rather than philosophical dimensions of this research. It can be best portrayed by giving answers to the following four questions:

- What is the research trying to find out?
- Why is this important?
- How is the research trying to find this out?
- Are the ‘what’ and the ‘how’ questions, in principle, compatible?

These questions will be discussed in the order raised.

‘What is the research trying to find out?’

Placing the ‘what’ question at the top of the list is by no means a chance decision. It is a question of particular importance for only once a clear answer is given can the research problem at hand be consciously placed at the heart of the research design. It is taken that this question was thoroughly answered in preceding chapters hence no further elaboration will be attempted here. The reader is however urged to refer to the objectives of this research outlined in Appendix I, for, it is this writer’s belief that moving from broad problem statements to specific research objectives is a process that further enhances research awareness.

Why is this important?

Having presented the ‘what’ of the research the next important step in establishing second order research awareness is to justify the significance of the proposed research. Designing and conducting research is an endeavour that requires considerable time, effort and commitment on behalf of both the researcher and the participants, hence justification for undertaking such a task should move beyond the sheer pleasure of ‘finding out’. Demonstrating that the research questions are worth being investigated can be achieved by answering the following three questions, proposed by Fraenkel and Wallen (1993).

1. How might answers to this question advance knowledge in my field?
2. How might answers to this question improve educational practice?
3. How might answers to this question improve human condition? (p. 28).

All three questions were answered in the two preceding chapters yet their importance in establishing second order research awareness justifies a brief reminder. First, this thesis aims to tackle a highly under-explored area for which not much is currently known. By doing so, it anticipates not only making a contribution in relation to the specific problems studied, but, equally important, influencing a shift in focus of CCL research towards post-learning issues.
Second, it anticipates an approach to *situated metacognition* that can be applied by ordinary teachers under everyday classroom conditions, in order to confront the dual problem of pupils rapidly forgetting newly learned material, and pupils being unable to utilise their knowledge in different contexts. Third, although making claims for improving the human condition might seem at worse, ungrounded and at best, over-ambitious for a study of the size and the resources of the research presented, this thesis can be thought of as indirectly making a contribution towards this direction. Following the realisation that the amount of global knowledge is growing at a rapid rate and that individuals cannot possibly acquire all this knowledge, obtaining an insight into the mechanisms involved in retaining and using learned material and the role of metacognitive activity can only make a positive contribution.

*How is the research trying to find this out?*

Contrary to what the heading of this section suggests, presenting the specific methods used is left for a section to follow. The discussion attempted here deals mainly with the underpinning ideas to the 'how'. The first point to make relates to the multi-method approach followed by this researcher since the use of different techniques within a single study has been the cause of much debate among researchers. This debate mainly originated through the positivistic assumptions of *triangular techniques*, which argued that when a claim is supported by data collected from a number of different sources, its validity is largely enhanced. This thesis does not regard the use of different techniques as a means of verifying 'findings' in a positivistic tradition; rather it proposes the use of different techniques, in a supplementary way, as to investigate different dimensions of the problems under inquiry using the most suitable methods each time. This is a choice made on the realisation that the depth of multi-dimensional issues such as human learning cannot possibly be portrayed by monolithic approaches. Without, therefore, sharing the idea of trying to verify a single 'valid truth', this thesis does not reject the use of triangular techniques as long as they

> ... attempt to map out, or explain more fully, the richness and complexity of human behaviour by studying it from more than one standpoint and, in so doing, by making use of both quantitative and qualitative data (Cohen and Manion, 1992, p.269).

Cohen and Manion's last point inevitably shifts the discussion to another long-standing debate, that of *quantitative versus qualitative* designs. The literature is rich in arguments in favour of either of the two approaches, the most commonly encountered 'theorem' being one of sharp distinction between use of the two. This, however, is a view that is not shared by this thesis, which advocates a shift to a 'unity-of-purpose' approach such as the one advocated by Robson (1993)

> Taking a multi-method stance involving the collection of both qualitative and quantitative data, and claiming that the whole is, or should be, regarded as a
The adoption of this approach can best be identified in the way different data-gathering tools are used in this study. Written tests focus on issues of different contexts, interviews are particularly interested in the durability of conceptions, and observation is employed in order to track and monitor metacognitive activity. However, while using different research methods to tackle different research questions, in most cases there is 'overlap of purpose' since data gathered through one method can be used for yielding conclusions in more than one areas. For example, pupils' performance in written tests provides information on their ability to use conceptions across different contexts, but the tests are also used to determine how durable conceptions are. Conclusions about metacognitive activity during teaching have to be based on data gathered through observation, but classroom discussions and material produced by the pupils can prove to be even more enlightening. The continuous blend of qualitative and quantitative information is therefore a distinctive characteristic of this research (Figure 5.2).

**Figure 5.2 Quantitative and qualitative dimensions of the research**
In doing so, this writer seriously takes into account health warnings from the literature. Hammersley and Atkinson (1983), for instance, warn that

one should not adopt a naively 'optimistic' view that the aggregation of data from different sources will unproblematically add up to produce a more complete picture (p.199).

In a similar vein Fielding and Fielding (1986) caution

The accuracy of a method comes from its systematic application, but rarely does the inaccuracy of one approach to the data complement the accuracies of another (p.35).

This thesis therefore exhibits both intention for an integrated approach of multiple data-gathering tools, and awareness of potential pitfalls in this endeavour. The actual 'doing' involved with the approach followed is further discussed in Chapter 6 in setting the framework for the analysis of data.

A last point that relates to the ‘how’ of this research is directly linked to the research questions of this study. It is a recurring theme in research methods literature that good research questions possess at least four essential characteristics: the question must be feasible, clear, significant and ethical (e.g. Cohen and Manion, 1992; Robson, 1993). It is taken that clarity and significance of the research questions of this study have been sufficiently demonstrated by the preceding discussion. The extent to which the questions are feasible and whether approached in an ethical manner, are further issues which are tightly related to practical aspects of the research design. No further discussion will be attempted at this point in order to pinpoint these characteristics within the research. This will be left to emerge through the discussion on practical aspects of the research, which comes in the following sections.

Before examining more practical aspects of the methodology of this research, a last question needs to be addressed that will not only put the final touches to the picture of research awareness drawn by this chapter, but will also help in making the transition from theory to practice.

**Compatibility of the ‘what’ and the ‘how’**

Having identified the ‘what’ and the ‘how’ of this research it is important to judge how the two come together, an issue that is raised in the literature by a number of researchers. Novak (1977), for instance, has indicated the need for research methods to be ‘compatible’ with the underlying assumptions of the research approach. Pope and Keen (1981) argued for ‘coherence’ between theory and methodology while Watts and Bentley (1986) advocated ‘methodological congruence’ as a form of consistency between collection and analysis of
data, on one hand, and the general philosophy of the research, on the other. Before attempting such judgements for this thesis an important point ought to be made. The order in which this section is presented does not represent the actual order followed in conducting this research, since methodological compatibility is not something that can be left to be demonstrated at the very end. Such a choice would have implied taking methodological compatibility for granted, rather than treating it as an essential element of the decision-making involved in choosing the methods of the research. What is therefore being emphasised is that in spite of the order in which this issue is raised in this chapter, in practice compatibility between methods and ideas underlying this thesis was dealt with as an integrated aspect of methodology decision-making.

In order to demonstrate methodological compatibility within this thesis its main areas have to be revisited. First, this research is based on a broad CCL background. Change being the predominant notion, and the chronological durability of conceptions being one of the main research questions, this research could not follow a static ‘one-instant-approach’. It therefore employs a longitudinal design both during the period of implementing the experimental approach (teaching for four weeks) and during the ‘purely’ data-gathering period (three rounds of tests and interviews). Tightly linked to CCL, constructivism is another major theoretical notion of this research advocating the gradual construction of knowledge by individuals. This is in agreement to the longitudinal element of the research and the taking of ‘snapshots’ at a number of selected instances in order to reach (or construct) informed conclusions. The use of a number of different research methods is also an approach that regards the construction of (this researcher’s) understanding through a number of different sources of information. Constructivism’s dependence on the subjective interpretation of knowledge is something that is also reflected in the process of analysing interviews, where this researcher must inevitably make judgements in order to construct an understanding of pupils’ own understanding. Similar subjective interpretation is employed in defining what is ‘context’, in order to construct tests; in devising questions for the interviews; in considering whether pupils’ responses constitute adequate explanations of the phenomena examined etc. Metacognition is the main experimental proposal of this thesis and the methods used are thought by this researcher to be in agreement with what metacognition stands for. By interviewing pupils, or by asking them to respond to a written test the main requirement placed upon them was to revisit their learning and reflect on their understanding. Similarly, in the case of both written tests and interviews, the pupils had to make choices, justify their answers and identify the applicability of their knowledge in different contexts, all of which are processes compatible with being metacognitive. Finally, this discussion is itself all too compatible with the metacognitive assumptions of this research since what is being attempted
is to reflect upon the research design and evaluate its agreement with the framework of ideas supporting this thesis.

In sum, discussion to this point has sought to demonstrate that this thesis holds sufficient research awareness, which in essence serves in both guiding and justifying choices methodological made by this researcher. It is upon this awareness that the following section builds in discussing the research design.

5.3. Research design and methods of enquiry

5.3.1. Outline of the research design

The basic idea underlying all experimental research is really quite simple: try something and systematically observe what happens (Fraenkel and Wallen, 1993, p.242).

In the case of the research presented by this thesis 'trying something' has meant taking an experimental and a comparative group of Year 5 pupils and teaching them a complete science unit over a four-week period. The treatment of the two groups was 'identical' in terms of objectives, content, allocated time, classroom arrangements and apparatus used, apart from the incorporation of metacognitive activities in the teaching of the experimental group. One week after completion of the subject-unit both groups took the same written test, assessing their ability to make use of taught scientific conceptions in different contexts, and a number of pupils from each group was interviewed in order to gain a qualitative outlook of their current understanding.

The test and the interviews with the same pupils were repeated at the end of the semester (i.e. two months later) and at the end of the school year (i.e. eight months later), in order to examine how durable learned material proved to be. Figure 5.3 presents a summary of the research design in diagram form. Further details of the design are given in the following sections where practical aspects of the research are thoroughly discussed. Discussion at this point addresses quasi-experiments, which is the approach associated with designs such as the one just described.
Figure 5.3 Research design

T1, T2, T3: selected time instances
5.3.2. The quasi-experimental approach

By aiming to examine the possible effects of metacognition on durability of pupils’ conceptions and their ability to use these across contexts, the present research clearly poses an experimental orientation. The choice of the experimental approach is not irrelevant to the underpinning views of this research as presented in previous sections. By regarding educational studies as a ‘practical’ science emphasis is placed on some form of expected action. Many scholars believe that the approach that best incorporates action is the experiment. As Fraenkel and Wallen (1993) point out

*Of all the research methodologies...experimental research is unique in two very important respects: it is the only type of research that directly attempts to influence a particular variable, and it is the only type that can really test hypotheses about cause-and-effect relationships* (p.241).

They also highlight the fact that experimental research enables going beyond description, prediction and the identification of relationships to at least a partial determination of their cause. Although this thesis shares similar views, the experimental approach was adopted in a manner far from the positivistic tradition, which is usually regarded as directly linked to experiments. As was discussed earlier in this chapter the scope was to investigate possible effects of a new approach, without attributing ‘measurements’ to any impact this may have.

Experimentation is broadly regarded as a research strategy that involves a) the assignment of subjects to different conditions; b) manipulation of one or more variables (called ‘independent variables’) by the researcher; c) the measurement of the effects of this manipulation on one or more other variables (called ‘dependent variables’); and d) the control of all other variables (Robson, 1993).

Random assignment of subjects to different treatments is considered to be the distinctive characteristic of ‘true’ experiments. The fact that random sampling could not be employed by the present research has led to adopting a *quasi-experimental* approach. Campbell and Stanley (1963) defined the quasi-experiment as

*a research design involving an experimental approach but where random assignment to treatment and comparison groups has not been used* (cited in Robson, 1993, p.98).

Similarly, Cohen and Manion (1992) point out that

*The single most important difference between the quasi-experiment and the true experiment is that in the former case, the researcher undertakes his study with groups that are intact, that is to say, the groups have been constituted by means other than random selection* (p.193).
As with most research conducted in contexts of organised education, random assignment of pupils to treatment groups was not possible in the case of the present research for practical and ethical reasons. The children were already placed in classes and any movement of pupils from one class to another, for the needs of this research, would have caused serious disruption to the operation of the schools and possibly reactions on behalf of the pupils, their parents and the teachers. Randomly choosing classes of equal numbers, on the other hand, was not a problem since the size of the classes was an easily controlled variable. The risk, however, of applying random sampling was one of choosing classes that might differ considerably in aspects such as the children’s level of cognitive development, their background knowledge in science, the average socio-economic background of the group, school resources available etc. It was, therefore, concluded that the classes had to be ‘matched’ because differences in one of the aforementioned areas (and possibly others) could considerably affect the groups’ comparability and, consequently, the trustworthiness of the research outcomes.

Once the classes were ‘matched’ they were then simply assigned as ‘comparative’ and ‘experimental’. The same approach was followed for both big and small classes.

Following the presentation of the research design and the approach accompanying this, the next section describes the specific methods employed by this study. In going through the discussion the reader is urged to bear in mind that this thesis shares the view that

*Quasi-experimentation is more of a style of investigation than a slavish following of predetermined designs* (Robson, 1993, p.108).

It is under this light that absence of any ‘recipe-like’ approaches, or divergence from ‘normal’ research practice, should be viewed.

5.3.3. Methods of enquiry

Having specified both the research philosophy and the approach employed by this thesis, a turn is necessary towards specific data gathering tools.

In carrying out real world enquiry, Robson (1993) says, *our options are essentially the same as those available to the detective and to ourselves in day-to-day living. We can watch people and try to work out what is going on; we can ask them about it and we can look out for fingerprints (as well as any other evidence they leave behind them)* (p.187).

The research presented by this thesis made use of all three options as each one of them bears strong limitations when viewed on its own. This is a consequence of the multiple research objectives and the different areas covered within the study.
Written tests were used to investigate pupils' ability to apply their conceptions of science in different contexts and a repeat of these tests served for studying the durability of these conceptions. Interviews were employed in an effort to gain deeper understanding in what is durable over the period under study. Classroom observation was applied in an attempt to track metacognitive activity, while material produced by the children was also used towards the same goal. Following is a detailed presentation of the data-gathering methods of this study.

Conduct of tests in three phases
Written tests are among the research tools that can yield a large volume of data in relatively short time and can cover broad areas of research interest. The participants can choose which questions to reply to first, and they can omit questions without the embarrassment of facing an interviewer. In the case of school-based research where pupils form the population being researched, taking a test is not something unusual rather it is an expected thing to do on completion of every subject-unit. The added advantage, therefore, of using tests as a means of research is that pupils do not feel that they are being researched and any anxiety they may feel should be no more than the anxiety felt for most tests taken throughout their school lives. Moreover, tests can allow for fairness in marking if dealt with anonymously (using numbers for follow up purposes) and if a set of marking criteria is consistently used.

The most common criticism of tests focuses on the fact that the respondent has to work in pre-specified time limits that can affect one's performance and that the test is marked in the absence of the respondent, therefore not giving the researcher the chance for clarifying obscure or ambiguous replies.

This research made use of written tests in a 'post-test-only' mode because the children involved had not been taught the specific concepts before, therefore the use of pre-tests (other than the tests used for matching the groups) would have no real meaning. The first test was employed on completion of the four lessons of the subject-unit, over a fifth meeting during which the unit was assessed. A full 80-minute period was allowed for this purpose. The test used was also the main tool for obtaining quantitative data for the needs of this research.

In order to investigate the role of different contexts, three main directions were considered in designing the test:
1. Assessing learned material in a 'context-free' mode ('Type A' exercises).
2. Assessing learned material in contexts that resembled the ones in which teaching took place ('Type B' exercises).
3. Assessing learned material in contexts considerably different than the ones in which teaching took place ('Type C' exercises).

The test comprised three parts each of which corresponded to one of the directions described above. Each part included five exercises with a number of questions or tasks in most cases. The three parts were presented to the students as one integrated test and no reference was made to differences between them. Each of the five exercises included in the three parts of the test referred to one of the five main concepts covered within the subject-unit on electricity, namely: a) ‘Current / Electron flow’, b) ‘open-closed circuit / the role of switches’, c) ‘burnt-out light bulbs’, d) ‘conductors and insulators’, and e) ‘short-circuits’. The five concepts were therefore tested three times throughout the test, placed in a different context each time as described in Chapter 3. The test made use of a variety of ‘closed-type’ exercises such as ‘fill-in’, ‘right-or-wrong’, and ‘multiple choice’ questions, and ‘open type’ exercises, in which further explanation or justification of prior answers was sought. All exercises of the second (Type B) and third part (Type C) of the test were accompanied by pictorial representation of the problem (or some other related picture) that helped in providing a context for the problem. Exercises in the first part did not include any pictures in an attempt to keep a ‘context-free’ mode. Only one Type A exercise in part A had a figure, which was necessary for testing the direction of electron flow.

The first part of the test contained exercises requiring a very brief answer, without offering a particular context in which to place the question, as shown by the examples in Figure 5.4.

- 'When an electric circuit is open, electrons ________'
- 'Name two conductors and two insulators that you know'.
- 'When a light bulb 'burns out' what really happens inside the bulb?'

Figure 5.4 Examples of Type A exercises

The second part comprised exercises with contexts similar to the ones in which the concepts were taught. They were accompanied by pictorial representations similar to the ones appearing in the textbook used throughout the unit and all resembled the arrangements used for classroom experiments. The nature of the problems and the degree of difficulty were very close to the experimental activities performed in class. Figure 5.5 presents an example of Type B exercise.
The diagram below shows an electric circuit. It is made of a battery, wires, two light bulbs (A and B) and a switch (S). What will happen when the switch (S) closes?

Put the correct answer in a circle:

a) Light bulb A will glow first
b) Light bulb B will glow first
c) Both light bulbs will glow simultaneously (together)
d) None of the light bulbs will glow

Justify your answer:

(4 points)

Figure 5.5 Example of Type B exercise

The third part of the test made use of five problems, all placed in contexts that did not resemble the ones in which teaching took place. Problems were placed in a story-like setting taken from real-life events or from children’s interests and a relevant picture was included that helped visualise the setting, as shown in Figure 5.6. None of these exercises referred to classroom experiments or school science, while the use of ‘technical’ terms that would directly relate the problems to the science learned in class was specifically avoided.

During the first round of administering the test, the following question was added as an attachment to the test: ‘Which of the exercises in this test do you think was the most difficult one? Why?’ The scope of this question was to examine children’s views on how hard different types of exercises were thought to be and to relate these views with their performance in the three parts of the test. This question was thought by this researcher to have
a direct link to the prevailing metacognitive interest of this thesis, mainly because of the reflective requirement it posed. Further reference to children's responses to this question, in relation to the broader objectives of this research, follows in Chapter 6 during analysis of data.

At Kate's house they have an old electric kettle that they have been using for many years. Kate has recently noticed that the kettle's wire is worn. The plastic cover has been removed and the little bare wires inside can be seen...

a) What will happen if the two bare wires make contact (touch each other)?
Explain why. _______________________________________________________

b) What else can cause the same effect?
___________________________________________

(4 points)

Figure 5.6 Example of Type C exercise

As reported in previous sections the test was administered three times with considerable time intervals between them: one week after completion of the subject-unit; at the end of the first semester (two months later); and at the end of the school year (eight months later), hence examining durability of learned material along with ability to use conceptions in different contexts. Tests were marked by this researcher following a set of predetermined criteria. This approach to marking was thought to be the most appropriate one, both due to the inclusion of open type questions and the longitudinal nature of the study. Because of the time interval between the three administrations of the test, the marking criteria were revisited each time and
random comparison of the marking of the same questions in different tests was performed, in order to maintain fairness in the marking process in the three phases of the research. Aspects of the marking process are discussed further in Chapter 6 before presenting the outcomes of the research. More details on the methodological checks employed for authenticating this research follows in a proceeding section of this chapter.

Conduct of interviews in three phases

It has been suggested that the direct interaction of researcher and interviewee during an interview is the source of both its advantages and disadvantages as a research tool (Borg, 1963). Interviews have been extensively used by CCL research over recent years (e.g. Vosniadou and Brewer, 1992; Watts and Alsop, 1997; Borges and Gilbert, 1999) because they provide a means of data gathering that can be flexible and adaptable to the needs of the inquiry. The interviewer can follow up ideas, probe responses and investigate motives and feelings, while further development and clarifying of points is also feasible. The non-verbal aspects of a response (facial expression, hesitation, etc.) can provide information that a written response would never be able to reveal. Moreover, the interviewer can clarify any points that are obscure and can also ask the interviewee to expand on answers that might be of particular interest.

On the other hand, interviews can bear a number of drawbacks.

...like fishing, Cohen (1976) says, interviewing is an activity requiring careful preparation, much patience, and considerable practice if the eventual reward is to be a worthwhile catch (p.82).

Interviews are time consuming, since they take considerable time to complete and transcribe, and they require the physical presence of both the interviewer and the interviewee, something that can prove highly problematic if mutually convenient time for both interviewer and interviewee is hard to arrange. They are highly subjective and they can pose serious problems in analysing responses, while the presence and the facial or verbal reactions of the interviewer may considerably affect what the respondents say (or what they do not say). Problems of trust between the interviewer and the interviewee can also be evident especially when interviewing young children. This is a problem that has been reported in the literature by a number of researchers. Bell et al. (1981), for instance, warn that the interviewer may be seen by children as 'a teacher in disguise' giving an oral examination, whereas Powney and Watts (1987) report a case study where the interviewer was regarded with extreme suspicion, 'as though I were a spy from the enemy camp wanting to know what they thought of the staff' (p.48). The attitude, if not the whole personality of the researcher, can, therefore, decisively affect the success of an interview.
In deciding the use of interviews as a research tool the researcher also has to make a decision on the specific type of interview to use, for the research literature provides a long list of different types of interviews. Cohen and Manion (1992), for instance, identify four types of interviews: 'structured', 'unstructured', 'non-directive' and 'focused' interviews. Bell (1993), on the other hand, refers to: 'structured', 'semi-structured', 'informal' and 'retrospective' interviews; while Powney and Watts (1987) follow a dyadic classification, of 'respondent' and 'informant' interviews. In any classification scheme the variable is usually the degree of flexibility of the content and format of the interview, in other words, the extent to which the researcher controls the interview. Cohen and Manion (1992) point out that regardless of the choice made, a common denominator in every type of interview is the transaction that takes place between seeking information, on the part of the interviewer, and supplying information, on the part of the interviewee.

The research presented in this thesis made use of semi-structured interviews, defined by Robson (1993) as the arrangement

where the interviewer has worked out a set of questions in advance, but is free to modify their order based upon her perception of what seems most appropriate in the context of the 'conversation', can change the way they are worded, give explanations, leave out or include additional ones (p.231).

This was a choice made primarily due to the comparative nature of the study, which required comparisons to be made on equal grounds. This researcher also shares Bell's (1993) view that The advantage of a focused interview is that a framework is established beforehand and so analysis is greatly simplified (p.94).

Had the choice been to incorporate unstructured interviews in which the course of the discussion would be determined by the interviewees rather than the researcher, the richness of the material gathered would probably be enhanced, yet, comparisons would have been largely inhibited in cases where areas of particular interest were not treated equally in subsequent interviews. The questions of the interviews were pre-specified by this researcher and a checklist was used to keep track of the questions covered at every point (Figure 5.7). Although all interviews started off with the same questions, the order of subsequent questions was not strictly the same to all but it was largely determined by the pupil's reaction to previous questions.
<table>
<thead>
<tr>
<th>Pupil's number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

**1. What makes a light bulb glow?**
Explain conditions

**2. What is the role of the battery? Refer to terminals.**
Does the battery 'create' new electrons?

**3. Where are electrons in the first place?**
Anywhere else? e.g. inside the battery?

**4. Describe the way electrons move.**
Explain / Give example.

**5. Figure 1: Which lamp glows first?**
Explain why.

**6. Figure 2: Explain what is the use of the switch in the circuit?**
Where does the term 'diakoptis' (switch) come from?
What material is the switch made of? Justify.

**7. Describe what happens in an open v a closed circuit.**

**8. Explain what is the role of the fuse inside plugs?**
Describe how it is made inside. How does it operate?

**9. Figure 3: Does a 'burnt-out' bulb glow? Why?**
Explain with reference to electrons and open circuit

**10. Figure 4: The role of a burnt-out bulb in series...What happens?**
Explain Why? Refer to electrons and open circuit

**11. What is the difference between conductors and insulators (Examples).**
Explain why they behave differently. Refer to electrons inside

**12. What is the use of knowing about conductors and insulators?**

**13. What is a short circuit? How can it be caused?**
Where does the term 'vrahikikloma' (short-circuit) come from?

**14. Figure 5: In which of the three cases will there be a short-circuit?**
Why? Show the flow of electrons

**15. Why can a short-circuit be dangerous?**
Does anything happen to current in a short-circuit? Why does this happen?
All children of both small (experimental and comparative) classes along with four children from each of the big classes (i.e. total: sixteen children) were interviewed in an attempt to gain an insight into their conceptions and ideas after being taught about electricity. The children from the big classes were selected on the basis of their scores in the cognitive development test administered at the beginning of this research, in such a way as to representatively include children from the whole spectrum of scores ranging from very high scorers to very low scorers. The four children chosen from the comparative group were then ‘matched’ with four children from the experimental group on the basis of their scores in the same test. The first round of interviews took place on the same day as the first test that assessed the subject unit taught and the duration of each interview was approximately 25 minutes.

The venue for the interviews was an empty classroom or office not used by anyone at the time, though, this was not the same for the three rounds of interviews in each school. At the beginning of each interview the researcher spent a couple of minutes chatting with the pupil to establish a friendly, non-threatening atmosphere. Pupils responded positively to the idea of being interviewed as they felt that they were doing something important. Interviews were by no means a source of stress or anxiety to the children. A very relaxed atmosphere was employed and jokes were made by the researcher suggesting that the situation resembled that of politicians, or other famous people, being interviewed by reporters. In this case the ‘famous’ persons were the pupils, something they seemed to enjoy immensely. Typical of their positive attitude was the fact that during follow-up visits the children were very eager to find out if they would be interviewed again, and they seemed very pleased when they were told that indeed that was the case. It is therefore possible to claim with confidence that the interviews were conducted under a friendly, non-threatening setting, hence eliminating the possibility of a negative effect on pupils’ responses or attitude due to stress or anxiety.

Conversations were recorded using a small tape recorder that was placed at the side of the table in such way as not to be at the centre of attention during the interview. No other person, student, or staff was present in any of the interviews. The arrangement was kept identical in all three phases and for every one of the interviewees. The researcher and the pupil shared the same table; a few sheets with drawings (see Appendix III) and a checklist (Figure 5.7) were held in front of the researcher, and the pupil was shown from the very beginning what was on the sheets. Emphasis was placed on explaining that the checklist was not a sort of marking system, rather it was for helping the interviewer keeping track of the questions he wanted to ask. In the follow up interviews the same points were raised even if the pupils were already familiar with the procedure.
No other materials were used in the first two rounds of interviews. The interviews did not follow the Predict-Observe-Explain method used by other researchers (e.g. White and Gunstone, 1992; Borges and Gilbert, 1999) because of the longitudinal interest of the research. Providing interviewees with apparatus and the opportunity to re-observe and test their predictions or explanations could act as reinforcement of knowledge, or as a chance to modify prior beliefs, hence affecting performance in the meetings to follow. The risk was that when interviewed at Phase 3 their answers would possibly not be based purely on learning that took place at the beginning of the school year but also on further experience gathered during the interviews in between. In the third round of interviews simple apparatus was used for setting up basic circuits that allowed use of the Predict-Observe-Explain approach. In this case the concern of reinforcing knowledge was no longer valid. The interviews followed exactly the same structure as in the two previous rounds, the only difference being that the children could test their prediction by performing the experiment and further explanation was required in cases where observation did not verify prediction.

In the case of a pupil saying that s/he did not know or did not remember the answer to a question, the researcher assured the pupil that was not important and then moved on to the next question. No judgmental comments were made when a wrong answer was given. During the course of the interview no notes were taken by the interviewer in order to maintain the informal character of the conversation. Once the interview was completed and the pupil left, the researcher took brief notes about the pupil’s overall attitude, reactions to the questions or any striking incidents that happened during the course of the interview.

All interviews were tape-recorded, transcribed, translated and analysed by this researcher. In translating this material from Greek the main concern was on portraying what the respondents have meant, rather than on strict verbatim translation into English, because translated idioms and expressions used would make no sense to the English speaking reader. In order to maintain fairness and consistency in the analysis of the transcripts a set of criteria was followed, in a way similar to the approach used in the case of written tests. In an attempt to authenticate the interviews a number of transcripts were given to colleagues and fellow researchers who were asked to comment on the analysis made by this researcher. Further information about the interviews follows in Chapter 6 along with the analysis of data gathered.

Follow-up interviews with the same children were repeated two months (December 1998) and eight months (June 1999) after completion of the subject-unit. The children were not informed of this researcher’s intention to repeat the interviews because this might affect their
performance during follow-ups (e.g. pupils putting extra effort not to forget what they learned; or pupils revising taught material before the second and third round of interviews).

Conduct of classroom observation

Classroom observation was thought by this researcher to be important as an additional source of information for the needs of this research, for as Robson (1993) points out:

...direct observation in the field permits a lack of artificiality which is all too rare with other techniques (p.191).

Bell (1993) identifies the importance of observation in the fact that:

It can be particularly useful to discover whether people do what they say they do, or behave in the way they claim to behave (p.109).

In the present study, however, observation acted as a supplementary source of information, rather than as a means of verifying claims. Its main objective was to monitor children's involvement in metacognitive activities and to enable adjusting the teaching process, so that metacognition could best be incorporated.

By applying participant observation it was clearly impossible for this researcher to be 'an unnoticed part of the wallpaper' as should be the case for the 'pure observer' (Robson, 1993). However, the fact that the researcher was at the same time acting as the teacher, contributed to keeping him 'unnoticed' from one point of view, as children did not feel 'under observation'; at least no more than they are in everyday classroom conditions. More detailed observation would have been possible if this researcher could be a non-participant observer with the class teacher doing the teaching, yet, this would have been a choice generating other serious problems, as was demonstrated earlier in the discussion. Using other means for recording classroom behaviour proved to be equally problematic. On the one hand, audio-recording the lessons was not a good solution as shown by attempts to do so in the pilot study. The problem was that there was usually too much background noise and it was impossible to record clearly all conversations taking place in the classroom, or to identify the speaker when playing the tapes. On the other hand, the option of having the lessons video-recorded was unfortunately not a feasible solution. Since a stationary camera would not serve sufficiently, this meant that a second person was required who would be free and willing to travel to different schools everyday, four times a week, for four weeks. Unfortunately the assistance of such a person could not be obtained due to the long-term commitment required and the limited resources available to this researcher. As a result, classroom behaviour was recorded mainly in the form of notes made by this researcher during and immediately after each lesson, following a qualitative, unstructured approach traditionally associated with participant observation.
Consequently, this research cannot present observation-generated data in the commonly used sense of the term, rather it is restricted to reporting this researcher's accumulated impressions from classroom interactions. In analysing, therefore, the outcomes of this study in the following chapter, a distinct section on classroom observation is not included, rather such information is accommodated in the discussion of outcomes generated by means of the other research methods employed and the implementation of the experimental approach of this study.

**Material produced by the pupils**

The scope of gathering additional material produced by the children is not related to the research questions regarding 'durability' and 'context' but it is primarily linked to the practice of metacognition. Material such as children's questions, or comments expressed during the lessons, children's notes in the form of a diary, annotated drawing and concept maps produced in the classroom, were thought to be essential 'on-the-go' information that indicated whether pupils were gradually practising metacognition. Such feedback was important because, had this material suggested that the children were not engaged in metacognitive activities, then the direction of the study would have altered considerably. Children were specifically asked to try being conscious in reporting their thoughts, regardless the nature or format of the task (e.g. either in the form of a diary, a question, or even annotated drawing). Samples of such material are given in Chapter 6, which deals with the analysis of data, and in Appendix IV.

**5.3.4. Design details**

**5.3.4.1. Participants**

**Numbers**

The fact that the research design required all teaching to be done by this researcher, the involvement of considerable travelling, and the need for equal treatment of participating classes in terms of the periods during which teaching took place, imposed limiting teaching to only one class per day. Having left one day of the week free as a safety measure (in the event of a public holiday, or other school activity that could result in missing the lesson at one of the schools), the maximum number of classes that could take part in the research was four. The involvement of a greater number of classes would of course enable experimentation on a larger scale consequently yielding conclusions of enhanced reliability, yet the practical reasons outlined did not allow this to happen.
This research was conducted with sixty-eight Year-5 pupils from schools within the educational district of Nicosia in Cyprus. The pupils were divided into two big classes of thirty and two very small classes of four children. Both experimental and comparative group comprised one big and one small class (i.e. 30+4). The big classes enabled research under 'real-life' classroom circumstances with all the usual problems encountered by teachers (e.g. number of pupils, mixed abilities, lack of time etc). The small classes, on the other hand, offered an excellent setting for qualitative research. They provided an environment where deeper understanding of children's ideas was facilitated and personalised feedback was possible, while following the same curriculum and the same timetable as the big classes. None of the classes had been taught by this researcher in the past.

Selection process

The sampling approach followed two directions as shown in Figure 5.8. On one dimension (X-axis) lies the difference in treatment, resulting in allocating 'comparative' and 'experimental' groups. On the other dimension (Y-axis) the class size specifies 'small' and 'big' groups. By introducing this 'two-dimensional' sampling, the analysis of data is largely enhanced by enabling a number of comparisons between 'adjacent pairs', as indicated by the arrows in Figure 5.8. No direct comparisons will be possible for pairs in diagonal 'relation', because of the simultaneous inclusion of more than one variables.

\[ N = \text{number of pupils} \]

Figure 5.8 Sample groups
One of the most important tasks during the pre-research period was to eliminate the impact of extraneous variables that could have unintended effects on the dependent variables of the research. A number of factors had to be taken into consideration during the sampling process, in order to maintain that all groups selected were ‘matched’ on a number of characteristics, hence enhancing reliability of research outcomes.

In selecting classes to participate in the research the following steps were taken by this researcher. First, information was gathered from the Department of Primary Education of the Ministry of Education and Culture of Cyprus in order to obtain a list of classes with equal number of pupils. The search was limited to suburban schools of the educational district of Nicosia, in order to exclude both privileged schools in the city centre and poor, under-achieving schools in rural areas. This research was therefore placed in an ‘average’ environment. (This criterion did not apply in choosing the two small classes, since schools with such small numbers of pupils form a distinct category of their own). The list of schools was then further limited to schools of roughly the same size, in areas that shared the same socioeconomic background and schools without any known serious problems. Following this, four classes were chosen in which two tests were administered. The first test aimed at giving an indication of pupils’ level of cognitive development while the second test examined their current knowledge on science topics taught in Year 4 (More information about these tests is given in a following section of this chapter). Lastly, the results of the tests were used to pick up the two classes with most convergent scores. The ‘matched’ classes were then randomly assigned as ‘comparative’ and ‘experimental’. The same procedure was later repeated in choosing the two small classes. Table 5.1 offers a summary of the results of the two ‘matching’ tests.

### Results of ‘matching’ tests used during sampling

<table>
<thead>
<tr>
<th></th>
<th>Big Classes</th>
<th>Small Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comparative C.D.*</td>
<td>Experimental C.D. Y4</td>
</tr>
<tr>
<td>Mean</td>
<td>7.43</td>
<td>53.53</td>
</tr>
<tr>
<td>%</td>
<td>74.33</td>
<td>53.53</td>
</tr>
<tr>
<td>Median</td>
<td>7.38</td>
<td>53.00</td>
</tr>
<tr>
<td>S.D.</td>
<td>1.49</td>
<td>16.67</td>
</tr>
</tbody>
</table>

C.D. = cognitive development test
C.D.* = test on Year-4 science

Table 5.1
**Other Characteristics**

All four classes that participated in this research were of mixed gender (Table 5.2/ Figure 5.9) and abilities. This resulted in having both very able pupils and pupils with severe learning difficulties taking part, something that placed the research in a very ‘real’ setting. No behavioural or other serious problems were met with regard to the participants. Apart from sharing similar socio-economic backgrounds and being ‘matched’ by means of the two tests referred to earlier, the children shared one more important characteristic. In previous years the pupils had all been taught using exactly the same books and, to a great extent, followed the same objectives and methodology as specified by the Ministry of Education and Culture of Cyprus (this being the result of the highly centralised educational system of Cyprus).

<table>
<thead>
<tr>
<th><strong>GROUP</strong></th>
<th><strong>Male</strong></th>
<th><strong>Female</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Big comparative group (E1)</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Big experimental group (E2)</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Small comparative group</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Small experimental group</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>38</td>
<td>30</td>
</tr>
</tbody>
</table>

*Table 5.2*

*Figure 5.9 Participants by gender*

Once access to schools was gained, this researcher was treated from the very first day (by both staff and children) as ‘the new science teacher for Year 5, for the next few weeks’. This resulted in maintaining a normal classroom environment, which did not suggest in any way that the work in progress had anything to do with research or experimental methods. The class teachers were not informed whether their class had been allocated as ‘comparative’ or ‘experimental’ nor were they given details of the intervention activities used. This was a
decision made in order to avoid any (intentional or non) replication of these activities in other lessons, something that could affect the outcomes of this research.

**Refusals / Missing data**

The research did not face any serious problems with refusals or missing data. All school headteachers and staff approached were willing to co-operate and in no case was the researcher denied access in schools. In two cases one pupil was absent from one of the lessons. This must have, of course, affected these particular pupils’ performance in the specific topic taught on the day(s) of absence, but as they were two isolated cases it is taken that no significant effect was caused to overall results. None of the pupils were absent during the first testing at the end of the subject-unit hence there are no missing data. During the second test, administered in December 1998, two pupils from the big comparative class were absent. In the third testing round in June 1999 one pupil from the comparative group was absent. In calculating statistical measures such as the arithmetic means or medians, these cases were treated as missing cases and were not taken into account.

5.3.4.2. Materials

**Books**

All classes used the book *'Prota vimata stin epistimi'* ('First Steps in Science') which is issued by the Department for Primary Education of the Ministry of Education and Culture of Cyprus. The book comprises sets of detachable worksheets, samples of which can be found in Appendix II. These were removed by the children in each lesson and were used for making predictions, describing experiments, solving exercises, reporting results, writing conclusions etc.

**Experimental materials**

All practical activities involved in the teaching of the subject unit required simple material and equipment like, for example, 1.5V batteries, light bulbs, wires, wooden boards, bulb holders, switches, conducting and insulating materials. All materials were provided and prepared by this researcher in order to avoid the risk of children forgetting to bring these from home, and for maintaining the use of identical material by both experimental and comparative groups, in both big and small schools. The materials were available to groups of six pupils who were expected to carry out most experiments themselves. Only a very limited number of experiments were performed in the form of demonstration by this researcher - mainly for safety reasons (e.g. causing a short-circuit).
Tests

Three tests were used for the needs of this research. Following is a brief description of the tests and the objective served in each case.

a) Cognitive development test

This was a test devised by this researcher based on material from extensive work by Case et al. (in press) specially designed for describing cognitive development in young children. The purpose of this test was to enable selection of comparative and experimental groups that would demonstrate convergent scores on tasks related to cognitive development. This was a pre-research step of particular significance since considerable differences between the two groups would not allow fair comparisons to be made, given the important role of cognitive development in school performance and, even more so, in practising metacognitive activities.

Due to the need for specialised knowledge from the field of psychology, in order to employ such measures with confidence, this researcher decided to seek professional advice. The use of the test by Case et al. (in press) was recommended by one of its co-authors, who is himself a Professor in Psychology, suggesting that this can serve the purpose required by this researcher. It is of course acknowledged that a number of other tests might have been equally appropriate, yet the use of a different test designed for a similar purpose would not have made any difference to the design or conduct of this research. In other words, the fact that this test could provide a sufficient basis for comparing the children’s level of cognitive development was the only criterion behind the decision to use material from Case et al. (in press) and not from another source. Using a more detailed standardised test was not thought by this researcher to be necessary mainly because the scope was not to measure or ‘label’ pupils’ level of cognitive development, rather it was one of providing a means of comparison for the two groups. The test comprised five main tasks, each corresponding to one area of cognitive development taken from five ‘task batteries’ used by Case et al. (in press): the ‘spatial-imaginary’; ‘verbal-propositional’; ‘quantitative-relational’; ‘qualitative-analytic’; and ‘causal experimental’ task battery. (For more details on the original tests please see Case et al., in press).

b) Test on Year 4 science syllabus

This test comprised a selection of exercises taken from the assessment booklet that complements the book ‘First Steps in Science’ (Ministry of Education and Culture of Cyprus, 1995b). This is used by teachers at the end of each subject-unit as their basic assessment tool with regard to the attainment level that the pupils should achieve. One or two exercises were taken from each unit in order to construct the test. The scope was to enable selection of comparative and experimental groups that would not only be ‘matched’ on cognitive
development, but which would also demonstrate similar average scores on material learned during the previous year. This served as an extra safety measure taken for matching the two groups, since the results of the present research could possibly be questioned if participants had considerably different science backgrounds.

c) Final assessment test

This test was constructed by this researcher for assessing the results of the subject-unit taught and, of course, for collecting data for the purposes of the present research. This test was common to both comparative and experimental group and was taken one week after completion of the subject-unit. In order to investigate durability of conceptions the same test was repeated two months (i.e. at the end of the first semester / December 1998) and eight months later (i.e. at the end of the school year / June 1999). Particular attention was paid to structuring the test in three parts (discussed in Chapter 3) in order to facilitate testing of pupils’ performance in different contexts. A copy of this test can be found in Appendix III.

5.3.4.3. Procedure

Setting

a) Big classes

In the case of the two big classes the setting was a modern, newly-built public school, situated in a suburb eight kilometres from the city centre of Nicosia. The school was well equipped, employed sixteen full time teachers and accommodated approximately 350 pupils. The lessons were held in ordinary classrooms due to absence of science laboratories, an arrangement that is the rule rather than the exception in all primary schools in Cyprus. This did not cause any serious problems other than the fact that the rooms were rather small to accommodate thirty children who, in addition, had to move during practical activities. The pupils were seated in five groups of six.

b) Small classes

The setting for the small classes was radically different than the one for the big classes. Both small schools were situated within a radius of thirty-five kilometres from Nicosia, with only two full time teachers and two classrooms available. The usual arrangement for this kind of school is to have classes of Years 1-3 sharing one classroom while Years 4-6 share the second. This was the arrangement made during the course of this research. Although this meant that teaching was undertaken simultaneously by two teachers who were facing two different audiences in the same classroom, this caused no problem since pupils of such schools are used to working very quietly under these circumstances. The fact
that this researcher had prior experience as a teacher working in such a setting was an added advantage that enabled problem-free teaching.

**The lessons**

The subject-unit 'Introduction to Electricity' comprised four 80-minute lessons. A fifth class was taken in order to assess the unit. The day and time for the lessons were set in co-operation with the class teacher in each case. This was not a very flexible issue because the class timetable had already been set and any changes would affect other classes and/or teachers. Each class was taught on a different day during the 5th and 6th teaching period. Unfortunately it was not possible to have the lessons during the first periods of the day. No lessons were held on Fridays. Teaching commenced on the 21st of September 1998 and was completed four weeks later on the 15th of October 1998 (Figure 5.10)

![Figure 5.10 Time scale of the research](image)

Choosing to teach only one subject-unit in the course of the research, rather than a series of units that would allow this researcher to employ his experimental approach for a longer period of time, and consequently enable more trusted conclusions to be drawn, was another choice imposed purely by practical reasons. The research design entailed eight visits to each one of the four classes (including follow-up interviewing and testing) during which rather than been taught by their normal teacher the classes were taught by this researcher for reasons that are explained in the following section. It was therefore feared that if permission was sought by the Ministry of Education of Cyprus to conduct research that would extend over a longer period of
time than the one proposed, this would possibly be declined and, even if it was not, it would have raised particular concerns among headteachers as to the danger of causing considerable disturbance to the operation of their schools. At the same time the researcher was required to be in full-time attendance at his university in London, while being on leave of absence from his teaching duties in Cyprus. The two-month-period required for the first phase of the research was therefore considered to be a reasonable compromise.

The teaching procedure which was followed and the activities used were the same for all four classes based on the guidelines set by the Ministry of Education and Culture of Cyprus. The main adjustment made to the activities suggested in the 'teacher's book' was to incorporate a CCL approach, since this had not been the underpinning philosophy for these guidelines. The approach followed by this researcher resembled the one developed by the SPACE project in the UK, according to which the teacher makes explicit children's ideas and then tries to develop or revise these ideas (Nuffield Primary Science, 1995). The only difference in treatment for the experimental group was the metacognitive instruction that was implanted at selected points of the teaching sequence. The aims for each of the four lessons, as specified by the textbook used, can be found in Appendix I (this writer’s translation).

The teacher - Why follow the 'researcher as teacher' approach?

The decision to have this researcher (who is himself a teacher and has prior teaching experience in primary schools in Cyprus) doing the teaching, rather than the usual class teacher is an important decision that needs to be discussed and justified. According to Fraenkel and Wallen (1993)

"...an essential requirement of a well-conducted experiment is that researchers have control over the treatment - that is, they control the what, who, when, and how of it (p.266).

The first argument, therefore, in favour of this choice is the fact that the 'researcher-as-teacher' arrangement enabled greater control of what was happening during the research. Training the class teachers would have been an alternative, yet would also have introduced a number of problems, the most important being the teachers' different perceptions of how and to what extent to 'control the what, who, when and how of it'. Related to this problem is the warning given by Kirby and McKenna (1989)

'Remember that who you are has a central place in the research process because you bring your own thoughts, aspirations and feelings, and your own ethnicity, race, class, gender, sexual orientation, occupation, family background, schooling, etc. to your research (p.46).

Involving four teachers in the research would practically mean quadrupling these factors, therefore introducing serious doubts regarding equal treatment of different groups by different
teachers. The decision, therefore, in favour of the 'researcher-as-teacher' approach is thought by this researcher to be the best way of treating such methodological problems.

5.4. Metacognition in practice: The *metacognitive instances* approach

5.4.1. *Description of the approach*

In order to describe the *metacognitive instances* approach a point that was repeatedly made in previous chapters needs to be brought to mind again. Contrary to work previously conducted in the field, the study presented by this thesis does not attempt to 'generally promote metacognition' (Baird and Mitchell, 1986) nor does it advocate the teaching of metacognition for the improvement of general thinking skills (Adey, Shayer and Yates, 1991). The scope is that of investigating the feasibility of *situated metacognition* with primary school children and examining any positive impact of such activity on the durability of learners' conceptions of science and their ability to utilise these in different contexts.

This basic difference in scope is the determining factor for not following the approach of other researchers in the field who have incorporated metacognition in their studies. Adey, Shayer and Yates (1991), for example, who worked with secondary school children, followed an approach which involved substituting 'normal' science lessons with 'thinking science' lessons once every two weeks. These lessons were spread over a two-year period and were based on specially designed material with activities that were targeted towards encouraging students 'thinking about their own thinking'. The material used was clearly process-oriented and there was absolutely no effort to accommodate metacognitive (or other) activities within the science content taught during 'normal' science lessons.

The rationale behind the *metacognitive instances* approach is that, if it is to be realistically applicable in practice, metacognition should not be promoted at the expense of content but the two should be intertwined. By incorporating metacognition alongside normal teaching activities this thesis advocates a place for metacognition in everyday teaching and questions approaches treating it as something special, only to be taking place during specially allocated time. Notably, allocating extra time for 'thinking lessons' is an option not favoured by most educational systems, therefore making the proposal put forward by this thesis more attractive.

The approach followed in the present study attempts to incorporate metacognitive instruction within existing teaching structures, following an existing science curriculum and without the
allocation of any extra time or the substitution of normal science lessons with ‘special’ lessons. The teaching sequence followed was identical for both comparative and experimental group, the only difference being the implanting of metacognitive instruction at selected points of the teaching procedure. On average 5-6 metacognitive activities were employed during each 80-minute lesson, the duration of which varied up to a maximum of 6-7 minutes. Further discussion of the ‘how’ of the metacognitive instances approach follows the presentation of the metacognitive activities used by this researcher.

5.4.2. Metacognitive activities

There is currently growing literature on theoretical as well as practical aspects of metacognition in relation to the field of education (Hacker, Dunlosky and Graesser, 1998), a result of which has been the appearance of lists of metacognitive activities for teaching purposes (e.g. Novak, 1985; Baird and Mitchell, 1986). This researcher has made use of four different metacognitive activities, namely a) classroom discussions, b) keeping a diary, c) annotated drawing and d) concept mapping. The selection of more than one activity was based on the belief that

... there can be no single general strategy for teaching metacognition - the particular content and context will significantly constrain possible activities (Mitchell, 1986b, p.64).

This is a methodological choice that needs to be justified and contrasted to the options of choosing a single activity or a different set of activities.

A primary characteristic of the research presented by this thesis is its experimental orientation. The scope was to investigate whether the practice of metacognition can have any positive impact at all. As discussed earlier, the question was initiated by the debate in the literature as to whether metacognition as a higher-order thinking skill is or is not available to primary school children, and by research that showed that children of eleven years of age, or less, did not benefit from intervention programmes that made use of metacognitive activities. (Adey, Shayer and Yates, 1991). Choosing and incorporating a set of activities advocated as being the ‘best’ or ‘most appropriate’ ones, would be taking for granted that metacognitive instruction does have a positive impact with young children and that the scope is to enhance that impact. The fact that this would be overlooking one of the major questions of this research has led to employing a variety of activities without any a priori claims regarding their success. A completely different set of activities might as well have been used without that affecting the whole approach.
This research did not employ only one metacognitive activity because of this researcher's intention to have a variety of activities, so that the children maintained high interest in the process, and were exposed to different stimuli. Prior research (Baird and Mitchell, 1986) has shown that when just one metacognitive activity is systematically being used, not only does it become unpopular with the students, but it is also treated in a mechanistic way without really causing any reflection. Quite the opposite, it has been demonstrated that when teaching practices alter frequently, automatic behaviour is not given enough time to develop, therefore reflection is sustained (White and Gunstone, 1989). This researcher has also taken into consideration that one kind of activity can be more successful with some children but not with others, hence the need for incorporating a variety. Figure 5.11 presents examples of metacognitive activities employed by this researcher. The comments that follow offer further justification for selecting the four metacognitive activities, in particular.

**QUESTIONS/DISCUSSION:**
e.g. Before having this lesson, what was your belief regarding (X...)? Have you changed your views? If so, why?
- What was wrong with your initial reply?
- Explain to your friend the way you solved that problem (e.g. How did you decide which of the materials are insulators and which are conductors?)
- Can you explain the use of plug fuse?
- What was the information/knowledge you had that helped you reach a decision (regarding X)?
- Have you learned something from this activity?
- What is the purpose of this activity? What are you asked to do?
- Can you name two reasons why we are learning these things? How can they be useful in everyday life?
- Is there something you had not noticed before... (e.g. that there is a thin wire in the lamp)
- Name an analogy that describes the use of a switch in a circuit. Explain.
- Tell your partner where does the word 'short-circuit'/ 'switch' come from.
- Tell your partner something that you or your family usually do, which is related to electricity, and which you may have now realized that it's wrong.
- What was the purpose of this activity?
- How does this activity relate to what we learned about...X?

**KEEPING A DIARY:**
e.g. 'Write down three things you learned during today's lesson and any points which might not be very clear...'. (This can also be done in the form of a 'Question Box' where students put their anonymous questions without the risk of being ridiculed by their classmates)

**ANNOTATED DRAWING:**
e.g. 'Draw any tool you want that can safely be used by an electrician, indicating the material(s) from which it is made of'.
'Draw little arrows to show the flow of electrons in order to check whether your response was correct'.
CONCEPT MAPPING:
Concept mapping can be used first as whole-class activity, and gradually become group, or individual activity. (It has proved to be particularly useful in making pupils aware of the material learned, and in tracing relationships).

Figure 5.11 Examples of metacognitive activities

Classroom discussion
This writer strongly believes that classroom discussion is among the most appropriate ways of offering metacognitive stimuli to the pupils in a way that can be fully incorporated in the flow of the rest of the lesson. Children can be given opportunities to express thoughts and ideas, question findings and reflect upon procedures followed, by means of group or whole-class discussion that can be implanted in the teaching sequence. The sharing of metacognitive ideas with the rest of the class can be a stimulating experience, for it can help pupils become more conscious of what and how they learn, and help them concentrate on aspects of their learning that they had not thought of before. However, as Mitchell (1986b) points out ‘... a student could be quite metacognitive without ever saying a word in class’ (p.59). What this suggests is that albeit being a powerful means of practising metacognition, sole use of classroom discussion might not be enough for the needs of this study, hence other – in some cases non-verbal - means of experiencing metacognition had to be offered.

Diaries
Diaries are good for shy and introverted children who do not wish to share their thoughts or queries with their classmates. It is an activity that allows one’s thoughts to be expressed privately and at one’s own time without the threatening feeling of having these ideas judged in public. The fact that this is a task done privately also allows the generation of more original ideas from individuals, without the influence of the majority’s views or line of thought.

Concept Mapping
Concept mapping (Novak, 1998) is a flexible activity that can be used as whole class, group, or individual activity, its main virtue being the identification of relationships between learned concepts. This is thought to be an important element of exhibiting metacognition, since scientific concepts such as the ones related to electricity cannot exist in isolation, but have to be intertwined in a meaningful manner if the learner is to maintain an understanding of the area under study. Concept mapping offers the opportunity for highlighting such relationships, making connections between what might look as two unrelated phenomena, and summarising with very few words the concepts and phenomena taught within the subject-unit.
Annotated drawing

Having included activities that might inevitably be hard for some pupils to deal with or to commit to (e.g. concept mapping / diaries), the need for a more ‘light’, children-friendly activity was evident. Such an activity had to offer pupils the opportunity to reflect on their learning within a task that would be relatively easy, welcome and enjoyable. Drawing is one such activity, which, in addition, can generate material containing a wealth of information for researchers as de Bono’s (1970; 1993) work has shown. Annotating the drawings is a way of making children’s thoughts more explicit and of showing those children who might feel that they are not very good at drawing, that they should not worry too much about the artistic quality of their drawings, since they can explain in words anything they feel that is not clear. Conversely annotating a drawing is a good way of engaging children with poor linguistic ability in expressing themselves either orally or in writing.

In general, the idea behind the selection of these activities was to have simple, easy to carry out activities that could blend with the rest of the teaching activities without taking considerable time for training children in carrying them out. By trying to blend metacognition with the rest of the teaching activities and by not presenting these as ‘new’ activities, the scope was also to avoid appearance of the well known ‘Hawthorne effect’, that is, the condition whereby any improvement in performance can be attributed to the novelty of new treatment or conditions, irrespective of their nature. The researcher presented the activities in exactly the same way as the ones included in the textbook, thus treating them as an undistinguishable part of the lesson, and avoided making comments as to the novelty or difference of these tasks. The fact that most of the (‘normal’) activities included in the science books used in public primary schools in Cyprus, and consequently the teaching approach followed by the teachers, are clearly child-centred (this being the result of the highly centralised guidelines and materials provided by the Ministry of Education of Cyprus), is thought to have contributed in making metacognitive activities even less ‘noticeable’ by the children of the experimental group, something that would have obviously been the case had their normal learning style been highly didactic. The only such ‘side-effect’ of the research can be attributed to the fact that teaching was undertaken by a (new) ‘guest-teacher’, rather than the pupils’ usual teacher, and this could act as a factor affecting their interest, attention and performance in class. However, the fact that only one person was involved in teaching all classes is taken to eliminate the importance of such an effect, since this is reasonably expected to be of similar extent in all cases.

The decision not to inform children of the experimental approach followed was also based on experience reported by other researchers in the past, where informing children of the novelty...
of the learning activities resulted in considerable pressure and disappointment for the class, once time was spent on the new approach but no immediate positive results were observed by the students (Baird and Mitchell, 1986).

Having presented the four metacognitive activities used and the rationale behind their selection, discussion can now concentrate on the ‘how’ of implementing the metacognitive instances approach. The timing of introducing metacognitive activities at each point of the teaching procedure was largely pre-specified in planning each lesson of the subject unit, although on occasions this took place in a more spontaneous way. The use of metacognitive instances by this researcher did not follow a strictly predetermined course or sequence, rather it was adjusted to the specific circumstances of each lesson. Although all four activities were used in all lessons, this was not done in a ‘routine-like’ way. However, some features of the approach were inevitably repeated in subsequent lessons. It was more likely, for instance, to use classroom discussion early in a lesson and reserve the use of concept mapping for the last minutes of the lesson. The only pre-specified task was the writing of diary-like notes that was assigned as homework, or as a last activity for those pupils who finished their work early. At the beginning of the next lesson children were encouraged to share what they had written with their classmates.

The fact that the research design entailed use of experimental activities for one group alongside, rather than in substitution of, normal activities, raises the justified question as to what was happening in the comparative group during the time spent on metacognitive activities in the experimental group. As is further discussed later, the teaching mode for the experimental group was intensive in contrast to a more relaxed approach followed with the comparative group that allowed greater time for conducting normal activities. In practice this meant that whenever this was possible, the time for each of the normal activities in the experimental group was reduced by 1-2 minutes so that time accumulated in this way would then be used for metacognitive activities. The experimental group’s engagement in metacognition was further facilitated by the fact that pupils who finished their normal work were immediately assigned metacognitive activities, while some of their classmates were still dealing with normal activities. The apparent implication from this arrangement was that some children inevitably had more opportunities to engage in metacognitive activities than others. This, however, is not regarded to be a negative feature of the research design since no comparisons were attempted among children of the experimental group with regard to the extent of their engagement in metacognition.

The last point to make with regard to practical dimensions of the experimental approach is
that the inclusion of classroom discussion as one of the metacognitive activities employed by this researcher, does not suggest that no discussion took place in the comparative classes for this would have severely disabled the conduct of the lessons. On the contrary, discussion was a prevailing feature of teaching in the comparative group in setting problems, describing experimental investigations and announcing outcomes of individual or group work. The difference between the discussions in the two groups was that, on top of the discussions made in the comparative group, children of the experimental group had the opportunity to engage in further discussion that entailed metacognitive reflection, addressing in greater depth questions of ‘why?’ and ‘how?’ in relation to the processes and the content of their learning.

A sample lesson outline is given in Appendix II showing how metacognitive activities were implanted in the teaching sequence followed by this researcher. This lesson plan refers to the third lesson dealing with short-circuits and switches. The worksheets used by the pupils in this lesson can also be found in Appendix II.

5.4.3. Recording metacognition

In order to close this section on the metacognitive instances approach, a last point to make is concerned with the recording of metacognition. Without underestimating the importance of being able to substantiate the claim that metacognitive activity was indeed taking place, the methods used in this research did not attempt to demonstrate this by means of ‘measurements’. The reason for this lies in the fact that recording and measuring metacognitive activity was clearly not the objective of this research, not least because it is highly questionable whether mental activities such as metacognition can easily be quantified and measured. The fact that the debate regarding what is metacognitive and what is not, is still in development within the literature, has contributed to this choice. The approach followed resembles, to use an analogy, the administration of medicine to a patient, in which case the importance is not in recording the medicine’s action or in ‘measuring’ its effectiveness, rather in (observing) the results of its action. The outcomes, therefore, of observation during teaching of the subject unit are not seen as ‘concrete evidence’ provided by numbers, tally sheets or checklists; instead they report overall impressions about the classroom as a whole and this researcher’s views on whether metacognitive techniques ‘worked’, or not. Similarly, in examining material produced by the children during metacognitive activity, what is being reported is this researcher’s subjective judgement on whether signs of metacognitive activity are apparent, or not. The following figures present examples of children’s reactions to metacognitive stimuli during the implementation of the metacognitive instances approach.
- 'I used to think that a burnt-out lamp could glow a little, but not as much as a 'good' lamp.'
- 'Now I see what's the use of that thin wire (filament) inside the lamp.'
- 'Before this lesson I didn't know how to connect the wires and make the lamp glow.'
- 'I used to hear about the risk of short circuit but I didn't know how it could happen.'
- 'I will never forget that pencil tip (graphite) lets electricity pass through it. It was so strange!'

Figure 5.12 Examples of children's responses to metacognitive instruction during classroom discussions

Figure 5.13 gives an example of annotated drawing produced by a child in the experimental group, while Figure 5.14 presents an extract from a pupil's diary.

(a) It is made of iron so that it's solid

(b) It is made of plastic because it is an insulator and doesn't let current pass (it doesn't have electrons). It is so for the electrician's safety

Figure 5.13 Example of annotated drawing
I knew that plastic and wood don’t let current pass and that they are safe but I didn’t know why. Now we learned that insulators don’t have electrons inside them.

Figure 5.14 Extract from a pupil’s diary

Concept mapping was the fourth type of metacognitive activity used, an example of which appears in Figure 5.15.

Figure 5.15 Example of concept mapping
The examples presented obviously demonstrate varied levels of reflection on the learners' behalf. No discussion of this aspect of the research is attempted at this point, for these examples are intended to give the reader a first taste of the nature of the activities used. More samples of material produced by the children during application of the *metacognitive instances* approach are presented and analysed in Chapter 6 during the discussion of the outcomes of this research and in Appendix IV.

The following section, which concludes this chapter, outlines those measures taken by this researcher in order to confront methodological threats and avoid pitfalls that would undermine the value of this research and its outcomes. Considering these measures should be particularly important in shaping the reader’s verdict on the quality of this study.

### 5.5. Methodological checks and other practical concerns

#### 5.5.1. Choosing a ‘camp’

*Research has no status unless the methods and findings are open to public scrutiny and debate* (Powney and Watts, 1987, p.2).

In order to facilitate public scrutiny of research Halpern (1983) proposed that when conducting an enquiry the researcher should make sure that an ‘audit trail’ is left behind (comprising raw data, field notes, analysis products, observation formats etc.), such that a person appointed as ‘auditor’ will be able to replicate, judge and confirm the trustworthiness of the study. Presenting a list of methodological checks that were carried out during the course of this research and providing justification for decisions that have specified practical aspects of this study, are thought by this researcher to be serving towards both establishing such status for this thesis, and providing the reader with as detailed an ‘audit trail’ as possible.

Traditionally researchers were particularly concerned in demonstrating the quality, professional standard, and the ‘worth-being-taken-seriously’ of their work by use of methodological checks such as *validity* and *reliability*. Validity generally referred to whether a specific research tool or approach measured what it was designed to measure. Reliability, on the other hand, was a measure of the extent to which the study would give similar results if replicated under similar circumstances. Kirk and Miller’s (1986) example of using a thermometer helps distinguish between the two.

*A thermometer that shows the same reading of 82 degrees each time it is plunged into boiling water gives a reliable measurement. A second thermometer might give readings over a series of measurements that vary from around 100 degrees.* The
second thermometer would be unreliable but relatively valid, whereas the first would be invalid but perfectly reliable (p. 19).

Although analysis of the two terms lies beyond the scopes of this study, a comment regarding the analogy by Kirk and Miller (1986) is necessary. Successful as their analogy might be, the problem with phenomena studied by the social sciences is that although unreliable measures can easily be identified and rejected, the same does not apply for cases that exhibit lack of validity. This is so, because social phenomena are not as clear-cut as is, for instance, the knowledge that water boils at 100 degrees Celsius, hence there is no commonly accepted reference point to which comparisons can directly be made to base one’s verdict on validity.

In spite of extensive use of this twofold approach by the huge majority of the research community, a number of scholars diverged from this practice over the years, basing their decision on primarily philosophical grounds. Watts (1983), for instance, made use of an approach he called ‘communicative authentication’ offering detailed justification for his choice. The main argument behind Watts’s ‘communicative authentication’ is the constructive alternativist theoretical basis of his work that regards all data as being open to a wide variety of interpretations, each of which can be as ‘valid’ as the other depending upon the view of the interpreter. By suggesting that there are no absolute ‘right’ or ‘wrong’ interpretations, the suitability of notions such as a single validity or reliability is overtly been questioned, as was previously the case with other researchers (e.g. Reason and Rowan, 1981).

Having identified the two ‘camps’ available to this researcher, the question seeking an answer is whether the use of traditional methodological checks is appropriate for the present study, or whether it should pursue its own course of authentication. Checks such as the ones of validity and reliability are thought to be compatible with studies with a positivistic orientation. Although the present study poses a quasi-experimental orientation this is not done in the traditional positivistic sense. Quite the contrary, numerous elements of a subjective approach are being incorporated (e.g. participant observation, interviews, interpretation and judgements on students’ responses etc.) that were described in earlier sections. The fact, therefore, that this discussion is held against a similar philosophical framework to the one advocated by Watts (1983) makes his remark all too relevant

...to be compatible with a study that hopes to gain insights into the ‘constructed worlds’ of the participants and the researcher, the ‘validity’ of such construction is not at issue (p.7.3).

A further point that should not be overlooked is the fact that the recipe-like following of traditional checks is not always possible, but it is highly dependent upon the characteristics
and circumstances of the specific research. In the case of the present study, for example, establishing validity of the tests that investigated pupils’ ability to make use of their knowledge across contexts was a highly problematic task, mainly because the literature has not reached a consensus on the meaning of ‘context’. As a result, judging whether these tests really test the effect of different contexts becomes highly subjective and should be judged within the framework set by this study.

After considering a number of philosophical and pragmatic dimensions of both camps, the stand taken by this thesis is one of incorporating both traditional and other means of authenticating the research in a complementary mode. This is not to be seen as an easy ‘middle’ choice, rather it should be viewed as an attempt to map more fully the methodological considerations of this research by making use of diverse in principle approaches.

5.5.2. Traditional measures of authenticating research

By ascribing to traditional methodological checks such as validity and reliability, this thesis does not consider these to be a predetermined checklist compliance to which should guarantee the trustfulness or the authority of the results. However, it does acknowledge that if a number of points on such a checklist are not met then the chances of obtaining outcomes of limited trustworthiness are considerably increased. It is under this light that the following discussion should be viewed. In addition, the analytic approach employed should be seen in relation to the study’s effort for establishing and further enhancing second order research awareness on pragmatic aspects of this research.

Looking first at issues of reliability, subject error and subject bias are two common causes of unreliability. Subject error refers to the situation where the participants’ performance might fluctuate considerably from occasion to occasion, depending on a number of extraneous variables. Subject bias, on the other hand, refers to the case of participants making extra effort to score highly in a test, hence artificially boosting the results. These problems were dealt within this research by trying to keep extraneous factors to a minimum and by maintaining similar conditions for both experimental and comparative groups (e.g. teaching all classes during the same periods of the day, and holding no lessons on Fridays). The pupils were not aware of the treatment they were receiving hence they did not feel that they ‘had’ to score particularly well, nor were they informed of the (repeated) tests in advance in order not to prepare for them. The assessment tests used by this researcher were piloted with three other Year-5 groups, who were taught electricity the year prior to the research. The results of the
pilot study proved to be particularly important since they indicated problems with the wording or the layout of a small number of exercises, which were reconsidered in the final version of the test. The three pilot groups obtained convergent results indicating that a claim of reliability for the tests could be made. The same approach was followed for the questions included in the interviews, although this was a check that was restricted by the extent to which the teachers of the pilot groups had emphasised the specific concepts on which the interviews focused. Other methodological problems, such as the risk of exhibiting observer error or bias during the marking of tests, or the analysis of pupils' responses to interviews, were confronted by means of a list of predetermined criteria, which were consistently used and revisited in the follow-up administrations of the tests and interviews.

Robson (1993) lists a number of threats to internal validity of an inquiry suggesting that the quasi-experiment is more vulnerable to this kind of threats. He further points out that only by ruling out these threats will the researcher be able to show that the experimental treatment has indeed caused the recorded outcomes. Because of the importance attributed to these threats and the overall intention to provide as detailed as possible a description of practical aspects of this research, a list of threats to internal validity is given in Figure 5.16. In each case Robson's (1993) description of the threat is quoted (in italics) and the corresponding treatment applied by this researcher is briefly presented.

1. **History** - 'Things that have changed in the participants' environments other than those forming a direct part of the enquiry'

   All groups were involved in the research over the same period of time during which no uncontrolled changes that could considerably affect their science learning took place.

2. **Testing** - 'Changes occurring as a result of practice and experience gained by participants on any pre-tests'

   No pre-tests were used. The repeat of the same tests two months and eight months later are not thought by this researcher to have affected the pupils' performance because of the long intervals between the tests. Had their performance been affected, any such effect should reasonably be of common extent to all participants, hence not distorting comparison between experimental and comparative groups. The same applied to interviews.

3. **Instrumentation** - 'Some aspect(s) of the way participants were measured changed between pre-test and post-test'

   All groups were tested using the same test at all points and interviewed using the same interview schedules. No changes were made to either tests or interviews during testing intervals.
4. Regression - *If participants are chosen because they are unusual or atypical (e.g. high scorers), later testing will tend to give less unusual scores ('regression to the mean').*

This threat is not applicable to this research. Participants were neither unusual nor atypical.

5. Mortality - *Participants dropping out of the study.*

There was no real risk of pupils dropping out of the study because of incorporating the research within their school science. Cases of pupils being absent during testing were excluded from the analysis of data.

6. Maturation - *Growth, change or development in participants unrelated to the treatment in the enquiry.*

In spite of some cognitive maturation reasonably occurring among pupils over the ten-month period of the research, this did not cause any problems because: a) the case was not one of comparison between performance at a pre-test and a post-test (or interview) and b) any overall change that could be attributed to maturation, should, on average, be the same for all groups since the groups were tested at the same time.

7. Selection - *Initial differences between groups prior to involvement in the enquiry.*

Initial differences were minimised by ‘matching’ the groups as described elsewhere.

8. Selection by maturation interaction - *Predisposition of groups to grow apart (or together if initially different).*

There was no interaction between the groups and consequently no predisposition to grow apart.

9. Ambiguity about causal direction - *Does A cause B, or B cause A?*

The research design ruled out the event of such ambiguity occurring. For example, if A is metacognitive instruction and B is longer durability of conceptions, then the claim that B caused A would not make any sense.

10. Diffusion of treatments - *When one group learns information or otherwise inadvertently receives aspects of a treatment intended only for a second group.*

The children were not in a position to identify the difference in treatment between the two groups, even if they did exchange information about the lessons. This is mainly because metacognitive activities for the experimental group were brought in as ‘normal’ activities while keeping the content taught to the two groups identical. Moreover, their teachers were not aware of the exact nature of the treatment given, nor were they informed whether their class had been appointed as ‘comparative’ or ‘experimental’.

11. Compensatory equalisation of treatments - *If one group receives ‘special’ treatment there will be organisational and other pressures for a control group to receive it.*

No such pressures were put on the researcher mainly because of not informing the teachers which class was assigned ‘comparative’ and which ‘experimental’. The fact that both groups were following the same curriculum did not allow any ‘special treatment’ to be evident.
12. Compensatory rivalry - 'As above but an effect on the participants themselves (referred to as the 'John Henry' effect after the steel worker who killed himself through over-exertion to prove his superiority to the new steam drill)...'

The groups had no reason to see themselves under threat since, as far as the pupils knew, both groups were taught the same subject-unit by the same teacher.


**Figure 5.16 Threats to internal validity**

**Generalisability**, or **external validity**, to use the alternative term by Campbell and Stanley (1963), is another important methodological check concerned with the issue of generalising the results of the study to other settings or populations. A list of threats to external validity, similar to the one given for interval validity, is shown in Figure 5.17.

1. **Selection** - Findings being specific to the group studied.
2. **Setting** - Findings being specific to, or dependent on, the particular context in which the study took place.
3. **History** - Specific and unique historical experiences may determine or affect the findings.
4. **Construct effects** - The particular constructs studied may be specific to the group studied.

(After LeCompte and Goetz (1982); cited in Robson (1993) p.73)

**Figure 5.17 Threats to external validity**

Threats to external validity are treated in a more holistic way than the 'checklist approach' followed for threats to internal validity because they are thought by this researcher to be of a more convergent nature. As described in previous sections, a primary concern of the design of this research, particularly the sampling process, was to conduct research in an 'average' setting involving participants without any prominent characteristics when compared to the broader school population. The setting of the research maintained a lack of artificiality since it was placed within everyday conditions with real problems and real constraints, hence not differing from everyday practice in any way. Any 'historical differences' that could be of significance to the study would have reasonably appeared during the pre-research testing employed for matching the classes to participate in the research, therefore, no such
differences are thought to be affecting the research outcomes. The claim of generalisability of the study is therefore regarded as justified and substantiated provided that any such claim is restricted to similar conditions and populations.

Another widely regarded virtue of well-conducted research is objectivity. Reporting a study that is dependent upon the researcher's subjective interpretation on a number of occasions makes objectivity of this thesis hard to demonstrate. The recruitment of teachers and fellow researchers for expressing views or making comments on the material and the approaches used, or the analysis of the outcomes, was one way of adding to the positive features of this research. Most importantly, though, it was a means of demonstrating that this researcher was consciously aware of the problem.

At points attempts to reduce the subjective nature of the investigation were hindered by practical problems. For example, in considering ways for collecting observation data that could enhance to some extent the objectivity of the study, an obvious choice would be to ask the teachers of the two big classes who were relieved from their teaching duties, to observe the lessons as independent parties. However, their presence at the back of the room would have created a feeling of artificiality in the class suggesting that what was taking place was not 'normal', and possibly affect pupils' behaviour, something that was considered by this researcher to be a serious drawback. Also the fact that, following classroom observation, the teacher from the experimental class would familiarise himself with the metacognitive instances approach gave rise to the concern that he would either consciously or subconsciously adopt similar methods in his teaching, something that could potentially distort the outcomes of this research. The decision was therefore not to involve the teachers as independent observers.

This researcher will refrain from attempting to make a case about objectivity, not least because such a claim will inevitably be (once again) highly subjective and up to the (subjective) persuasion, or not, of the reader. To what extent objectivity can be maintained, or to what extent the term itself is valid, are philosophical issues that lie beyond the scopes of this discussion.

Having said so, the last word of this section goes to the notion of credibility. According to Shipman (1988) every piece of research should provide sufficient detail concerning the way the 'evidence' is produced, if the credibility of the research is to be assessed. This thesis has, to this point, presented a detailed account of the course of the inquiry, provided justification of a number of methodological choices made and thoroughly discussed the philosophical
background of the methodology by extensive reference to the notion of research awareness. The final judgement on whether this thesis manages to be credible, or not, is left with the reader.

5.5.3. Other means of authenticating research

Following the discussion in the preceding section regarding ‘traditional’ measures taken by this researcher for authenticating the processes and the outcomes of this research, attention now shifts to alternative, less conventional directions. In doing so, this researcher considers Watts’s (1983) view that the question ‘for whom is the research valid’ needs to be addressed. Following Elliott’s (1980) argument that research can only be validated by the participants involved in the study, Watts (1983) identifies three different audiences to be directly related with the research, in terms of authenticating research:

a) the researched (students involved)

b) the possible users of the outcomes (science teachers), and

c) interested members of the research community.

This list determines the three directions of authentication followed by this thesis.

a) Authenticating with pupils:

During interviews this researcher spent some time obtaining feedback from the children in order to verify or clarify their answers, and make sure that the meaning perceived by the researcher was the one intended by the pupils. For example, this researcher made frequent use of questions such as: ‘So, do you mean that...?’ or ‘Are you saying that...?’ following a response given by a pupil, in order to offer a chance for confirming what was being said. In some cases, wrong assertions were made by the researcher in a na\000ve way such that would test whether pupils were truly conscious of the difference between their understanding and the researcher’s wrong ‘view’. In using this method there is always the risk of pupils agreeing with the interviewer, either because they cannot really identify the discrepancies between their version and the one presented by the interviewer (possibly due to limited understanding), or because they tend to trust the older, more knowledgeable interviewer. This researcher made use of multiple questions that were phrased in different ways, in order to assure that the meaning and purpose of the questions were perceived correctly by the pupils.

The inclusion of the question ‘Which of the exercises in this test did you think that was the most difficult one? Why?’ in the test administered in Phase 1 of the research, is thought by this researcher as an additional measure of authentication, for it offered a means of recording
pupils' views, rather than their understanding, and consequently enabled comparisons between the two.

b) Authenticating with teachers:
A point that was discussed in a preceding section was that it was a conscious choice of this researcher not to inform the teachers of the details of the research carried out in their classes, in order to prevent any interference of theirs in any way. In the course of the study, however, brief meetings were arranged with the teachers to discuss the purposes of the research, and their views on the areas covered by this study were asked. Feedback obtained from teachers can be summarised in the following four points:

1. All teachers agreed with the significance of both problems of pupils' inability to use knowledge in different contexts and short durability of newly constructed conceptions. Typical of their views is the fact that when this researcher expressed the wish to hold follow-up tests at the end of the school year, the teachers said with a sense of humour: 'You don't have to come back at the end of the year. They definitely won't remember anything!'; something that is clearly indicative of their experience as to how durable pupils' learning usually is. They all indicated strong interest in being informed of the outcomes of the research and, more specifically, of the experimental approach proposed for confronting these problems.

2. They all demonstrated a positive attitude towards the idea of incorporating metacognition in their teaching, basing their views on experiential rather than theory-laden arguments.

3. All four teachers said that they do 'kind of' use metacognitive activities in their teaching but the case was again one of not having a real theoretical background to support their choice. As the conversations were kept short and informal, this researcher has no means of specifying with certainty whether the teachers were actually referring to metacognition or to more simple forms of repetition in their teaching.

4. They questioned the applicability of the metacognitive instances approach due to lack of time and the overloaded curriculum they have to deal with. Nevertheless, they expressed the belief that if less subject content is to be taught, then such instances can have a chance of proving successful.

c) Authenticating with other researchers.
Interviews were validated by asking colleagues and fellow researchers to make judgements on the analysis conducted by this researcher, or to attempt their own analysis, that were then compared to the approach followed by this researcher. Colleagues were also asked to give their views on the tests used for assessing the subject-unit taught and comment on the three
types of exercises used. In both cases feedback obtained was valuable in highlighting different perspectives for dealing with the material and in avoiding potential pitfalls.

Before concluding this chapter that attends to the ‘how’ of this research, it is important to refer back to the research awareness established in earlier sections, that served as the guiding framework for the design and implementation of this research. The point to make at this stage is that, in the eyes of this researcher, the measures taken for authenticating this research have not caused diversion from the framework of second order research awareness (that covers more of the practical dimension of this thesis) in ways that would potentially make this incompatible with first order research awareness (that attends to the philosophy behind this research). The attempt, therefore, to establish the validity of this study remained in a research framework placed in a predominantly educational context, portraying a subjective outlook of knowledge, and attending to its research questions in a systematic, empirical and critical way.

5.6. Summary

Looking at methodological issues this chapter has described the philosophical framework behind the ‘doing’ of the research and has addressed the notion of research awareness as sine qua non for the study. The research design was outlined and the metacognitive instances approach was described, along with the supporting rationale and a listing of characteristic examples of metacognitive instruction. This was followed by a description of the data-collecting course of action of this study, portraying an integrative multi-method approach that draws from both qualitative and quantitative traditions. The chapter concluded with reference to methodological checks followed by this researcher as a means of authenticating the processes and the outcomes of this study.

The next chapter attends to the description and analysis of data.
Figure 5.18 Graphic summary of Chapter 5
6.1. Introduction to Chapter 6

6.2. Philosophical framework to the analysis
   6.2.1. Qualitative versus quantitative analysis
   6.2.2. Objectives of the analysis
   6.2.3. Status of the analysis and its outcomes

6.3. Practical aspects of the analysis

6.4. Pupils' conceptions of electricity prior to teaching
   6.4.1. Current / Electron flow
   6.4.2. Conductors – Insulators
   6.4.3. Lamps – 'Burnt-out' lamps
   6.4.4. Switch
   6.4.5. Short-circuit

6.5. Material produced by the children
   6.5.1. Questions / Classroom discussion
   6.5.2. Diaries
   6.5.3. Annotated drawing
   6.5.4. Concept mapping

6.A. Quantitative analysis of tests
   6.A.1. Introduction to quantitative analysis
   6.A.2. Big classes
      A.2.1. Durability of pupils' conceptions
      A.2.2. Pupils' performance by type of exercise
   A.2.3. Concept-based analysis
   6.A.3. Small classes

6.B. Qualitative analysis of interviews
   6.B.1. Introduction to qualitative analysis
   6.B.2. First order qualitative analysis - Broad perspective of the data
   6.B.3. Second order qualitative analysis - Case studies

6.6. Post-script to Chapter 6
6.1. Introduction to Chapter 6

_The unexamined life is not worth living_ (Socrates, in Plato: Apology, 38a)

The unexamined knowledge is not worth having

This chapter deals with the description and analysis of data. It starts by considering theoretical and philosophical stances with regard to analysis, followed by the discussion of practical aspects of the endeavour and the presentation of pupils' conceptions of electricity prior to teaching. Following a brief presentation of samples of material produced by the children during the implementation of the metacognitive instances approach, this chapter is divided into two sections: one on the quantitative analysis of tests and the other on the qualitative analysis of interviews. Each of the two parts are further divided into smaller sections looking at specific areas or aspects of pupils' understanding worth of specialised analysis.

6.2. Philosophical framework to the analysis

Analysis of data is an undertaking that undeniably enjoys a _sine qua non_ status in research. It is probably the most crucial stage of a study since this is the point where collected data are utilised in a successful -or less successful- way, trends and relationships are identified and valid -or less valid- conclusions are drawn.

The actual task of analysis of data is largely specified by the definition of the term itself. ‘_Analysis_’ is a Greek word deriving from the prefix ‘_ana_’, which means ‘_above_’, and the root ‘_lysis_’, which means ‘_to break up_’. As Dey (1993) puts it:

_You can’t make an omelette without breaking eggs. And – to extend the aphorism – you can’t make an omelette without beating the eggs together. ‘Analysis’ too involves breaking data down into bits, and then ‘beating’ the bits together_ (p.30).

What Dey’s analogy is suggesting is that for analysis to take place the researcher should attempt to break up available information and then take a ‘top view’ of the result of the breaking process. This ‘top view’ of data should help identify important dimensions, trends, emerging relationships, or striking cases that should all contribute to a fuller and more critical account of the outcomes of the study. It becomes apparent, therefore, that analysis is a procedure that entails considerable ‘doing’ on behalf of the researcher. However, albeit an endeavour with a highly practical dimension, analysis should not be seen as a task that can be undertaken in a philosophical vacuum, for the approaches and methods selected should be
theoretically founded, ideally in agreement with the accompanying claims of the study. As Powney and Watts (1987) put it

...the analysis of data should be consistent or compatible with the general underlying philosophy of the research (p.158).

In order to establish such underlying agreement a number of related issues have to be revisited.

6.2.1. Qualitative versus quantitative analysis

A first question of philosophical essence that needs to be addressed is the one of qualitative versus quantitative analysis. In the methodology chapter it was argued that quantitative and qualitative techniques can and should be considered together if there is 'underlying unity of purpose' (Robson, 1993). It is taken that such unity of purpose was demonstrated earlier in this thesis, therefore, discussion at this point will be restricted to highlighting the prospect of using quantitative measures in the presentation of qualitative analysis, and vice versa.

Being an advocate of the combined use of the two approaches Robson (1993) points out that although

*Counting and statistical analysis are viewed as anathema by many advocates of qualitative research (...) a surprising amount of counting goes on when judgements based on qualitative data are concerned (p.400).*

He regards quantification as

*...a powerful data reduction device, assisting in making sense of large and intractable mounds of data, and because of the necessary explicitness of definition gives greater protection against bias (Robson, 1993, p.401).*

The eventual interplay between quantity and quality is also reflected in the words of Fielding and Fielding (1986) who reverse the argument

*ultimately all methods of data collection are analysed 'qualitatively', in so far as the act of analysis is an interpretation, and therefore of necessity a selective rendering. Whether the data collected are quantifiable or qualitative, the issue of the warrant for their inferences must be confronted (p.12).*

An analogy from the world of medicine will help demonstrate how the co-existence of qualitative and quantitative measures in the analysis of data, is perceived by this writer. If a person is ill with influenza s/he will probably develop the two common symptoms of fever and cough. Fever is usually treated with pills whereas cough with syrup. If one tries to mix the two medicines (i.e. their ingredients) the outcome will most probably be of questionable efficiency, if not harmful. Simultaneously taking the two medicines, on the other hand, is perfectly advisable because they are treating different symptoms of the same illness targeting
it from two different angles. The approach employed in the course of analysis is precisely one of following ‘two different angles’, while acknowledging and respecting the differences in principle between the two methods (i.e. their ‘ingredients’).

To conclude this section is to say that the complementary way in which qualitative and quantitative approaches were advocated in previous chapters is a recurring theme employed in the analysis of data. This thesis fully adopts Robson’s (1993) view that although there is virtue in the generation of both quantitative and qualitative data none of the two types has a secondary or subservient role to play. It is further supported that use of both traditions is, in this writer’s view, not only justified but will gradually become the prevailing trend in social research in the next few years. Eventually this will bring to life what Bruner (1990) calls ‘openmindedness’

... a willingness to construe knowledge and values from multiple perspectives without loss of commitment to one’s own values (p.30).

6.2.2. Objectives of the analysis

Taking the discussion a step forward, a central question at this stage is one referring to the purpose of analysing data. This writer believes that the objective of analysis should be to describe in as much detail as possible the results of the research and then attempt such insights that will highlight relationships, striking events, noticeable and less noticeable trends. In doing so, it is a strong position of this thesis that description should move in two main directions: describing the ‘what’ and describing the ‘how much’. This researcher’s belief that the former is best described by means of qualitative analysis, and the latter by a quantitative approach, has been another reason contributing to the complementary employment of the two approaches.

To make the scope of analysis more explicit one has to refer back to the driving objectives of the research. Placed within the broader constructivist framework, this thesis investigates the durability of pupils’ conceptions and their ability to use these conceptions across different contexts, in relation to offering metacognitive instruction during teaching. As was repeatedly emphasised in previous chapters, this researcher did not attempt to teach children how to be metacognitive, nor how to improve their general thinking skills. If, therefore, analysis of the results is to be in agreement with the research awareness established in Chapter 5, then identifying or measuring children’s metacognitive performance is obviously not the key question. The focus of the analysis is to identify and describe differences in performance on scientific concepts taught during the course of this research in the twofold direction of ‘durability’ and ‘different contexts’, the claim being that such differences -if any- can be
attributed to the difference in treatment of participating groups. Differences in individual pupils' understanding are also of interest to this study yet not as a theme per se. This thesis, therefore, does not look into pupils' understanding in the way other studies in the past attempted detailed insights into their theories or alternative frameworks, rather these are identified and discussed in relation to the treatment offered to the two groups.

6.2.3. Status of the analysis and its outcomes

A third important point that needs to be addressed at this stage is the perceived nature, or status, of both analysis and its outcomes. The literature widely acknowledges that considerably reducing data is an inevitable step of conducting research, for the sheer volume and richness of the data gathered can restrict thorough analysis of it all in a manageable manner (Cohen and Manion, 1992; Bell 1993). This research offers no exception to this convention for a great deal of reduction of data has to be made, especially with regards to its qualitative dimension drawn from interviews.

According to Van Maanen (1988) there are 'first-order' concepts - the so-called facts of a study, which never 'speak for themselves' - and 'second-order' concepts - the 'notions used by the researcher to explain the patterning of the first-order concepts' (p.39-40). The 'facts' that a researcher discovers are already the products of several levels of interpretation (Van Maanen, 1988). It becomes apparent, therefore, that analysis is a highly subjective undertaking and this is something that researchers should explicitly acknowledge in their reports, along with a clear presentation of their views and assumptions underpinning the process. As Huberman and Miles (1994) suggest,

It is healthy medicine for researchers to make their preferences clear. To know how researchers construe the shape of the social world and how they mean to give us a credible account of it is to know just who we have on the other side of the table (p.429).

Having said so, it is this writer's belief that the data collected, the analysis and the outcomes of this endeavour should all be seen as only a snapshot of the complex phenomena under study. The results should be seen as instants that were selected, captured and analysed by this researcher using his own perception and his own set of criteria. It should also be acknowledged that a different researcher might have dealt with this in a different manner, of equal value and interest for, although data provide a basis for the analysis, they do not dictate it (Burgess, 1982). This is a position that is all too compatible with the principles of constructivist philosophy advocated throughout this thesis and, in addition, it is exactly what contributes to the richness and diversity of academia.
6.3. Practical aspects of the analysis

Having looked at the necessity, the importance and the underpinning philosophy to analysing the data of this study, the next step to take is to look at ways of implementing the task. Miles and Huberman (1984) identify three broad components of data analysis, namely 'data reduction', 'data display' and 'conclusion drawing and verification'. This chapter looks at the first two components, conclusion drawing left for discussion in the following chapter. In doing so, description and analysis of data are consciously interwoven in this chapter for this writer shares the view that

*Description lays the basis for analysis, but analysis also lays the basis for further description* (Dey, 1993, p.30).

In order to help the reader follow the two processes from a close distance, these are interchangeably brought together.

A number of scholars (e.g. Sadler, 1981; Robson, 1993) have listed numerous deficiencies of the human as analyst, which, if left uncontrolled, can considerably affect the final outcome of the research. These include limitations on the amount of data that can be dealt with by the analyst; paying less attention to information that is difficult to obtain; ignoring the fact that some sources of data are more reliable than others; showing excessive confidence in one's judgement; and differing repeated evaluations of the same data (Sadler, 1981). This thesis takes these concerns seriously and, as will be shown in the course of the discussion, employs such techniques and precautions as to minimise these kinds of pitfalls. It is precisely for this reason that comments, suggestions and feedback were sought from fellow researchers during the course of the analysis, in order to minimise research bias and to consider different directions for analysing the data.

Data were gathered by means of 48 interviews and 201 tests conducted during the three phases of this research that extended over the time span of one school year. Analysis of quantitative data was conducted using *SPSS (Statistical Package for the Social Sciences) version 9.0* and a graphical depiction of the results was made using *Excel 5.0 for Windows*. The qualitative analysis of interviews was conducted without use of computerised means.

The preceding sections have served in setting the theoretical background to analysis of data. Before looking at the main body of data it is important to look at two further directions that contribute in setting a more pragmatic background to analysis. The first direction is to present a summary of pupils' conceptions of electricity *prior* to teaching (section 6.4). This should
inform the reader of children’s ‘starting points’, help in putting the sections to follow in context, and later enable more informed conclusions to be drawn in relation to the outcomes of this study. The second direction tackled in section 6.5 presents samples of material produced by the children of the experimental group during the practice of situated metacognition, and discusses briefly the extent of pupils' engagement in metacognitive activity. Although admittedly important for appreciating more fully the outcomes of this research, the supportive nature of these two directions largely imposes a summative approach in their presentation, compared to the detailed discussion of the outcomes of this study in subsequent sections of this chapter.

6.4. Pupils’ conceptions of electricity prior to teaching

Among the first teaching aims pursued by this researcher at the beginning of each lesson was to make explicit children’s existing ideas of the scientific concepts under study. This was in line with the CCL tradition portrayed by this research and was attempted by means of both classroom discussions and written material produced by the children. Following is a brief presentation of ideas held by the pupils prior to instruction, regarding the five main concepts covered by the unit, namely a) current/electron flow, b) conductors and insulators, c) lamps and ‘burnt-out’ lamps, d) open and closed circuits / switch, and e) short-circuit. In doing so, this researcher obtained numerical data depicting pupils’ ideas only in the case of current/electron flow, which was central to the subject-unit of electricity. The remaining concepts were treated by means of classroom discussion that attempted to establish children’s degree of familiarity with the concepts and their current views, if any. Obtaining a more detailed insight was not among the priorities of this study, nor was it practically possible to allocate extra time for this purpose. This presentation, therefore, is not meant to be an in-depth analysis of pupils’ prior conceptions, rather it serves as a means of providing a general picture of their ‘starting points’ that should help in assessing the outcomes and the effects of the intervention implemented during the course of this research.

6.4.1. Current / Electron flow

In explaining how a light bulb in a circuit glows the striking majority of the children (Table 6.1) reported the ‘clashing currents’ model while there were also some who adopted the ‘unipolar model’ (Osborne and Freyberg, 1985). Very few pupils reported the correct scientific model, in which cases this researcher cannot be sure if their response was a conscious choice or simply a lucky guess. Broadly speaking these results verify international
literature on children’s prior conceptions on electricity, according to which, children of age 12 tend to hold the ‘current consumed’ model and the ‘clashing currents’ model. The scientific model was reportedly held by less than 10% of 12 year olds (Osborne and Freyberg, 1985; Shipstone, 1985; Driver et al., 1994b), which is exactly the outcome recorded by the present study.

As expected, no reference was made to electrons or charge since the children had not been taught about electricity in previous years, other than some safety measures and everyday uses of electricity. It is further noted that nearly all pupils thought that the role of the battery is to provide energy or ‘force’ to the bulb. As discussed earlier, the battery as a ‘giver’ of something to the light bulb is also an outcome recorded in the past by other researchers (Driver et al., 1994b).

<table>
<thead>
<tr>
<th>Students’ Initial Views</th>
<th>Big</th>
<th>Big</th>
<th>Small</th>
<th>Small</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Comparative</td>
<td>Experimental</td>
<td>Comparative</td>
<td>Experimental</td>
</tr>
<tr>
<td>'Scientific' model</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>'Clashing current' model</td>
<td>19</td>
<td>18</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>'Unipolar current' model</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unspecified / Other</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL (number of pupils)</td>
<td>30</td>
<td>30</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 6.1

6.4.2. Conductors-Insulators

Children reported generally correct ideas about conductors and insulators based mainly on their everyday experience at home. The terms ‘conductor’ and ‘insulator’ were practically alien to their vocabulary and, as a result, early discussion revolved round specific materials or objects. They distinguished the two categories by saying that insulators ‘stop electricity’ or ‘stop current’... ‘so it can’t catch us!’; whereas conductors are the ones that ‘let electricity pass’. The children were not able to give any justification of this difference other than ‘these (conductors) are made of iron’. Nearly all of them tended to either consider all conductors as made of iron, or regard iron as the most representative of conductors. The broader term ‘metals’ was used by very few of the children.
6.4.3. Lamps – ‘Burnt-out’ lamps
During preliminary classroom discussion most of the children said that they had noticed the lamp’s filament before (calling it 'very thin wire') and the majority knew that a ‘burnt-out’ lamp cannot glow. Most of them, however, could not explain what happened to the lamp. It is worth mentioning that among the ideas expressed by pupils was that 'the burnt-out lamp may glow a little' or that 'it can be fixed by the other lamps' when connected in series with other ‘good’ lamps. Following a practical activity on making the lamp glow (using a battery and two wires- no lamp-holder given) most children admitted that at the beginning of the activity they thought that touching the wires at any point on the lamp (even on the glass) could make it glow.

6.4.4. Switch
All children knew the basic function of the switch basing their explanations on examples from everyday life (e.g. 'we use the switch to turn on or off the lights'). Some of the children could even describe roughly the way switches are made, or rather the materials used to make them (e.g. 'there is a piece of iron inside ... but it is plastic on the outside, so that we don't get an electric shock'). However, none of them could explain what really happens inside a switch. A point of particular importance is a problem caused by certain idioms of the Greek language, as used in Cyprus. When a Greek speaking person asks someone to turn on the lights or set an electrical appliance in operation, one of the expressions s/he can use is: 'open the light' or 'open the switch' whereas for the opposite the expression can be 'close the light' or 'close the switch'. This obviously causes a huge problem to the children because the expression 'close the switch' (an expression they have probably been using for a number of years at home) has exactly the opposite effect from what they learn in their science class about a 'closed switch'. Of course the same goes for ‘opening the switch’ at home and ‘opening the switch’ in their science class.

6.4.5. Short-circuit
Most children said that they had heard the term before, usually during discussions at home or on the news on television in cases where a short-circuit had caused fire. However, they could not explain what causes a short-circuit, nor why it may cause fire. For the majority of the pupils the cause for a short-circuit was water. This was not just based on information picked up at home but it was, once again, a result of the use of the Greek language. The term that describes a short-circuit in Greek is 'vrahi-kikloma'. The prefix 'vrahi' comes from ancient Greek meaning ‘short’, and 'kikloma' stands for ‘circuit’. However, in modern Greek the sound of ‘vrahi’ resembles 'something being wet' hence the justified confusion among children.
Another interesting point is that the majority of the pupils tended to regard electric shock in causal relationship to short-circuit (i.e. they took for granted that if a short-circuit happened, someone would receive an electric shock). The case of short-circuit happening when, for example, nobody is at home seemed to be an idea they had not considered before.

This completes the presentation of pupils' ideas prior to teaching, reference to which will be made again at selected points in the course of the analysis. The next section looks at material produced by the pupils of the experimental group during the implementation of the metacognitive instances approach.

6.5. Material produced by the children

A point that was made earlier in the discussion is that the material produced by the children did not relate to the research questions regarding 'durability' and 'context', rather it was a means of practising metacognition by the children of the experimental group, and a guide for this researcher for detecting the extent to which metacognitive activities were successful, or not. Analysis, therefore, of such material should focus on identifying metacognitive elements in children's responses, and should be considered to be indicative rather than exhaustive. The examples presented in this section are intended to give the reader a taste of the extent to which children engaged in metacognitive activities and the kind of responses they gave. More samples of such material can be found in Appendix IV.

6.5.1 Questions/ Classroom discussion

Classroom discussion was the metacognitive means employed most frequently during the course of this research for reasons relating to the ease with which discussion can be triggered, its independence from any materials, and the catholic way in which children can potentially participate.

As expected, some children engaged more fully in the discussions than others who were less willing to reveal their thoughts and ideas, or to attempt any kind of analysis that would potentially add to the complexity of school science. The great number of pupils in the big experimental class made the involvement of all children in the discussions a difficult task to accomplish. On the other hand, the fact that some pupils did not seem to participate was laden with ambiguity as to whether they benefited from these discussions, for, as was discussed
earlier, metacognition is a personal and internal mental activity. Notably discussions held in the small experimental class proved more successful since it was easier for this researcher to engage all four children in a friendly group atmosphere.

I knew that it was dangerous to switch on the lights with my hands wet, but I didn’t know why. I didn’t know that water has got electrons.

I used to think that lamp glows instantly because current is very fast. Now I know that electrons move just like the seats of a ski-lift.

First I said that the good lamps would glow but when I did the experiment I saw that they didn’t. It’s because the burnt-out lamp breaks the circuit.

I no longer think that a burnt-out lamp can glow a little because in the experiment it didn’t glow at all.

I liked the experiment with the wire-wool burning. It helps me remember how a short-circuit can set fire.

**Figure 6.1 Examples of children’s responses to metacognitive stimuli during classroom discussions**

Figure 6.1 presents characteristic quotes from classroom discussions noted by this researcher either during or immediately after the lessons. Pupils were encouraged to compare prior and current beliefs, and to consider different potential explanations to the phenomena observed, something that explains the strong comparative elements in their remarks. They also made value judgements as to the examples or analogies used by the teacher, and the experiments conducted in class, specifying what was in their opinion successful or not. They could also justify their views or choices by referring to recently constructed knowledge. More extensive quotes such as the cases of pupils explaining something to their partners are not available due to the previously discussed practical problems in recording classroom interactions.

In general it is this researcher’s belief that classroom discussions managed to engage the majority of the pupils in metacognitive reflection of varied degrees, which, considering the young age of the children and their unfamiliarity with metacognitive activity, is judged by this researcher to have been successful. Engagement in metacognitive reflection is thought to have acted in a twofold way. It helped pupils who had grasped intended meanings correctly to reflect on their understanding and become more conscious of their learning, and offered those pupils who might hold partial or inaccurate understandings of the phenomena studied, the chance to reconsider their views towards the scientific explanation. Cases of children
admitting ‘Now I see!’, following these discussions, contributed to the shaping of such an impression.

6.5.2 Diaries
In keeping diary-like notes as a metacognitive activity, sheets were used rather than an exercise book (pupils were asked to write at the back of the worksheets used in class). This way the task was given an informal character and there was a better chance of pupils remembering to bring these sheets with them next time, rather than a booklet they were not used to having in science lessons. The use of diaries was not a problem-free choice since a number of difficulties were associated with it. For one, not all pupils remembered to do the task when this was assigned as homework, and in most of the cases their writing was restricted to 1-2 sentences. Moreover, most of pupils’ remarks were primarily descriptive of work done in class, rather than projecting a reflective nature, and a tendency to be rather generic in their thoughts was evident (Figure 6.2).

The contribution of the use of diaries partly lay in the highlighting of points that were not clearly understood by children at the end of the lesson. This offered this researcher the chance to revisit briefly these areas in the following lesson, before addressing new concepts (Figure 6.3).

We learned about the positive and the negative terminal, about closed and open circuits and about electrons

Figure 6.2 Sample of diary extract
I didn't understand the negative terminal ... I didn't understand why it's the negative terminal that sends electrons

Figure 6.3 Sample of diary extract

In those cases where some reflection was evident, children's comments were, once again, of a comparative nature, usually comparing their ideas prior and following teaching. Figures 6.4 and 6.5 present extracts from pupils' diaries, showing some reflection on learned material and contrasting this to their understanding prior to teaching. Notably Figure 6.5 shows what appears as substantial change in the learner's understanding, whereas the case in Figure 6.4 is one of addition of new information without rejecting the one already held by the learner. This said, it has to be acknowledged that these statements do not themselves furnish sufficient evidence of learners truly holding changed understanding, yet they are an indication in this direction.

It is also noted that in Figure 6.5 reference is made by the pupil to the use of analogies during teaching, acknowledging the usefulness of these analogies in changing her understanding, therefore, exhibiting reflection on the means of her learning.
Before I knew that “short circuit” can be caused by water on wires. Now I know that it can also be caused when two wires touch together because electrons always choose the easiest route.

Figure 6.4 Sample of diary extract

When we started to learn about open and closed circuit I thought that it was very confusing because at home we say “open the light” and “close the light” but here we learned about “open circuit” and “closed circuit”. I think that the example with the bridge that rises to let boats through will help me remember that when the switch is open, electrons stop like cars do.

Figure 6.5 Sample of diary extract
Figure 6.6 presents a diary extract following the last lesson of the subject-unit on electricity. This pupil shows ability to summarise important concepts of electricity, describe briefly associated phenomena, and explain the meaning of terms such as ‘short-circuit’. In spite of an error made in referring to conductors and insulators he still shows that he is aware of their difference in nature. In sum, this is a case of a pupil who could report substantial amounts of information for the subject-unit taught.

Now we have learned about the positive and the negative terminal. The negative pushes electrons. We learned about closed and open circuit. When we have closed circuit the light bulb glows but when the circuit is open the light bulb doesn’t glow. We also learned about conductors who don’t let electrons pass through them. Insulators though allow electrons to pass through them. We also learned about vrahikikloma (short-circuit) which means short-circuit.
6.5.3 Annotated drawing

Annotated drawing proved to be the most enjoyable activity for the children who, in general, appeared very willing to be assigned such a task. The level of reflection involved in their annotations varied considerably from being merely descriptive of the object they drew (Figure 6.7) to explaining and justifying the why of things (Figure 6.8).

Figure 6.7 Sample of annotated drawing

(a) These screws are used by electricians when the fuse is not working
(b) These are made of iron
(c) This is made of plastic

In Figure 6.7, for instance, the drawing is clearly being descriptive of a plug without showing any reflection on behalf of the learner as to why different parts of the plug are made from different materials. Figure 6.8, on the other hand, that describes the same object, clearly shows that this pupil engaged in revisiting her knowledge at a level higher than the descriptive. She managed to describe the materials from which the plug is made, she explained why these materials are used in particular and, in doing so, she used the right scientific terminology. Notably, she even moved a step further to explain what can possibly happen if the plastic cover of the wire is removed, exhibiting hypothetical thinking in relation to her understanding.
(a) It is made of iron for current to pass
(b) This is plastic so that it's safe when we touch. It is an insulator
(c) The wire is like rubber so that current doesn't get through when we step on it.
If the plastic goes there can be a short circuit

Figure 6.8 Sample of annotated drawing

In order to achieve involvement of more pupils in the activity, including children who might not be willing to draw something (because they felt that the quality of their drawing was low) and children who were very slow in producing a drawing, this researcher also made use of ready-drawn figures which children had to annotate. Figure 6.9 presents one such example in which the pupil exhibits ability to say what is happening and briefly explain why. In doing so, he demonstrates understanding of the concept of short-circuit and of more basic concepts such as electron flow and the role of the battery.
Here what is happening is the following: Electrons prefer the short route. And the light bulb will not glow.

Figure 6.9 Sample of annotated drawing

(A) If it closes it will glow and current will pass through the other wire
(B) If it closes it will not glow and it will pass through the top wire

Figure 6.10 Sample of annotated drawing
Figure 6.10 presents a rather unusual case. When asked to draw a case of short-circuit and briefly explain what was happening, one pupil constructed his own multiple choice question. This is thought by this researcher to be an important case of metacognitive activity in action. The pupil not only produced a drawing that represented correctly the arrangement for a short-circuit to happen, but he further presented the scientifically correct and a wrong response to choose from. This suggests that this pupil was conscious of different potential explanations of the phenomenon and was able to choose the correct response by revisiting his knowledge, as suggested by the arrows he used to represent electron flow.

Overall children produced rich material by means of annotated drawings. Even in their most basic form of being merely descriptive, annotated drawings are thought by this researcher to have served their metacognitive purpose by having pupils represent knowledge they were holding. This researcher unreservedly suggests that in their more advanced forms children’s drawings entailed signs of metacognitive reflection on their understanding, therefore proving a successful tool of the metacognitive instances approach.

6.5.4. Concept mapping

Concept mapping was used initially as whole-class activity and later as pair or individual activity. It was used particularly during the first or last minutes of each lesson, aimed at summarising taught concepts and highlighting relationships between them. Figures 6.11-6.13 present samples of concept maps produced by the children of the experimental group. In judging these figures, the reader is reminded that the children had never used concept mapping before, nor had they received considerable training during this study on the construction of concept maps.

The complexity of the concept maps produced by the pupils varied considerably as can clearly be seen in the two examples presented here. On one hand, were cases of pupils restricting their concept maps to basic connections or relationships between learned concepts (Figure 6.11) and, on the other hand, were cases of pupils presenting more complex and detailed associations (Figure 6.13). Given the lack of prior experience in the construction of concept maps by the pupils, these outcomes are thought by this researcher to be satisfactory in serving the needs of this research.
Electrons don't move

Electrons move

Figure 6.11 Sample of concept mapping

Open circuit

Closed circuit

Figure 6.12 Sample of concept mapping
Figure 6.11 presents a concept map produced at the end of the first lesson that introduced the concepts of open and closed circuit. The concept map is quite simple yet manages to represent correctly basic relationships and connections between taught concepts of electricity. The concept map in Figure 6.12 was produced during the second lesson following learning about conductors and insulators. This concept map accommodates both knowledge acquired on that specific day (conductors and insulators), and knowledge obtained in the previous lesson (electrons / open-closed circuit). This is thought to be important because in producing this concept map the pupil had to revisit previously held knowledge and relate this to new information in a way that the two co-exist in a mutually supportive manner. This kind of mental activity is taken by this researcher as a sign of metacognitive reflection.

![Figure 6.13 Sample of concept mapping](image)

During the last lesson of the subject-unit concept maps of greater detail and complexity were
produced. This can be attributed to the fact that pupils learned a number of concepts or phenomena associated with electricity and had, in the meantime, acquired some experience in constructing concept maps. The concept map in Figure 6.13 clearly presents more concepts and more relationships, showing ability on behalf of the learner to depict a system of interrelated pieces of information (e.g. electron flow, role of the battery, open-closed circuit, conductors and insulators, switches and burnt-out light bulbs).

In general, the concept maps produced by the children of the experimental group entailed signs of metacognition. This judgement is based on the fact that children gradually managed to simultaneously represent numerous concepts and identify relationships and connections between them, something that could not possibly be done had the pupils not exhibited reflection on their constructed knowledge. This researcher believes that had the pupils received further training in concept mapping this would have resulted in the production of even richer concept maps.

A last comment with regards to the material produced by the children of the experimental group during the practice of metacognitive activities is that, in general, such material seemed fuller and richer in the case of the four children from the small experimental class. This is so because the small number of children enabled this researcher to offer personalised feedback and further stimuli during the production of this material. In the case of annotated drawing, for instance, a pupil might have simply indicated that a screwdriver's handle was made of plastic, restricting his annotation to a descriptive level. When the researcher observed this and encouraged the pupil to write a few words explaining why this was so, this resulted in the pupil explaining that plastic is an insulator and because of the absence of free electrons it cannot allow electricity to pass through it. Similar prompts were used in classroom discussions and concept mapping eventually resulting in richer material and, most importantly, in what appeared as greater reflection on behalf of the children.

This completes the presentation of the material produced by children of the experimental group during the implementation of the *metacognitive instances* approach. Having set the background to analysis of data, the remaining parts of this chapter are divided into two broad sections addressing the following areas with respect to analysis of data:
6.A. Quantitative analysis of tests
   6.A.1. Introduction to quantitative analysis
   6.A.2. Big classes
      A.2.1. Durability of pupils' conceptions
      A.2.2. Pupils' performance by type of exercise
      A.2.3. Concept-based analysis
   6.A.3. Small classes

6.B. Qualitative analysis of interviews
   B.1. Introduction to qualitative analysis
   B.2. First order qualitative analysis, offering a broad perspective on the total of 48 interviews.
   B.3. Second order qualitative analysis, employing a focused perspective of four case studies.
6.A QUANTITATIVE ANALYSIS OF TESTS

‘There are lies, damn lies and statistics’ (Disraeli)

6.A.1. Introduction to quantitative analysis

The rationale behind Disraeli’s eye-catching dictum has been the cause of widespread scepticism and suspicion regarding the use of statistical analysis as a means for substantiating claims in the social sciences, and yet another reason for researchers to turn towards the qualitative camp. For the present thesis, though, the above dictum has acted as a ‘health-warning’ causing considerable reflection over the processes employed in the analysis of data. The result of this conscious reflection was to define the scope of quantitative analysis as one of providing a numerical-based summary, depicting a rather general picture of the outcomes of the study that will serve as a framework for viewing qualitative aspects to be presented in the second part of the analysis. As a result of this being the driving force behind the quantitative dimension of analysis, this thesis chooses not to immerse in a discussion of complex statistical methodology or terms. This is a choice made in the belief that focusing on extensive statistical scrutiny would shift discussion to positivistic fields that lie beyond the philosophy, the scopes and the priorities of this study, not least because the approach followed was not a ‘true’ experiment.

This last point also determines that analysis should be restricted to forms and types appropriate for a quasi-experimental design. The scope, therefore, of the quantitative dimension of the analysis is not to prove claims based on thorough statistical manipulation of numbers; rather it is to provide a means of comparison that can summarise the outcomes of the quasi-experimental approach applied and to provide a framework for the qualitative analysis that is to follow. Consequently the main effort will be on presenting what is known as descriptive or summary statistics.

Having said so, this thesis does not exclude keeping an outlook for causal relationships since such a stand is in agreement with the practice-oriented philosophy of the study. This writer fully ascribes to the views of Bryman and Cramer (1990) who point out that
findings which establish cause and effect can have considerable practical importance: if we know that one thing affects another we can manipulate the cause to produce an effect (p. 7).

Causality is taken to refer to the likelihood of an effect occurring following the application of the independent variable, without suggesting that the latter will necessarily take place nor that it is totally influenced by the former. If the ultimate objective of educational research is to enhance knowledge that will enable improved practice, then this line of thought should be inexplicably tied to the philosophy of any research conducted within the field of education.

The following analysis is based on a total of one hundred and seventy-seven (177) tests taken by the pupils of the two big classes during the three phases of this research. Twenty-four (24) tests taken by the pupils of the two small classes are not included in the results presented initially, because these classes form a distinct category that will be treated separately at the end of this section. This is a methodological choice based on the fact that statistical analysis is not appropriate in the case of the small classes due to the very small number of participants. Reference to the two small classes is therefore restricted to aggregated percentages, knowing that even this kind of statistical processing might not be appropriate for small groups of this size. Outcomes from the small classes should be seen only as indicative of the effects achieved and should be viewed in close relation to the qualitative analysis that is to follow in the next section.

The reader is advised to refer to Appendix III, which includes a sample of the test used in the three phases of the research, presenting the scoring system applied for marking the tests. The maximum score was 60, representing 20 points for each of the three parts of the test (i.e. 20 points for Type A exercises, 20 points for Type B exercises and 20 points for Type C exercises), or 12 points for each of the five concepts tested. In most cases only one answer was correct therefore marking the exercises was quite clear-cut. In those cases where justification of one's response was required, points were allocated depending on the detail of the explanation given. In question D2, for instance, (Figure 6.14) two points were given for the first part of the exercise where pupils had to choose the correct answer, and two points for justifying their choice in the second part of the exercise. Pupils answering, for example, that Irene should buy the screwdriver with the plastic handle 'because it's plastic', or 'because it is safer', received only one point because their responses were judged to be partial or incomplete. Answers, on the other hand, such as 'because the handle is made of plastic, which is an insulator, and it's safe for her dad because
electrons cannot pass through the handle'; were given two points. In presenting the results in tables, percentages are used in most cases to enable easier comparisons.

**Figure 6.14 Illustration of scoring system**

This first section of quantitative analysis of data will look at mainly three distinct -yet often overlapping- directions:

a) Pupils’ overall performance in the three phases of the research

b) Pupils’ performance in the three types of exercises

c) Pupils’ performance in different concepts of electricity
6.A.2. Big classes

A.2.1. *Durability of pupils’ conceptions*

Drawing from the main objectives of the present research, the first dimension to be addressed by quantitative analysis is how durable pupils’ conceptions of taught science concepts appeared to be over the ten-month period of the research. This is achieved by means of looking at pupils’ overall performance in the three tests administered during the course of this research. Table 6.2 presents a summary of the most important outcomes of the study in this respect. This information is then broken down in smaller sections and discussed accordingly in the following pages.

Summary of the outcomes of the study – Big classes

<table>
<thead>
<tr>
<th>Group</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N=30)</td>
<td>(N=30)</td>
<td>(N=28)</td>
<td>(N=29)</td>
</tr>
<tr>
<td>Mean*</td>
<td>41.20</td>
<td>38.71</td>
<td>37.76</td>
</tr>
<tr>
<td>%</td>
<td>68.67</td>
<td>71.64</td>
<td>62.93</td>
</tr>
<tr>
<td>Median*</td>
<td>41.50</td>
<td>45.25</td>
<td>41.00</td>
</tr>
<tr>
<td>S.D.</td>
<td>11.27</td>
<td>12.29</td>
<td>12.97</td>
</tr>
</tbody>
</table>

* maximum score = 60, N= number of pupils

Table 6.2

Results in Table 6.3 show that scores achieved by pupils of the experimental class were consistently higher than the ones obtained by their counterparts of the comparative class. Further comparison of average scores shows that in the case of the comparative class there is a descending tendency in overall performance over the three testing instances, whereas for the experimental class the picture is one of a more consistent performance (Figure 6.15).

Pupils’ average overall performance - Big classes

<table>
<thead>
<tr>
<th>Group</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative group</td>
<td>68.67% (N=30)</td>
<td>64.52% (N=28)</td>
<td>62.93% (N=29)</td>
</tr>
<tr>
<td>Experimental group</td>
<td>71.64% (N=30)</td>
<td>70.17% (N=30)</td>
<td>72.92% (N=30)</td>
</tr>
</tbody>
</table>

N= number of pupils

Table 6.3
Table 6.4 gives a summary of children’s performance per quartile range in the three phases of the research. What is particularly striking is the fact that in the case of the experimental group the number of pupils scoring within each range remains largely the same, something that is taken as a first indication of stability of group performance. In other words, the experimental class appears to have maintained more consistent, or less fluctuating, performance compared to the performance of the comparative group. This said, the information presented in Table 6.4 should not be treated as evidence of stable individual performance; for example, that the 15 pupils of the experimental group in the top score range at Phase 1 include the 14 in the top range of Phase 2. Such evidence should come from the study of individual cases.

Figures 6.16-6.19 represent individual pupils’ performance at the first and third test, for the two groups. The order in which cases of pupils are presented on the horizontal axis is the same for each pair of graphs, thus enabling clearer tracking of individual pupils’ performance. (One case that appears to have scored ‘zero’ in Figure 6.18 represents a pupil who was absent on the day of the third test). As shown in the scatter-grams difference in performance between comparative and
experimental class became more apparent during the third testing phase. Although in Phase 1 both the arithmetic means for the scores achieved by the two classes and the distribution of individual scores were very close to each other, during the third testing phase there was considerable difference in both the means and the distribution of individual scores. Scores of the experimental class appear to be more closely clustered around the mean, whereas in the case of the comparative class there is a tendency towards lower scores. For example, although 9 pupils from the comparative class scored in the top range of 50-60 during the first testing phase, this number dropped to 3 pupils in the third testing. Similarly for lower scorers, although only 2 pupils from the comparative class scored below 25 during the first testing, their number increased to 6 in the third test. The tendency, therefore, for lower scoring from pupils of the comparative group over the third testing phase is apparent, and contrasts with the picture of a more stable—in some cases increasing—performance, presented by the experimental group.

![Scattergram for big comparative class - Phase 1](image1)

*Figure 6.16*

![Scattergram for big experimental class - Phase 1](image2)

*Figure 6.17*

![Scattergram for big comparative class - Phase 3](image3)

*Figure 6.18*

![Scattergram for big experimental class - Phase 3](image4)

*Figure 6.19*
The tendency of the experimental group towards higher and more clustered performance when compared to the one of the comparative group in Phase 3 can be seen more clearly in the box-plots in Figure 6.20 and 6.21.

In sum, results with regard to overall performance suggest that pupils from the big experimental class exhibited higher and more consistent performance compared to the performance of pupils from the comparative class, which decreased with time. In terms, therefore, of the ‘durability’ dimension of this research, pupils who practised situated metacognition appeared to hold more durable knowledge than their counterparts from the comparative group.
This section looks at the second main direction of the research, namely pupils' ability to apply knowledge in different contexts. A summary of the outcomes of this research with respect to the dimension of context is given in Table 6.5.

<table>
<thead>
<tr>
<th>Pupils' performance by type of exercise - Big classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative class (N=30) Phase 1</td>
</tr>
<tr>
<td>Type A*</td>
</tr>
<tr>
<td>71.50%</td>
</tr>
<tr>
<td>Type B*</td>
</tr>
<tr>
<td>72.83%</td>
</tr>
<tr>
<td>Type C*</td>
</tr>
<tr>
<td>61.67%</td>
</tr>
<tr>
<td>(N=28) Phase 2</td>
</tr>
<tr>
<td>Type A*</td>
</tr>
<tr>
<td>67.23%</td>
</tr>
<tr>
<td>Type B*</td>
</tr>
<tr>
<td>66.34%</td>
</tr>
<tr>
<td>Type C*</td>
</tr>
<tr>
<td>60.00%</td>
</tr>
<tr>
<td>(N=29) Phase 3</td>
</tr>
<tr>
<td>Type A*</td>
</tr>
<tr>
<td>63.88%</td>
</tr>
<tr>
<td>Type B*</td>
</tr>
<tr>
<td>64.40%</td>
</tr>
<tr>
<td>Type C*</td>
</tr>
<tr>
<td>60.52%</td>
</tr>
<tr>
<td>Experimental class (N=30) Phase 1</td>
</tr>
<tr>
<td>Type A*</td>
</tr>
<tr>
<td>72.33%</td>
</tr>
<tr>
<td>Type B*</td>
</tr>
<tr>
<td>71.75%</td>
</tr>
<tr>
<td>Type C*</td>
</tr>
<tr>
<td>70.83%</td>
</tr>
<tr>
<td>(N=30) Phase 2</td>
</tr>
<tr>
<td>Type A*</td>
</tr>
<tr>
<td>68.00%</td>
</tr>
<tr>
<td>Type B*</td>
</tr>
<tr>
<td>72.00%</td>
</tr>
<tr>
<td>Type C*</td>
</tr>
<tr>
<td>70.50%</td>
</tr>
<tr>
<td>(N=30) Phase 3</td>
</tr>
<tr>
<td>Type A*</td>
</tr>
<tr>
<td>74.08%</td>
</tr>
<tr>
<td>Type B*</td>
</tr>
<tr>
<td>75.74%</td>
</tr>
<tr>
<td>Type C*</td>
</tr>
<tr>
<td>69.24%</td>
</tr>
</tbody>
</table>

Table 6.5

* 'Type A' exercises: Exercises that tested taught concepts in a 'context-free' mode, requiring plain recall of learned material.
* 'Type B' exercises: Exercises that tested taught concepts within 'familiar' contexts, similar to the ones used in class during instruction.
* 'Type C' exercises: Exercises that tested taught concepts in 'unfamiliar' contexts, or settings from everyday life.

Children's performance varied for different types of exercises over the three phases of the research, the prevailing feature being one of consistently higher scores for the experimental group. Greatest difference in performance was evident between Type C exercises on one hand, and the other two types of exercises on the other.

In the three phases of the research the big experimental class outperformed the corresponding comparative class in Type C exercises. As shown in Table 6.6, Type C exercises were also the ones in which difference between aggregated performance of comparative and experimental classes over the three phases of the research was greatest.

Comparing the results of testing conducted immediately after completion of teaching (Phase 1) and testing that took place at the end of the school year (Phase 3) suggests that for both Type A and Type B exercises there was considerable drop in performance of pupils from the comparative class. Contrary to this outcome is the performance of pupils from the experimental class in Type
A and B exercises, which not only did not exhibit similar decrease, but quite the opposite, it was slightly higher in Phase 3 compared to Phase 1.

**Average aggregated performance over the three phases, per type of exercise**

<table>
<thead>
<tr>
<th></th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big comparative class</td>
<td>67.58%</td>
<td>67.93%</td>
<td>60.74%</td>
</tr>
<tr>
<td>Big experimental class</td>
<td>71.47%</td>
<td>73.05%</td>
<td>70.19%</td>
</tr>
<tr>
<td>Difference between classes*</td>
<td>+3.89%</td>
<td>+5.12%</td>
<td>+9.45%</td>
</tr>
</tbody>
</table>

* (+) indicates positive difference in favour of the experimental class

*Table 6.6*

The case for Type C exercises was very different since they were the ones in which less change in performance occurred over the ten-month period for both experimental and comparative class (Figures 6.22-6.24). In other words performance in Type C exercises was more consistent over the three phases of the research possibly indicating that the ability to utilize knowledge, once acquired, is more stable than ability to simply recall and report previously learned knowledge.
In 71 out of 177 tests taken by the big groups, performance in Type C exercises was the lowest when compared to the other two sections of the test (Table 6.7). This is an important outcome suggesting that ability to use knowledge in contexts considerably different to the ones in which learning took place is indeed problematic, hence verifying the literature on transfer of learning (e.g. Detterman and Sternberg, 1993).

### Overall cases of lowest and highest scores, per type of exercise

<table>
<thead>
<tr>
<th>Type</th>
<th>Overall cases of lowest score</th>
<th>Overall cases of highest score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>43*</td>
<td>56**</td>
</tr>
<tr>
<td>Type B</td>
<td>39*</td>
<td>66**</td>
</tr>
<tr>
<td>Type C</td>
<td>71*</td>
<td>31**</td>
</tr>
</tbody>
</table>

*Not including cases in which 'lowest' score was shared by two or more types of exercise.
**Not including cases in which 'highest' score was shared by two or more types of exercise.

Type B exercises received the highest score in 66 out of 177 tests. The fact that overall performance for the comparative class, that received no special treatment, was considerably higher for Type B exercises where a rather familiar context was given, rather than Type C exercises that required some form of transfer of knowledge, came as no surprise since there is plenty of evidence in the literature advocating the importance of putting knowledge in familiar contexts. The fact that pupils' performance in Type B exercises dropped over the three tests (in contrast to their performance in Type C exercises that was clearly more stable) could suggest that the positive effect of a 'familiar' context is fading out with time.
What did come as a surprise, though, was the high score achieved by both groups in Type A exercises where no particular context was provided, in an effort to test ability to recall knowledge in a context-free mode. The researcher was expecting performance in this section of the test to be lower than the one exhibited, because of the great time intervals between teaching and follow up tests. However, as will be discussed in the qualitative part of the analysis, a great number of pupils retained considerable amounts of details until the end of the year.

The last point to be made with respect to the role of context is drawn from an extra question given to the pupils at the end of the first test. When asked to comment on which type of exercise they thought as most difficult, the striking majority of the pupils named Type C exercises as shown in Table 6.8. Interestingly Type A exercises, that required plain recall of factual knowledge, were judged by pupils as the least difficult, possibly revealing that this kind of exercise was the one to which they were most accustomed.

<table>
<thead>
<tr>
<th>Type of exercise thought by pupils as 'most difficult' – Phase 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>'None'</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

N = number of pupils

In general the 'context' dimension of this research has given some very interesting results, the main finding being that exercises that placed knowledge in unfamiliar contexts were the ones in which lowest performance was recorded. Interestingly, albeit the lowest from the three types of exercises, performance in Type C exercises seemed to be the most stable, possibly suggesting that once ability to tackle such exercises is demonstrated, this is of a more durable nature. Throughout the context-based analysis of the results, the experimental group’s superiority in performance was confirmed.
A.2.3. Concept-based analysis

Although the interest of the present study lies beyond elaborating on the understanding of scientific concepts *per se* in the tradition of other CCL studies, reference to some numerical data relating to pupils’ performance on taught concepts of science will later enable better connection to the qualitative part of the analysis. A concept-based analysis of the results is therefore considered necessary, serving to describe more fully the results of this research and making the connection to the sections to follow. First, brief comments are offered on each of the five main concepts taught, that refer to pupils’ performance in Phase 1 and report this researcher’s impressions irrespective of group from which the pupils originate. These comments should help in putting numerical data (Table 6.9) obtained by means of the test administered over the three phases of this research, in context.

**Open - closed circuit**
In spite of some difficulty caused by idioms of the Greek language (described earlier), the majority of the children did particularly well at questions dealing with the concept of open and closed circuits. The fact that the effect of opening/closing a circuit was repeatedly experienced in class by observing the switching on and off of a bulb; the fact that the children could easily draw (or comment on a drawn) open / closed circuit; and the use of the ‘rising bridge analogy’ to help them remember how a switch operates, are thought to have contributed to the high overall scores in this concept.

**Conductors and Insulators**
Most children obtained high scores in exercises that referred to *conductors* and *insulators*, because it is a subject that pupils can easily relate to, through everyday experience. Although most children did particularly well at corresponding Type B and C exercises overall performance of both experimental and comparative classes in Type A exercises was always the lowest (in all three phases of the research) when compared to the other two sections of the test. This may suggest that although children held sufficiently valid conceptions of conductors and insulators and could apply these in Type B and C exercises, they faced difficulties in: a) plainly recalling the terms ‘*conductors*’ and ‘*insulators*’ and relating appropriate materials to each category, and b) explaining the difference in *nature* between conductors and insulators (in terms of electrons) when asked in a context-free mode.
Short-circuit
Albeit a difficult concept to understand and in spite of some confusion over the Greek term 'vrahikikloma', the concept of short-circuit was ranked third in overall performance. The majority of the pupils could explain with reference to electrons why a short-circuit happens, yet there was some confusion as to how or when a short-circuit happens. Most could identify the case of two bare wires making contact, but when asked to suggest other ways of causing a short-circuit, they were not very successful.

Burnt-out light bulb
The concept of a burnt-out light bulb was one in which highest average score for all participants was achieved in Type A exercises. This means that pupils could explain what happens in the case of a burnt-out light bulb, and say whether the light bulb glows or not, probably aided by experience from everyday life. In Type B and especially Type C exercises, some of the children had difficulties in both predicting and justifying the effect of a burnt-out light bulb in a circuit. In a number of cases the answer 'because the bulb is burnt-out' was given by the children as their explanation of the effect of a burnt-out bulb in the circuit, merely repeating information that was given to them rather than referring to the science underpinning the phenomenon.

Current / Electron flow
Being a highly abstract concept flow of electrons was the concept with the lowest overall score in the three testing phases of the research. The main problem areas traced in the tests with regard to this key-concept were: a) naming the negative terminal of the battery as the one that pushes electrons to the light bulb in a closed circuit; b) explaining the instantaneous glow of a light bulb as soon as the circuit is complete; and c) explaining the simultaneous glow of two light bulbs connected in series in a circuit. Nearly all pupils who gave an incorrect answer suggested that electrons 'move very fast', clearly demonstrating a 'sequential' understanding of current (Osborne and Freyberg, 1985; Driver et al., 1994b). This writer acknowledges that this specific alternative explanatory framework and the broader problems encountered with the concept of electron flow must have affected performance in other concept areas that relied on the key-notion of current (e.g. 'burnt-out light bulb in a circuit' or 'short-circuit'). This, however, was inevitable due to the central role of this concept in the unit of electricity.

The concept-based presentation of the outcomes in Table 6.9 repeats the experimental group’s lead in performance demonstrated in the two preceding sections, especially for the results of Phase 3. Notably, the lowest average performance was scored by the comparative class in the concept of electron flow, scoring nearly 15% lower than the experimental class. The central
role of this concept in the understanding of numerous phenomena associated with electricity offers a first explanation to the fact that average performance of the experimental class was higher for all concepts taught.

The importance of the ‘current/electron flow’ concept makes even more noticeable the fact that although the two groups’ average scores are very close for four concepts in Phase 1, there is a significant difference in favour of the experimental group for ‘current/electron flow’. Having highlighted this point, this researcher has no means of determining whether this was the result of the experimental approach managing a particularly positive impact in helping pupils overcome difficulties with the specific concept, wrong-doing on the researcher’s behalf, or a chance outcome.

Interestingly, the fact that pupils’ performance in the concept of electron flow varied on average between 51.8% and 65% suggests that there has been considerable shift in children’s ideas compared to the fact that only five pupils appeared to be holding the scientific model prior to teaching (Table 6.9). The fact that this researcher could not have obtained numerical data for pupils’ views on the other four concepts prior to teaching, does not allow other direct comparisons to be made.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Group</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Average Phase 1-3*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current/Electron flow</td>
<td>Comparative</td>
<td>55.5%</td>
<td>49.1%</td>
<td>50.8%</td>
<td>51.8% -8.46%</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td>68.2%</td>
<td>62.5%</td>
<td>64.3%</td>
<td>65.0% -1.74%</td>
</tr>
<tr>
<td>Open-Closed circuit</td>
<td>Comparative</td>
<td>78.5%</td>
<td>73.8%</td>
<td>74.6%</td>
<td>75.6% -4.96%</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td>76.3%</td>
<td>79.9%</td>
<td>85.1%</td>
<td>80.4% +11.5%</td>
</tr>
<tr>
<td>‘Burnt-out’ light bulb</td>
<td>Comparative</td>
<td>65.6%</td>
<td>63.7%</td>
<td>58.3%</td>
<td>62.5% -9.2%</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td>61.8%</td>
<td>61.1%</td>
<td>69.7%</td>
<td>64.2% +12.7%</td>
</tr>
<tr>
<td>Conductors-Insulators</td>
<td>Comparative</td>
<td>74.7%</td>
<td>71.3%</td>
<td>67.7%</td>
<td>71.2% -9.37%</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td>81.9%</td>
<td>78.6%</td>
<td>79.2%</td>
<td>79.9% -3.29%</td>
</tr>
<tr>
<td>Short-circuit</td>
<td>Comparative</td>
<td>69.0%</td>
<td>64.7%</td>
<td>63.2%</td>
<td>65.6% -8.40%</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td>70.0%</td>
<td>68.8%</td>
<td>66.8%</td>
<td>68.5% -4.5%</td>
</tr>
</tbody>
</table>

* % change of initial score

The last column in Table 6.9 shows how durable each concept proved to be at the end of the research period, comparing performance in Phase 3 to performance in the same concept in Phase 1. In order to obtain comparable measures the percentages given are not the result of
subtracting Phase 3 scores from Phase 1 scores, rather they represent percentile change of scores initially obtained in Phase 1. This breakdown of the results clearly shows that in the case of the experimental group children’s conceptions of electricity proved far more durable than those of their counterparts of the comparative group.

The results presented in Table 6.9 enable dividing taught concepts in two main groups with respect to their durability. On one hand are the cases of ‘current/electron flow’, ‘conductors and insulators’, and ‘short circuit’ in which the picture is one of recording greater decrease in average performance for the comparative class as opposed to a smaller decrease for the experimental class. On the other hand, are the cases of ‘burnt-out light bulbs’ and ‘open-closed circuits’ where not only difference in performance of the comparative class between Phases 1 and 3 shows some decrease, but in the case of the experimental class average performance in Phase 3 is higher by a significant percentage compared to their initial performance. The latter cases are quite unusual and admittedly difficult to interpret in terms of the theoretical discussion held in previous chapters, for no apparent reason exists why the metacognitive instances approach should have such different impact on different concepts. Conversely, this outcome could indicate some distortion of the outcomes of this research by external factors. This researcher is not in a position to know whether any intentional or not reinforcement of the two latter concepts was attempted by the teacher of the experimental class although, as noted earlier, he did not form such impression during his follow-up visits.

Figures 6.25-6.27 offer a graphic representation of pupils’ performance in different concepts, the highest score in each case being 12 (please see test in Appendix III for score allocation). Comparison of the three graphs clearly indicates that by Phase 3 of the research, pupils of the experimental class (E2) outperformed their counterparts of the comparative class (E1) in all concepts.

What is particularly interesting with respect to this outcome is that difference in performance between the two groups increased with time, hence suggesting that the positive effect of the intervention on the experimental group acted in the long-term rather than having an immediate impact.
Average score by concept - Phase 1

Concept
- Short circuit
- Conductors-Insulators
- Burnt bulb
- Open-Closed circuit
- Flow of electrons

Average score

Figure 6.25

Average score by concept - Phase 2

Concept
- Short circuit
- Conductors-Insulators
- Burnt bulb
- Open-Closed circuit
- Flow of electrons

Average score

Figure 6.26

Average score by concept - Phase 3

Concept
- Short circuit
- Conductors-Insulators
- Burnt bulb
- Open-Closed circuit
- Flow of electrons

Average score

Figure 6.27
The concept-based analysis of test results showed in detail how pupils from both big classes performed in each of the concepts taught in the subject unit of electricity. The concept of electron flow proved to be the most problematic, especially for the comparative class, something that may have considerably affected children's performance in the other concepts due to the central role of the former. Over the three phases of this research differences in performance for all concepts taught increased in favour of the experimental class, suggesting that rather than having an immediate impact, the positive effect of the experimental approach acted in the long-run.

6.A.3. Small classes

Results from the two small classes in general replicated to a great extent what was reported for pupils of the big classes. In the case of the small groups, however, difference in performance was much more evident in favour of pupils from the experimental class, who outperformed their counterparts of the comparative class in all three phases of the research, by between 8.33% to 15.62% (Table 6.10). When compared to their own performance at the beginning and at the end of the school year, decrease in performance of the comparative class was more than double the decrease in performance of the experimental class (-11.06% against -5.42%). It is therefore noted that difference in performance between small experimental and comparative classes increased with time, as was the case for the big classes. It is further pointed out that, had the results of the small experimental class in Phase 3 not been affected by the performance of one pupil who was ill but volunteered to take the test, the overall score for this class would eventually be higher.

Pupils' overall performance - Small classes

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small comparative class (N=4)*</td>
<td>75.42%</td>
<td>71.46%</td>
<td>64.38%</td>
</tr>
<tr>
<td>Small experimental class (N=4)</td>
<td>83.75%</td>
<td>87.08%</td>
<td>78.33%**</td>
</tr>
</tbody>
</table>

* N= number of pupils

** One of the pupils was ill but volunteered to show up for the test. It is believed that, had the specific pupil's performance not been affected, overall results for the experimental group would have been even higher.

Table 6.10
Looking at scores in terms of different type of exercise again, the picture is one of lowest scores in Type C exercises, as was in the case of the big classes. Highest scores by type of exercise were consistently achieved by pupils of the small experimental class over the three phases of this research (Table 6.11).

<table>
<thead>
<tr>
<th>Group</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative</td>
<td>76.25%</td>
<td>79.38%</td>
<td>70.63%</td>
</tr>
<tr>
<td>(N=4) Phase 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N=4) Phase 2</td>
<td>75.63%</td>
<td>75.63%</td>
<td>63.13%</td>
</tr>
<tr>
<td>(N=4) Phase 3</td>
<td>63.75%</td>
<td>63.75%</td>
<td>65.63%</td>
</tr>
<tr>
<td>Experimental</td>
<td>83.75%</td>
<td>93.13%</td>
<td>74.38%</td>
</tr>
<tr>
<td>(N=4) Phase 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N=4) Phase 2</td>
<td>86.88%</td>
<td>90.00%</td>
<td>84.38%</td>
</tr>
<tr>
<td>(N=4) Phase 3</td>
<td>77.50%</td>
<td>81.88%</td>
<td>75.63%</td>
</tr>
</tbody>
</table>

Table 6.11

With respect to the small classes’ performance in the concepts tested, the same general comments made in the case of the big classes apply to a great extent. Due to the small number of participants no quantitative concept-based analysis is attempted. This aspect of pupils’ performance will be addressed in detail by qualitative analysis.

This concludes the first part of the analysis of data addressing the quantitative dimension. As was previously explained, the scope was to present summary statistics that would paint a general picture of the outcomes of this study and enable comparisons between groups. In
doing so, this researcher remained conscious of the fact that even in their simple form used in this thesis,


Following this line of thought outcomes and their implications for the three directions investigated are discussed in Chapter 7. Before doing so, though, the second dimension of analysis of data, namely the qualitative analysis of interviews, has to be addressed.
6.B. QUALITATIVE ANALYSIS OF INTERVIEWS

The interviewer must come to the transcript prepared to let the interview breathe and speak for itself (p.89) (…) The story is both the participant’s and the interviewer’s. It is in the participant’s words, but it is crafted by the interviewer from what the participant has said (Seidman, 1991, p.92).

6.B.1. Introduction to qualitative analysis

Having highlighted the belief that both processes and results of analysis provide only a snapshot of the phenomenon studied, it is all too important to acknowledge that such a snapshot inevitably has a highly selective and interpretative nature. This is not a new problem within the research tradition. The high degree of interpretation involved in studies with a qualitative orientation, especially during the analysis of data, is something that is widely acknowledged in the literature. Powney and Watts (1987), for example, warn that

*Given that transcription cannot represent everything featured in the original spoken language, it follows that any transcription is an interpretation by the transcriber of what is being said. What is written down is inevitably selective* (p.147).

They further caution

*Analysis is a process of gains and losses, and it is important that researchers report both aspects as fully as possibly* (p.143).

Albeit one of the virtues of qualitative research, the potential diversity in interpreting the outcomes of a study can and should be regarded as a reason for concern. The point to be made, therefore, is that while admittedly being subjective this researcher is conscious of the need to be able to keep the balance between his version of the account and the participants’ original responses.

In order for analysis of data to be purposeful and meaningful the main objectives of the study and the specific research questions tackled have to be re-addressed, especially when devising categories that will reduce data into more manageable groupings. This is a task of particular significance in the process of qualitative analysis since the categories contain the very substance of the investigation (Berelson, 1952). The core idea behind the present research is that metacognitive instruction can prolong durability of pupils’ conceptions and enhance ability to utilise these conceptions by facilitating deeper understanding. Characteristics of deeper understanding move beyond the mere listing of facts to demonstrating ability to elaborate on one’s responses, offer appropriate examples, apply knowledge to solve problems or to predict potential outcomes, revise wrong responses and contrast different options or
potential solutions. Based on these assumptions the following focal points were devised by this researcher, on which pupils’ responses were judged. The descriptive list accompanying each category sets the range of behaviour included in each case.

1. Declarative ability
   Answering factual questions correctly; using appropriate terminology; associating correct terms to phenomena or their characteristics.

2. Ability to use or apply knowledge
   Solving hypothetical problems with or without pictorial representation; predicting outcomes of simple experimental arrangements; relating knowledge to applications from everyday life.

3. Solidarity of knowledge
   Showing signs of confidence or uncertainty in one’s responses; changing (or insisting on) initial reply when challenged; showing persistence of certain ideas for explaining a number of phenomena; recurring use of the same ideas over the three interviews.

4. Ability to elaborate on one’s own responses or ideas
   Explaining thoroughly one’s response; justifying responses by means of science knowledge; illustrating with appropriate examples or analogies.

5. Ability to reflect on one’s knowledge
   Reconsidering wrong response; showing consciousness of the purpose of one’s learning; exhibiting awareness of the meaning of terms used.

As reported in the preceding chapter, sixteen pupils were interviewed three times over a ten-month period, resulting in a total of forty-eight interviews. Each interview was approximately twenty-five minutes long and took place immediately after the pupils had taken the written test. After transcribing and translating the interviews from Greek to English the tapes were played again by this researcher and the recorded content was compared to the transcripts that were initially produced. This was a step considered necessary in order to fill in any details that might have been omitted during initial transcription and for establishing fairness in the process of transcribing in view of the considerable time interval between them. In other words, this was a safety mechanism verifying that the criteria and utterances used to depict interviewees’ answers and reactions were consistently applied in the three rounds of interviews, as well as for both comparative and experimental groups. This was followed by a further round of reading of the transcripts in order to identify repeating patterns, striking or less so similarities or differences in performance, and other points that might be of interest for further elaboration.

Before concluding this section it is important to refer to a problem that was encountered
during the process of judging pupils' responses or reactions, namely the interpretation of non-verbal elements. This researcher was particularly interested to know whether the experimental approach implemented had an impact on pupils' confidence over their knowledge, since such a characteristic is an important virtue of well-founded learning. The difficulty, however, was in judging whether a pupil who, say, took some time before s/he replied was unsure and unconfident about his/her response, or whether that silent interval was a sign of his/her effort to reflect back on his learning and retrieve the answer in a metacognitive manner. Similarly a pupil who was eager to give an answer could be showing signs of high confidence as a result of the solid knowledge s/he had constructed, yet this could equally be attributed to his/her impulsive character or his/her immaturity. In spite of the problematic nature of the task, and due to the belief that non-verbal elements are not simply important, rather they form an indispensable part of any interview, this researcher decided to include such information in the qualitative dimension of the analysis. By placing these elements within the wider context of the interview and seen in relation to the content of the pupil's responses, it is believed that the interpretation made by this researcher is very close to reality.

These general remarks set the background to the analysis of interview-generated data, which moves on two levels.

On the first level a holistic approach is employed by means of a narrative description of overall impressions from the interviews, as interpreted by this writer. Supporting extracts are offered and in some cases an attempt to quantify the information collected is made. This is done in order to present an additional source of information summarising certain aspects of the interviews, and to provide the reader with some 'concrete' means of comparing the performance of children from different groups.

On the second level a more detailed analysis follows focusing on the cases of four children, one from each of the four classes. Although these interviews are treated as case-studies in their own right, effort was put into choosing pupils with convergent scores at the cognitive development test administered during the early stages of this research, in order to facilitate some comparisons between these pupils in discussing the outcomes of the study. In sum, the remaining of this chapter is structured as follows:

PART A - First order qualitative analysis comprising a generic report on the interviews with selective comparisons between comparative and experimental group, and the highlighting of emerging points of interest.

PART B – Second order qualitative analysis comprising a detailed presentation of four case studies and the discussion of several aspects of pupils' performance.
6.B.2. First-order qualitative analysis report — Broad perspective of the data

Having to report on the basis of information collected through 48 interviews occupying more than 150 pages of transcribed conversation is a task that is not only bound to be highly selective but also in need of substantial organisation of the data. In order, therefore, to make this first part of qualitative analysis more systematic, this is structured in the form of a set of brief sections on various key-aspects of the interviews. In each case a summarising description of the specific characteristic or aspect of learning under study is given, accompanied by representative extracts from the interviews. At the end of each section comments are made with respect to the performance of pupils from the experimental group against that of their counterparts from the comparative group.

**Factual knowledge**

Children’s ability to report factual knowledge was high for both comparative and experimental group. This researcher was pleasantly surprised during the second and third round of interviews to discover that the amount of information and details retained by most of the pupils was higher than initially expected. The majority of the pupils gave definite replies and only very few questions received the ‘I don’t know’ response. They could remember numerous terms used during teaching of the subject unit on electricity, and most of them could make correct associations between the terms they were using and the corresponding phenomena or characteristics.

Table 6.12 offers five examples of pupils’ performance in reporting factual knowledge during the first interview. As suggested by the examples presented, a slight difference in performance was demonstrated in favour of the experimental group. The extent of this difference was already presented in the quantitative part of the analysis, hence no further elaboration is attempted here. Of particular interest at this point is the fact that difference could rather be traced in the type of knowledge retained. ‘Basic’ knowledge on electricity, such as open-closed circuits; conductors-insulators and burnt-out light bulbs, proved far more durable than more ‘sophisticated’ or complex applications such as the case of short-circuits and fuses inside plugs.
Examples of pupils' factual knowledge during the first interview

<table>
<thead>
<tr>
<th>Knowledge tested</th>
<th>Small class</th>
<th>Big class</th>
</tr>
</thead>
<tbody>
<tr>
<td>What happens in an open v closed circuit?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Why does a burnt-out light bulb not glow?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>What is the role of the battery?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>What happens to current in a short-circuit?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>How does a fuse operate?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6.12

The longitudinal nature of this research and the repeated interviewing of pupils also enabled the examination of how consistent their understanding was, based on their responses to the same questions over the three interviews. The fact that a great amount of factual knowledge was retained over the period of this research is by itself a first indication that knowledge initially reported in the first interview proved consistent enough to reappear in the two follow-ups.

Most pupils from both groups exhibited similar levels of consistency when comparing their expressed views over the three rounds of interviews. The same consistency characterised both correct and alternative explanations to the phenomena studied. Indicative of this is the fact that only in two cases did pupils report a scientific conception during the first interview to be replaced by an alternative explanatory framework in the third interview. In all other cases where some inconsistency was noted, these were cases of pupils either not remembering or offering partial repetition of their initial response, rather than cases of replacing one theory by another.
Extent of pupils' ability to elaborate on their responses

Asking pupils to elaborate on their responses was a central requirement for most of the questions raised during the interviews. Their performance in this respect varied considerably ranging from full and detailed explanations to vague and imprecise attempts to justify one's answer. In some cases although the pupils seemed to be holding theoretical knowledge, and in spite of applying part of it correctly, they failed to give a full explanation of the phenomenon. Aggela's case offers a good example of such behaviour: (I: interviewer, S: student / Figures referred to in the extracts can be found in Appendix III).

**I** - What about the case shown in figure 4. Light bulb B is burnt-out whereas bulbs A and C are good. What will happen when I connect the wires as shown?

**S** - Bulbs A and C will glow simultaneously, whereas bulb B will not.

**I** - Well, let's try this out and see. This is light bulb A, this is C, and this is the one that is burnt-out, ok? (Performing the experiment). What do you observe?

**S** - They are not glowing

**I** - None of them? Why is that? How can you explain this?

**S** - ... (No response)

**I** - The batteries I am using are good, the wires are properly connected, so what's the problem...? I understand the fact that bulb B is not glowing, but what about A and C which are good bulbs...?

**S** - ... (No response)

**I** - When I connect the wires, is the circuit open or closed?

**S** - It's open

**I** - Why? I am sure that all the wires make contact.

**S** - Light bulb B is burnt-out...

**I** - How does this affect the circuit?

**S** - It doesn't let electrons pass

**I** - So the circuit is...?

**S** - Open

(aggela, Phase 3)

Others, on the other hand, appeared to hold more solid knowledge like the case of Andri who was explaining how electrons move in a closed circuit:

**S** - Electrons don't start moving one at a time... they all start moving together...

**I** - Can you explain this a bit more? Maybe you can give me an example that will help me understand...

**S** - When we connect a light bulb to the battery, with wires... the battery pushes them, but it's not just one electron that goes... they all move together.

**I** - Do you remember a couple of examples I used in class that resemble the way electrons move, and help us remembering this?

**S** - Yes, the bicycle chain and the chairs that people sit on and go skiing.

**I** - Why don't you choose one of this examples, and explain it to me a bit further?

**S** - Electrons are like the bicycle chain because the whole chain moves... it doesn't move one at a time (the links)...

**I** - So, the moment one link of the chain starts moving...?

**S** - All of them start moving.

(Andri, Phase 2)
Cases of mixed theories and confusion were also evident. Confronted with the same problem of a burnt-out light bulb connected in series with two good light bulbs, Katia predicted that:

\[ S \text{- Possibly all of them will 'burn', but again they may not.} \]
\[ I \text{- This depends on what?} \]
\[ S \text{- It depends on... the fuse... all of them will possibly 'burn'.} \]

(Katia, Phase 2)

In sum, a number of pupils on occasions showed signs of limited ability to elaborate, justify, or substantiate their responses, restricting their replies to a declarative rather than explanatory level. This characterised to a greater extent the responses of pupils from the comparative group. Although in many cases pupils from the comparative group responded correctly to the interviewer's questions, when further probing in their answers was attempted they offered vague or imprecise explanations. A first important difference, therefore, between the two groups was traced in their ability to elaborate on taught material. This impression was shaped by this researcher on the grounds of qualitative rather than quantitative measures, and should therefore be considered in close relation to the detailed qualitative analysis of interviews that follows in the second part of this chapter.

Persistence of pupils' ideas and confidence over their understanding

Most of the pupils interviewed were characterised by high levels of confidence when asked to justify their responses. Even in those cases when the explanation they gave was wrong, they did so in a 'convincing' way portraying their own theory or explanatory framework, something that verifies fully the 'alternative framework' literature (e.g. Gilbert and Watts, 1983; Driver et al., 1994b). In some cases, when the interviewer probed into the question further with examples and clarifying remarks, pupils were able to revise their initial response towards the correct answer.

On a number of occasions children's responses were challenged by this researcher in order to test how confident they were about their knowledge, irrespective of whether this was correct or not. Once again their reaction varied considerably. On one hand were cases of reported knowledge proving to be temporary and superficial, as suggested in the following example:

\[ I \text{- Let's look at figure 4. Light bulb B is burnt-out whereas light bulbs A and C are good. What will happen when I connect the wires as shown?} \]
\[ S \text{- There will be no current at B, but neither the others will glow. (Initial response)} \]
\[ I \text{- Why? After all bulbs A and C are both good. (Challenge)} \]
\[ S \text{- Only bulb A will glow. (Changed response)} \]
\[ I \text{- Will light bulb A glow? Why?} \]
\[ S \text{- Because the current goes to A first... and in B the current is 'cut'. (Wrong explanation)} \]

(Pieris, Phase 1)
The reader is reminded at this stage that the scope of the interviews was not to focus on children's understanding as such, rather to examine how durable their understanding was. In cases, therefore, where pupils' responses were wrong no particular effort was made to elaborate on the underpinning alternative theory held by the pupils, for such a dimension was not among the objectives of this study.

Clearly contrasting the above case of uncertainty caused by questioning the pupil's initial response, is the case of Michael who was faced with exactly the same question:

- S - None of them will glow. (Initial response)
- I - Why? After all light bulbs A and C are good. (Challenge)
- S - Because bulb B will prevent electrons reaching the others, because they won't be able to pass through B. (Justification of initial response)
- I - You mean that electrons will come up to a point and then stop? (Further challenge)
- S - No they will stay right where they are, because the battery will not push them at all (Insistence on initial response)

(Michael, Phase 1)

In general, cases of pupils confidently insisting on a correct response were more a feature of the experimental group than was the case with pupils from the comparative group. Seen in relation to what was previously reported with respect to children from the experimental group demonstrating greater ability to elaborate on, or justify, their responses is suggestive of a connection between the two. In other words, the fact that pupils from the experimental group gave signs of greater confidence over their learning, by insisting on their responses when these were challenged, can be attributed to deeper understanding of taught material as demonstrated by their ability to talk about and explain in greater detail aspects of that knowledge.

**Pupils' consciousness regarding the purpose of their learning**

Although teaching children how to be metacognitive was repeatedly denied a place among the primary objectives of this research, investigating the extent to which pupils were conscious of their learning and its purpose was considered important as a feature of pupils' understanding.

Demonstrating consciousness of the purpose of their learning was another dimension on which pupils of the experimental group clearly outperformed their counterparts of the comparative group. Responses of the latter were usually vague and imprecise in need of substantial guidance for the researcher before pinpointing the usefulness of their knowledge, like, for instance, in the case of learning about conductors and insulators:

- I - Why do you think we have to know about conductors and insulators? Is it of any use to us?
S-Yes
I-Why?
S-To know how the light bulb glows... in what way it glows...
I-Why...? Couldn't you turn on a light bulb before you learned about conductors and insulators?
S-Yes
I-Well, in that case why did we have to learn all these things?
S-So that we know... (Silence)
(Petros, Phase 3)

Pupils from the experimental group, on the other hand, appeared to be more conscious of the purpose and use of their learning. The following extract is taken from an interview with a pupil from the small experimental class who was confronted with the same question, while Table 6.13 presents an indicative summary of pupils' responses in Phase 1.

S-Yes because it is dangerous to... for example, if someone with wet hands tries to switch off the light... because humans are conductors... he will die... Electrons will pass through him and he will die.
I-So now that we have learned all these things...?
S-We haven't got a problem!
I-You mean, we won't act like that, right?
S-Yes.
I-So, we've learned these things for...?
S-For our own safety!
(Andri, Phase 2)

Children's responses to the question 'Why do you think we have to know about conductors and insulators?' – Phase 1

<table>
<thead>
<tr>
<th>Response</th>
<th>Comparative</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Correct following interviewer's prompts</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Partial / unfocused</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Wrong / unable to answer</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 6.13

It is a strong view of this researcher that awareness of the purpose of one's learning is important in the sense that it shows ability on behalf of the learner to visualise potential use of his/her knowledge. As such it is also a measure of purposeful learning whereby one's understanding is related to its application – preferably in real life situations. In this respect, purposeful learning appears to have been achieved to greater extent by pupils who received metacognitive instruction during teaching.
Problems supported by pictorial representation and the Predict-Observe-Explain approach.

In the case of questions accompanied by pictorial representations pupils responded more positively and more confidently compared to their responses to questions without any visual aids. The fact that the figures used applied the same conventions as the ones used during the teaching of the subject-unit contributed to the problem-free use of this material. Most pupils would spend some time studying the arrangement drawn, and in giving their answers they would usually point on the drawing, taking the interviewer through their response.

In the last round of interviews the interviewer made use of the Predict-Observe-Explain approach (e.g. White and Gunstone, 1992) using simple electrical apparatus as explained in the methodology chapter (Chapter 5). In those cases where a correct prediction was made followed by its experimental verification, this acted as a boost of confidence for the pupil usually leading to correct explanation of what was being observed. In one such case, for instance, Christodoulos, a pupil from the big experimental class, explained why two light bulbs in a closed circuit glow simultaneously:

'When one electron moves, they all move together, and after bulb A there were more electrons, and when the first one moved, all electrons pushed the electrons that were after bulb A and they went to bulb B, and they glow they same time'.

(Christodoulos, Phase 3)

On the other hand, for those questions where a wrong prediction was made, children seemed to be far less confident in justifying the discrepancy between their initial prediction and later observation, apparently because of the fact that they were confronted with evidence disproving their views. Nevertheless, in most cases attempts were made to explain and resolve such conflicting situations. The extent to which such attempts were successful varied considerably. In the following extract Katia is reconsidering her views following a wrong prediction:

I -What about the case shown in figure 4. Light bulb B is burnt-out whereas bulbs A and C are good. What will happen when I connect the wires as shown?
S -Two of them may glow and the other one may not
I -So, in figure 4... are you saying that bulbs A and C will glow?
S -Yes
I -And bulb B which is burnt-out will not?
S -No it won't
I -Well, let's try this out. This is bulb A, this is C, and this is the one that is burnt-out, ok? (Performing the experiment). What do you observe?
S -None of them is glowing
I -How can you explain this?
S -Electrons don't pass through the bulbs because there is a problem with one of the bulbs.
I - Yes, but what about A and C? Why don't they glow since there is nothing wrong with them?
S - ... Because electrons... (silence)
I - I think you were right in saying that electrons don't pass through the bulbs... if they were passing through the light bulbs, how would we be able to tell?
S - Because the bulbs would glow then
I - Very good! So the first correct conclusion is that electrons are passing neither from A nor C. In what type of circuit electrons don't move?
S - In an open circuit.
I - So what can you say about this case?
S - That they don't glow because the circuit is open... and we have to change the bulb.
I - Which bulb?
S - Bulb B
I - So, can you show me where exactly the circuit is open?
S - Here
I - That's right! Inside bulb B.

(Katia, Phase 3)

The above extract is also a good example of how this researcher used the Socratic approach known as 'maieftiki' to help pupils retrieve knowledge that they were holding, rather than simply accepting what was possibly a hasty wrong response.

Pupils from the experimental group maintained slightly better performance in making use of their knowledge in problems with a pictorial representation (in the first two interviews) and simple experiments (in the third interview), as shown in Table 6.14 that offers a summary of the third round of interviews. Notably greater difference between the two groups was evident in children's attempts to explain observed outcomes rather than in making predictions before conducting the experiments.

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>No of P.O.E. instances</td>
</tr>
<tr>
<td>Comparative</td>
<td>40</td>
</tr>
<tr>
<td>Experimental</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 6.14

Use of analogies
Children's responses to questions regarding analogies used during the teaching of the subject-unit on electricity highlighted the importance of using such analogies and the extent to which these examples are imprinted in children's minds. Most children remembered the two main analogies used for depicting the flow of electrons, namely the 'ski-lift analogy' and the 'chain...
analogy' (Georghiades, 1999b):

I -Do you remember talking about the way electrons move...?
S -Yes, we said that they all start moving together, at the same time.
I -Can you explain this a little more, and perhaps give me a couple of examples that describe this movement?
S -Yes, they are just like the bicycle chain, where all the links start moving together, and like those seat-lifts for skiers, which go up and then come down.
(Michael, Phase 1)

Other analogies mentioned by the pupils were the 'rising bridge analogy' (representing the way a switch operates) and the 'race-track analogy' (depicting how electrons in a short-circuit take a low-resistance path to the battery or the socket, just like a driver on a race-track would choose the easiest route to win the race). Although most pupils referred to the analogies and were able to describe broadly common dimensions between the analogy and the phenomenon under study, they found it difficult to make relationships explicit when asked for further details.

Superficial understanding of analogies was also evident in some cases where pupils reported the analogies and their links to the phenomena, but in practice applied other explanatory frameworks when confronted with a problem requiring the specific piece of knowledge covered by the analogies. In one case, for instance, although the pupil referred to the ski-lift analogy in describing how electrons move in a closed circuit, he also repeatedly mentioned that 'electrons move very fast'. Later, once his prediction of two light bulbs in a closed circuit glowing simultaneously was verified, he explained that 'they both glow... because electrons move so fast' (Christos, Phase 3).

It can, therefore, be concluded that although analogies were helpful in representing scientific phenomena and were held in children's memories over long periods, reproduction of the analogies by the pupils and detailed explanation of the links between the analogy and the original phenomenon was not an easy task. In most cases this attempt was covered in vagueness while the risk of reinforcing alternative frameworks was also evident.

Pupils from both comparative and experimental group referred to analogies to equal extent. Difference in their performance could be spotted in a slight superiority of pupils of the experimental group in explaining links between the analogy and the original phenomenon, therefore demonstrating understanding of the analogies in greater depth.

Use of anthropomorphic images
On numerous occasions pupils' responses entailed strong anthropomorphic images,
attributing characteristics such as expressing thoughts, preference and intention for action to key-aspects of electricity:

*I - When I connect the wires as shown, what will happen?
*S - It won’t glow.
*I - Which one?
*S - None of them will glow.
*I - Why? After all light bulbs A and C are good.
*S - The battery will think that since the circuit is open inside one of the bulbs, why send (electrons) to the other bulbs?...
*I - So it won’t send any electrons at all?
*S - ... No, it won’t.
(Stavros, Phase 2)

This was a recurring theme in the three rounds of interviews, irrespective of group and for different concepts. In the following extract it is electrons that come to life:

*I - If I connect a burnt-out light bulb to a battery, will the bulb glow?
*S - No
*I - Why? What is the problem with that bulb?
*S - Because electrons are not athletes who can jump over the filament...
(Theodoros, Phase 2)

Other examples include statements such as ‘the battery knows’; ‘electrons know’; ‘electrons would fall down’; ‘when the fuse realises that...’ and ‘the battery is smart’. The apparent reason for the appearance of anthropomorphic images is the fact that this researcher made use of them during the teaching of the subject-unit. This was thought necessary because of the complex and mostly abstract nature of the concepts under study. In order therefore to help children relate to what was studied in a more accessible, memorable and enjoyable way a number of such metaphors were used. In the absence of essential scientific background knowledge (e.g. charge, repulsion etc) and in view of the mental limitations of children of this age to visualise all processes related to electricity, use of anthropomorphic metaphors by the pupils in their attempt to explain the phenomena is thought by this researcher to provide evidence of pupils’ understanding in a manner that is no less valid than other explanations depending more heavily on scientific terminology. In other words, in those cases where a naïve anthropomorphic explanation was used to represent (or used in agreement with) scientifically correct versions of the phenomena, such a response was classified among the positive features of a pupil’s interview.

No particular difference with respect to frequency of such features of the language was traced between the two groups. Difference was found in the fact that although pupils from the experimental group used such metaphors in parallel to scientific descriptions of the phenomena or the correct application of different aspects of them, the majority of their counterparts from the comparative group seemed to use them as the sole explanation to the
phenomenon. In other words responses of the latter indicated that for them the metaphor was the explanation they were looking for, hence showing some superficiality in their understanding.

Impact of the Greek language

An important and very common feature of children's responses during the interviews, were signs of the Greek language having a strong impact as explained in Chapter 5. In all cases this impact had a negative outcome acting as an impediment to pupils' understanding of important dimensions of the concept of electricity. The most common case was that of a short-circuit related to water mainly due to the sound of the Greek term 'vrahikikloma'. The fact that water was named during teaching as one of the causes of short-circuit apparently contributed to intensifying the problem. The following extract is characteristic of pupils' tendency to make such a connection.

I - When does a short-circuit happen?
S - When, let's say, there is a socket...
I - Yes...?
S - And next to it there is... water... like a wash basin, and water drips on it... then it will... short-circuit, and the electron will find a shorter way to...
I - To go where?
S - To go to the television or to the fridge... it will make fast movement, and current will become very fast, and there may be fire...
I - Oh I see! We'll come to that in a moment. Where does the name 'vrahikikloma' (short-circuit) come from?
S - From 'wet'...
(Christos, Phase 2)

Table 6.15 gives a summary of pupils' responses to questions over the meaning of the Greek terms for 'short-circuit' ('vrahikikloma') and 'switch' ('diakoptis') during the second interview.

Pupils' responses over the meaning of the terms 'short-circuit' and 'switch' – Second interview

<table>
<thead>
<tr>
<th>Term</th>
<th>Class</th>
<th>Small</th>
<th>Big</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comparative</td>
<td>Experimental</td>
<td>Comparative</td>
</tr>
<tr>
<td>'SWITCH'</td>
<td>Number of pupils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>'SHORT CIRCUIT'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Incomplete/Partly correct</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Wrong answer</td>
<td>4</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 6.15
Other cases of similar interaction of the Greek language were the ones of ‘opening’ and ‘closing’ the switch (described in Chapter 5) and the generic use of the term ‘iron’ to denote all different kinds of metals. Notably, the majority of the pupils from both groups interchangeably referred to materials and objects when asked by this researcher to name some conductors and insulators.

In sum, the impact of the Greek language proved to be of crucial importance for pupils’ understanding irrespective of group from which they originated. In all the cases where it was evident, such impact acted in the direction of strengthening resistance to changing their initial theories on a number of phenomena associated to electricity. The results show that problems with the Greek language were less severe for pupils of the experimental group. This could suggest that the offering of metacognitive instruction during teaching helped the pupils in becoming more conscious of the meaning of terms they were using, hence overcoming potential confusion.

A last point to make in relation to the first-order analysis of the interviews is that, contrary to what the reader may have expected, the preceding discussion is held in the absence of any numerical data from the interviews that could depict the frequency or the extent of children’s metacognitive thinking. This is so because measuring pupils’ metacognitive engagement was not among the objectives of this research nor were the interviews intended to provide such evidence. As was discussed in earlier chapters of the thesis, the experimental approach employed by this researcher did not attempt to teach children how to be metacognitive, not least because such an undertaking would be highly questionable in view of the short exposure of the children to metacognitive stimuli. The scope was solely to achieve an impact on their understanding of concepts of electricity at the time of teaching and it is their understanding of these concepts that is the object of interest in the interviews, rather than their metacognitive thinking. Any identification of metacognitive elements in the responses of children from the experimental group should therefore not be taken as an attempt to demonstrate that these children were more metacognitive during the interviews, rather they are impressions that were thought by this researcher worth noting. It is under this reasoning that no quantitative data such as numerical counts of metacognitive behaviour are presented.

This concludes the first-order analysis of interview-generated data. The next section presents the results of the second-order analysis.
With the categories presented earlier in this chapter acting as focal points for analysis, interviews of four pupils—one from each class—are examined in the form of case studies. Selection of these pupils was based on their scores in the cognitive development test administered at the beginning of this research, in order to include pupils with seemingly similar abilities and allow some comparisons to be made in discussing the outcomes of the analysis. Best and worst performers were excluded in order to avoid artificiality of the outcomes.

The bulk of the discussion is based on the last interview taken from each pupil (i.e. the third round of interviews conducted at the end of the school year). This was a choice based on the fact that the last round of interviews proved to be the most detailed and consequently the most revealing, since both researcher and children acquired considerable experience during the two preceding rounds. Choosing to focus on the last set of interviews was also determined by the fact that this offered the latest snapshot of pupils’ content knowledge and understanding, hence indicating how durable learning eventually proved over the period of one school year.

A detailed presentation of each participant’s interview is made in each case along with extensive extracts. Comments are made on different aspects of the interviews and comparisons are attempted with relevance to the same pupil’s responses in preceding interviews, noting both cases of consistency and considerable divergence.

Comparisons with respect to the group from which the four interviewees originate are left for the proceeding chapter that deals with the discussion of the outcomes of the analysis. The reader, however, is urged to bear in mind that the four cases presented cannot be directly compared, for interviewees may significantly differ on a number of characteristics that may have considerably affected their performance. Such comparisons should be treated as being merely suggestive of difference in performance between pupils from different groups.

The four cases to be analysed are the ones listed below:
Case 1 – Olga - Big comparative class
Case 2 – Christodoulos - Big experimental class
Case 3 – Petros - Small comparative class
Case 4 – Michael - Small experimental class
CASE 1 OLGA – Big Comparative Class

Olga’s ability to report factual knowledge was generally high. She could list, for example, characteristics of open and closed circuits, she could name conductors and insulators and describe how a switch is made and how it works. Some difficulty was traced in talking about more complex applications such as a fuse. In the three interviews Olga could not explain how a fuse operates or what purpose it serves, her attempts being characterised by vagueness and some confusion of the fuse with the notion of a switch.

The distinctive feature of Olga’s responses during the first interview was the fact that her explanations relied heavily on naïve anthropomorphic associations. The following extract is representative of such tendency:

I - When I connect a burnt-out light bulb to a circuit, like the one shown here, does the light bulb glow?
S - No.
I - Why? What’s the problem?
S - Because light bulbs have a wire inside (filament) and when we say that it is ‘burnt-out’ it means that, that wire was cut in the middle and electrons would fall down if the battery kept moving them.
I - Is the circuit open or closed?
S - It’s open.
I - What about the case in figure 10? Light bulb B is burnt-out whereas bulbs A and C are good. What will happen when I connect the wires as shown?
S - None of them will glow.
I - Why? After all bulbs A and C are both good.
S - Because electrons would fall down... the circuit is open...
I - Do electrons move in an open circuit?
S - No
I - Then how will they ‘fall down’?
S - They will go from the negative terminal... they will proceed to bulb C... then they will go to bulb B and when they proceed into the bulb they will fall inside.
(Phase 1, p.43)

In the follow-up interviews Olga retained the same naïve image of electrons ‘falling down’ in the event of moving in an open circuit, in spite of simultaneously using correct terminology and describing characteristics of such a circuit.

With respect to the concept of electron flow Olga’s responses varied in the three interviews. Explaining the simultaneous glow of two light bulbs in a closed circuit, in the second interview Olga said that:

‘Because electrons are throughout the wire... they are not just at one place... so when one starts, the others start too, so they all move together and they (light bulbs) glow... ’ (Phase 2, p.47)

Looking at the case of three light bulbs connected in series, one of which was burnt-out, she predicted correctly that none of the bulbs would glow and explained with reference to
electrons that:

'they won't proceed... to pass through bulb C and then go to bulb A and stop there'  
(...) 'they will stop completely' (Phase 2, p.49)

These two responses come in contrast to Olga's view of electron flow expressed during the first and third interview that entailed signs of a sequential concept of current. For example, when confronted with the same problem with the three light bulbs, she suggested that:

'They (electrons) will go from the negative terminal... they will proceed to light bulb C... then they will go to bulb B and when they proceed into the (burnt-out) bulb they will fall inside'. (Phase 1, p.43)

Olga's view of electrons and current was therefore characterised by some inconsistency, interchangeably using the scientific and a sequential model (Driver et al., 1994b) of the concept. Notably Olga reported the 'clashing currents' model (Osborne and Freyberg, 1985) prior to teaching. It can hence be concluded that although teaching resulted in changing Olga's initial alternative framework, this did not lead to the adoption of the scientific version of the concept, rather a sequential alternative.

Trying to describe the relation between electrons and the battery in a closed circuit, she repeatedly referred to the concept of energy indicating an attempt to link previously held knowledge with new constructs:

I -What's the role of the battery?  
S -It pushes electrons, and it gives energy in order to move  
(Phase 3, p.44)

I -Can you describe the way electrons move?  
S -Electrons are all inside the battery and the wires and when we connect the battery and the wires, the battery gives energy and they all move together.  
(Phase 3, p.44)

When it came to terms such as 'diakoptis' (switch) and 'vrahikikloma' (short-circuit) Olga could not give a correct explanation of the former -confusing it with a fuse- and said that she could not remember the latter. In spite of not being aware of the meaning of such terms, she seemed conscious of the purpose of her learning. She could explain, for example, that knowing about conductors and insulators is important for our safety and showed ability to relate everyday experience -such as the case of a burnt-out lamp- to her science knowledge:

I -Does a burnt-out light bulb glow?  
S -No  
I -Why? What's wrong with a burnt-out bulb?  
S -Because the filament inside the bulb... when it is burnt it is the same as when the circuit is open.  
I -I see. So... when the filament breaks, does the circuit open?  
S -Yes because electrons can't pass through.  
(Phase 3, p.45)
On a number of occasions Olga showed ability to use her science knowledge to justify her responses:

*I* -If I connect a light bulb to a battery, with a couple of wires, what will happen to the bulb?
*S* -The bulb will glow.
*I* -Are you sure?
*S* -As long as the circuit is not open, and the bulb is not burnt-out!

(Phase 3, p.43)

Showing awareness of practical aspects of her knowledge, in all three interviews she stressed the need for connecting the wires in a circuit correctly, therefore drawing from her class experience of conducting experiments.

Olga’s predictions were mostly correct. On a number of occasions, however, when her prediction was challenged by the interviewer she could not justify her choice. The concept of a short-circuit, that proved highly problematic for Olga was one such case. She made a wrong prediction when asked to chose from three potential cases of short-circuit and she could not justify her choice. She eventually changed her initial prediction and she was then able to explain what really happens:

*I* -Figure 5 shows three circuits, circuit A, B and C. Can you tell me in which case will there be a short-circuit?
*S* -... (No response)
*I* -It might help to think in terms of electrons... What will they do in each case...?
*S* -... In case C (Wrong prediction)
*I* -Why is that? Can you show me how will they move?
*S* -Electrons will pass from the negative terminal, then here and ... (silence)
*I* -They won’t pass through the light bulb?
*S* -No.
*I* -Why?
*S* -Because there is a wire... that is a little... (silence)
*I* -Well, let’s try this out. Here is the wire coming over the light bulb... like that... and I will connect the light bulb to the battery. (Experiment) What happened?
*S* -The bulb glows.
*I* -When the bulb glows, is it a short-circuit?
*S* -No
*I* -So, it doesn’t matter really if the wire is a bit bent over the lamp. Why don’t you take a look at the other two, and check if there will be a short-circuit...
*S* -In B.
*I* -Let’s try this out. Can you help me a little bit with this one? I will make the connection with the battery, and I want you to cause the short-circuit (Experiment). What do you observe?
*S* -The bulb doesn’t glow.
*I* -Why?
*S* -Because ... it prefers a shorter way.
*I* -Which is the shorter way?
*S* -The... green wire...
*I* -So, do electrons pass through the bulb?
*S* -No

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Problems with the concept of short-circuit were evident as early as the first interview when Olga's explanation of a short-circuit was vague and inaccurate.

I - Why did we say that a short-circuit can be dangerous, especially if it happens at home?
S - Because at home... current is too much... and we may... it may cause fire.
I - Why can it set fire? I mean... why is it that normally nothing happens but when we have a short-circuit there can be fire?
S - Because when it takes a different way... at the point where you connect the wires there is nothing to protect them and there will be fire.
I - Does anything happen to electric current in a short-circuit?
S - Yes it will find a shorter way... and because it will find a shorter way it will keep passing from the same way... and so most of the current will keep passing from there, and so we may get some damage.

(Phase 1, p.44)

In sum, over the three interviews Olga showed ability to offer sufficiently detailed and valid explanations of a number of phenomena associated with electricity. She maintained a marriage of scientific knowledge and naïve explanations that acted in a supportive way in her attempt to express her understanding. She showed limited awareness of the meaning of terms she was using and her factual knowledge was often confused, overlapping different phenomena or mechanisms. Some inconsistency in her reported understanding was also evident, interchangeably moving between scientific explanations and alternative frameworks, especially for the key-concept of electron flow. In some cases her responses were characterised by the persistent occurrence of constructs not taught during the teaching of the subject unit, such as the concept of energy that was used by Olga in a complementary way.

CASE 2 - CHRISTODOULOS - Big Experimental Class

Christodoulos responded to this researcher's questions with definite and in most cases correct answers. Indicative of his performance is the fact that he never gave the 'I don't know' response, nor did he leave a question unanswered. He used successfully the terminology associated with the phenomena examined and in all but one occasion he made correct predictions before the experiments. He could summarise his responses, rephrase his ideas and exhibited high levels of confidence. Only on one occasion in the first interview Christodoulos changed his initial response, when challenged by the interviewer, giving a compromising answer:

I - Does the battery create new electrons?
Moving beyond answering factual questions and plain reporting of content knowledge, Christodoulos was successful in offering good explanations of the phenomena or concepts engaged in the discussion. The following extract focuses on his explanation of how electrons move in a closed circuit:

I -Do you remember talking about the way electrons move? We said that they have a rather unusual way of moving...
S -When the circuit is open they don't move, and when the circuit is closed, they do.
I -That's right.
S -When there is a shorter way, then they take that way, and they pass very-very quickly, and then there is danger of causing a short circuit.
I -That's really very good! However, let's take one thing at a time. The moment I set up a circuit, what happens? Do we have to wait for the electrons that are down here to... (Christodoulos interrupts the interviewer)
S -No, electrons are ready and the moment the battery pushes one of them, then they all move because they are all connected.
I -Can you give me an example that might make this more clear?
S -Those things that take people who go skiing...
I -Oh the seats on a ski-lift! How are they similar to the electrons?
S -When one seat moves... the one that moves pushes the others, so they all start moving together.
I -Is it the same for electrons?
S -Yes
(Phase 3, p.65)

The apparent adoption of the scientific model of electron flow followed the use of the 'clashing currents' model (Osborne and Freyberg, 1985) by Christodoulos prior to teaching, suggesting that conceptual change indeed took place.

Christodoulos showed similar ability to elaborate in all three interviews. Another example of such ability is his explanation of a short-circuit:

'Vrahi' means short... it is an ancient word so 'vrahikikloma' means short-circuit. When a short-circuit happens, instead of electrons passing through their initial route, they find a shorter one, so they go faster, and there is danger of a spark... and there is also danger of fire'.
(Phase 3, p.67)

The above extract also shows that Christodoulos was conscious of the meaning of terms he was using, in this case for the term 'vrahikikloma' (short-circuit). Similar awareness was shown by the same pupil regarding the term 'diakoptis' (switch).
Interestingly his responses in the third interview were free from any anthropomorphic or naive explanations that were evident during the first two interviews. In the first interview, for instance, his responses involved statements such as 'the battery is smart', or 'the fuse realises that...'. During the second interview he even suggested that 'the battery orders' electrons to go to the light bulb. This change suggests that in the third interview he was able to focus purely on the scientific dimension of the phenomena, describing this in a vocabulary that did not need to rely on such metaphors or associations.

Christodoulos appeared to be conscious of the purpose of his learning. For example, when asked whether knowing about conductors and insulators is of any use to us, he responded:

'Yes, because our body is a conductor and we know that if we touch something that's got electrons inside, and it is connected to a socket, then there is danger of electrocution and die'.

(Phase 3, p.67)

He showed ability to apply his knowledge by offering explanations to phenomena associated with everyday incidents, based on his science knowledge. In the case of a burnt-out lamp at home, for instance, he explained that this does not glow because:

'Inside the bulb there is a filament through which electrons pass in order to give current to the bulb. And when that filament is open... then there is an open circuit, and electrons can't pass'.

(Phase 3, p.66)

Talking about the material used to make a switch, he explained that:

'It is made from plastic so that there is no danger... because man is a conductor and current can pass through... so he won't be 'caught' by current'.

(Phase 3, p.66)

One difficulty faced by Christodoulos was differentiating between materials and objects when asked to give examples of conductors against insulators. This was a problem encountered by most of the pupils and a problem intensified by the tendency to use the word 'iron' in a generic way referring to all sorts of different metals. In spite of this difficulty he could still explain the difference between conductors and insulators with reference to electrons:

I -Do you remember talking about conductors and insulators?
S -Yes
I -Can you name a couple of conductors?
S -Sharpener...
I -Why? What material is the sharpener made from?
S -From iron, and iron is a conductor...
I -I see.
S -And... iron!
I -Ok. Now a couple of insulators.
S -Rubber and ruler
I -Can you tell me what's the difference between conductors and insulators?
During the first interview Christodoulos gave mostly correct answers regarding the mechanisms involved in a short-circuit. However, some problems with the concept of short-circuit were evident when a causal relationship between an open circuit and short-circuit was implied in his responses. The same theme appeared in the second interview where the ‘burning-out’ of a light bulb and the subsequent breaking of a circuit were associated with the concept of a short-circuit. Interestingly his response in the third interview was identical to the one given in the second interview something that suggests that this is a strongly embedded idea for Christodoulos. This was verified by the fact that in the third interview the concept of short-circuit proved highly problematic for Christodoulos. He suggested that the light bulb continued to glow in a short-circuit and predicted wrongly when asked to choose from three cases of potential short-circuit. When prompted to rethink his choice in terms of electron motion he made the correct choice but again his explanation was characterised by some confusion as to the route taken by electrons. Only after conducting the experiment was he able to explain what really happens in a short-circuit. In follow-up questions during the third interview, his understanding of a short-circuit again appeared to be superficial. Although he reported correct factual knowledge as to the conditions and consequences of a short-circuit, his responses revealed holding wrong views of the mechanisms involved. After saying that short-circuit can be dangerous he explained that:

S - A short-circuit can happen when a wire is worn and you put water on it... if you touch it, the short-circuit will make the movement towards that ‘electronic thing’ (electrical device) that’s there, but it will also make the movement towards your body because it is a conductor and there is danger of getting hurt.

I - Do you have to be there and touch something, in order for a short-circuit to be caused? Because I heard of cases where short-circuit happened when nobody was at home.

S - It can happen when nobody is at home... when the wire is worn then the wires inside will connect and electrons will not take the route to that electronic thing, but they will continuously go to the lamp and come back through one wire.

I - Does anything happen to current in a short-circuit?

S - It stops.

(Phase 3, p.68)
to hold deep and durable understanding of all the concepts he was taught, with the exception of the concept of a short-circuit that proved problematic and was characterised by confusion and persistence of alternative explanatory frameworks.

CASE 3 – PETROS – Small Comparative Class

Although Petros gave definite responses to a number of questions his overall ability to report knowledge was not particularly high. Compared to his performance during the first two interviews this decreased even more in the third interview, suggesting that his knowledge was of rather short durability. His ability to report factual knowledge was to some extent restricted to simple aspects of electricity such as talking about open against closed circuits, which was correctly tackled in the three interviews. More complex applications, on the other hand, such as how a fuse operates, proved difficult for Petros to explain. In the second interview he made an attempt to talk about it in a vague and too general way, whereas in the first and third interview he admitted that he did not remember talking about it in class.

On a couple of occasions Petros would refer back to experiments carried out in class in order to make his claims explicit. For example, when his prediction of a light bulb glowing when connected in a closed circuit was challenged by the interviewer, he clarified that this would be the case ‘...if it is connected properly.’ Most of his responses, however, were characterised by lack of confidence and in some cases he would respond to the interviewer’s questions with a question. He made extensive use of anthropomorphic representations in his responses in the three interviews, using expressions such as ‘the battery is clever’, ‘electrons are not athletes’ or ‘electrons can’t jump’. Notably these explanations were often the only ones he could give without making any further attempt for an explanation based on his science knowledge.

Petros appeared more confident when explaining phenomena that were in some way closer to everyday experience like, for instance, talking about switches or burnt-out lamps:

```
I -What material is the switch made from?
S -Inside it is made of iron, and outside it is made of plastic.
I -So it is made of two different materials right?
S -Yes
I -Why did you say that there must be iron inside?
S -In order to operate.
I -What do you mean?
S -It operates ... because of copper... iron...
I -If there wasn’t any iron inside...?
S -It wouldn’t operate.
I -Why?
S -It needs iron, because... it is copper.
I -About the outer part... why did you say that it has to be made of plastic?
```
As shown in the above extract Petros could name the materials from which the switch is made of and justify to some extent why these materials are used in particular. At points, however, his responses were unfocused and superficial using only descriptive rather than explanatory utterances.

Problems with the explanations he was giving also appeared in the two preceding interviews, usually being of limited depth. In the first interview, for example, Petros could explain why light bulbs glow with reference to the need for a complete circuit but he could not explain why two light bulbs connected in series would glow simultaneously. On another occasion in the second interview when Petros was asked to justify his prediction that two light bulbs connected in series would glow simultaneously he replied: 'Because there is no damage anywhere that would stop them from glowing'. When the interviewer insisted with follow-up questions Petros again responded with descriptive and to some extent simplistic explanations, missing the very essence of the conversation: 'Because nobody is preventing them' (Phase 2, p.34).

In explaining the role of the battery he suggested that 'it gives energy', apparently making use of previously established constructs since no reference to the concept of energy was made during teaching. The notion of energy in relation to the operation of a battery was repeatedly used in the three interviews by Petros replicating the view he expressed on the role of the battery prior to teaching.

The concept of electrons, on the other hand, which is fundamental for understanding electricity and associated phenomena appeared to be highly problematic for Petros. He could not describe where electrons can be found nor how they move in a closed circuit:

I -How does the battery push electrons? Can you explain this a bit more?
S ... (No response)
I -We learned that electrons have a rather unusual way of moving... Do you remember this?
S ... (No response)
I -When one electron starts moving, what do the rest of them do?
S -They follow
I -Do you remember any examples we mentioned in class that were meant to help us remember how electrons move...?
S ... (No response)
I - We talked about something that can be found on the mountains ... or something about your bicycle ...
S - They choose the easy way...
(Phase 3, p.23)

From his pointing on the drawings (representing circuits) placed before him, he gave signs of abandoning the 'clashing currents' model (Osborne and Freyberg, 1985) that he used prior to teaching for explaining how a light bulb in a circuit glows, yet this did not help in identifying the exact model he adopted.

His explanation about electrons and insulators was imprecise and unfocused and he interchangeably used materials and objects when giving examples of different conductors and insulators:

I - Some time ago we also talked about conductors and insulators. Do you remember what do we call conductors and what do we call insulators?
S - Conductors ... when you stick them on the wire ... the bulb glows ...
I - Let's talk about current and electrons. Do conductors let current pass through them?
S - Yes they do.
I - What about insulators?
S - They don't
I - Can you give me a couple of examples? Two conductors first.
S - Pencil tip ... and...
I - Something that allows current to pass through it ...?
S - Copper
I - That's right. And two insulators ...?
S - Toothpick ... and ... (Silence)
I - What about plastic ... can current pass through it?
S - No
I - Why is it that conductors let current pass, whereas insulators don't? How can we explain this difference?
S - They have something like iron ... like copper ... and they let electrons pass through them, whereas insulators don't because they are like plastics ...
I - Something else about electrons ...?
S - ... (No response)
(Phase 3, p.23)

This was a theme that previously appeared in the two preceding interviews. In the first interview Petros exhibited some confusion relating the term 'conductors' with characteristics of insulators, and in the second interview he suggested that conductors '...are made of iron ... whereas insulators are made of wood ... and other ... wood, plastic ... ' (Phase 2, p.36).

Asking Petros about conductors and insulators also revealed his difficulty to explain the purpose of his learning.

I - Why do you think we have to know about conductors and insulators? Is it of any use to us?
S - Yes
I - Why?
S - To know how the light bulb glows... in what way it glows...
I - Why...? Couldn't you turn on a light bulb before learning about conductors and insulators?
S - Yes
I - Well in that case why did we have to learn all these things?
S - So that we know... (Silence)
I - For example, if I ask you to take an iron rod and insert it into a socket, will you do it?
S - No
I - Why?
S - Because I will be electrocuted.
I - How do you know?
S - Because it is made of iron... and if I put it into the socket I will be electrocuted
I - So by knowing these things, what can we do?
S - ... (No response)
I - We've learned about conductors and insulators, for our own...?
S - Life
(Phase 3, p.26)

Petros could describe the conditions for a short-circuit to happen and its consequences. He related the term 'wrahikiloma' (short-circuit) to water or 'something wet' and he was not able to explain what happens to current in a short-circuit. In the first interview, for example, he said that current 'turns off' in a short-circuit. In the third interview his response was far more unfocused:

I - Can a short-circuit be dangerous?
S - Sometimes
I - Why 'sometimes'?
S - ... (No response)
I - What can happen in a short-circuit?
S - A small explosion...
I - A small explosion! Recently I heard on the radio that some houses were damaged after a short-circuit...
S - They caught fire!
I - Oh, you heard that too?
S - Yes
I - Why is it that a house can catch fire after a short-circuit? What is it that causes the fire?
S - ... Current...
I - Does current usually cause fire? For example, why doesn't it cause fire, now that the photocopying machine is working, whereas it causes fire in a short-circuit? Does anything happen to current in a short-circuit?
S - ... The cover could be cut.
I - The wire's plastic cover?
S - Yes
I - Well, alright. The plastic cover, was removed, the wires made contact, and a short-circuit took place. The moment that the short-circuit takes place, does anything happen to electric current? Does anything change?
S - ... Short-circuit...
(Phase 3, p.27)
In general Petros's interviews revealed some superficiality in his understanding. Albeit being able to report correctly on substantial amounts of content knowledge when further probing in his responses was attempted he often failed to offer valid explanations. In doing so, he would usually re-describe components of the phenomenon rather than move beyond description to highlighting links or relationships. On a number of occasions he made use of conflicting ideas, or applied one theory in his attempt to solve a given problem although minutes earlier he reported a different theory related to the core of the problem at hand. The concepts of electron flow and short-circuit proved problematic for Petros who further showed weakness in describing the meaning of terms he was using and the purpose of his learning.

CASE 4 – MICHAEL – Small Experimental Class
Michael demonstrated high levels of understanding and ability to report taught knowledge. He answered this researcher's questions with ease and confidence, appearing to hold clear ideas regarding the concepts associated with electricity. He made correct predictions and was able to justify his choices. Only in a couple of cases, especially in the third interview, his responses were rather unfocused in need of guidance from the interviewer. However, even in these cases Michael was able to build on the researcher's hints in a manner that eventually revealed knowledge that he already held.

He showed high levels of declarative knowledge in all three interviews and for nearly all questions asked. He could explain, for example, what happens in closed and open circuits, why a burnt-out light bulb does not glow, and the difference between conductors and insulators. Michael demonstrated similar ability to explain more complex applications. The following extract, for instance, presents his explanation of how a fuse works:

\[ S - \text{Inside that fuse, there is a small wire... a very thin piece of wire, and when there is a short-circuit and more current than normal passes through, that wire will cut and so there won't be a short-circuit...} \]
\[ I - \text{What will happen to the circuit?} \]
\[ S - \text{It will open.} \]

(Phase 3, p.3)

Michael could also relate his explanation of how a fuse operates to experiments conducted in class. He mentioned, for example, an experiment during which a piece of wire-wool burned when the circuit was shorted, pointing out that this is exactly how a fuse acts. Interestingly Michael could make such a connection even if the interviewer’s question was initially addressing short-circuits. He hence demonstrated that he was holding clear-cut concepts of the phenomena studied in a way that allowed the overlapping of ideas without any confusion.
Michael appeared to be conscious of why certain terms are used (e.g. ‘*diakoptis*’, ‘*vrahikikloma*’) and of the purpose of his learning. For example, in explaining why learning about conductors and insulators is useful he said that this is so ‘*in order to avoid danger*’. He could also refer to examples or analogies used in class and explain in sufficient detail what he meant. When talking about the way electrons move in a closed circuit, for instance, he explained that:

‘...they are just like the bicycle chain, where all the links start moving together... and like those seat-lifts for skiers which go up and then come down.’

(Phase 1, p.1)

His responses to questions on the key-concept of electron flow were consistently correct in the three interviews, showing ability to apply his understanding to explain associated phenomena. Explaining, for example, the simultaneous glow of two light bulbs connected in series, he pointed out that ‘*electrons are inside the whole wire*’ (Phase 3, p.2) and that there are electrons right before both light bulbs. The same explanation was given by Michael in the two preceding interviews suggesting that this was a feature embedded in his understanding of electricity, which clearly moved away from the initially held ‘clashing currents’ model (Osborne and Freyberg, 1985) to the scientific version of the phenomenon.

He showed ability to understand the connection between theory and practice and relate his understanding to everyday incidents, as shown in the following extract:

```
I  - What's the role of the switch? What does it do?
S  - It opens the circuit and it closes the circuit
I  - I see. Then why don't we call it 'opener-closer', instead? Where does the name 'diakoptis' ('switch' in Greek) come from?
S  - Because it 'diakopti' ('stops' in Greek) current
I  - That's right. What material is the switch made from?
S  - From metal
I  - I have a... (Michael interrupts interviewer)
S  - And plastic...
I  - Well, I have a switch here, however, it doesn't look as if it is made of metal!
S  - No, I meant inside!
I  - So are you saying that there are two different materials on a switch?
S  - Yes
I  - Can you explain this a bit more?
S  - On the outside, it is made of plastic so that he doesn't get an electric shock...
I  - Who?
S  - The person who touches it
I  - I see... and...?
S  - Inside it is made of metal so that it connects the two wires
I  - If it wasn't made of metal inside would the switch function?
S  - No... it would have to be some other material that would be a conductor
I  - In that case, would it work?
S  - Yes
```

(Phase 3, p.2)
Even in cases where his responses were challenged he could insist on his response showing ability to substantiate his claim:

\[ \text{I - What about the circuit in figure 4? Light bulb B is burnt-out whereas light bulbs A and C are good. What will happen when I connect the wires as shown?} \]

\[ \text{S - It won't glow. (Initial response)} \]

\[ \text{I - None of them? (Challenge)} \]

\[ \text{S - No because the circuit is open (Insisting on initial response)} \]

\[ \text{I - Why? After all bulbs A and C are good (Further challenge)} \]

\[ \text{S - The circuit is open and so they cannot glow (Justification of response)} \]

\[ \text{I - At which point is the circuit open?} \]

\[ \text{S - Inside bulb B} \]

(Phase 3, p.3)

When faced with the same question in the second interview, he explained that even if electrons are ‘everywhere inside the wires’ they can not move because the circuit is broken and the battery is not pushing them. He therefore showed ability to distinguish when a certain piece of knowledge can account for a phenomenon and when this is not the case.

On one occasion he made reference to ‘energy’ in relation to short-circuit. He explained that a short-circuit can be dangerous:

\[ \text{‘Because in other appliances there is more... there is more energy, and so the house will catch fire.’} \]

(Phase 3, p.4)

As was the case with other pupils, this was apparently knowledge obtained through everyday experience in his family or social environment. Nevertheless he held correct understanding of the concept of short-circuit. Showing ability to describe the conditions for a short-circuit to be caused, he could clarify that current ‘goes back to the socket or the battery’ (Phase 1, p.3). Notably and in contrast to nearly all other pupils, Michael did not mention water in his explanation.

In general Michael’s performance was consistently high over the three interviews exhibiting very little differentiation. This suggests that his knowledge and understanding was not superficial but it was stable enough to be retained nearly one year after being taught. He showed high levels of factual knowledge for both simple and more complex phenomena associated with electricity, ability to explain and substantiate his responses even when these were challenged by the interviewer, and ability to give valid examples and make use of analogies. He was conscious of the meaning of terms he was using and the purpose of his learning. In cases where his initial responses were rather unfocused, these were followed by correct responses once the interviewer rephrased or clarified the questions at hand.
The four cases presented conclude this section on the description and analysis of data. In the next chapter follows the discussion of the outcomes of this study. In doing so, the attempt will be to bring together the two parts of the analysis, namely the quantitative and the qualitative, in a discussant blend that will enable conclusions to be drawn.

6.6. Post-script to Chapter 6

Constructivism being the underpinning philosophy to this thesis, applies finely to the chapter that has just been completed for what was presented is all but a construct of this researcher's understanding of what the data collected had to say. At the same time, it is equally the reader's construct since the reader has in the meantime constructed his or her own understanding of the story told. The emphasis placed on the reader by this writer is not an attempt to transfer any kind of responsibility to the former rather it is a choice that shares the same rationale as the one expressed by Ely et al., (1991)

The responsibility of a qualitative researcher in the final report is to bring public spotlight on her/his decision-making process in establishing findings. When this holds, readers have the information with which to judge for themselves whether the findings are reasonable (p.156).

This thesis fully ascribes to these views. The attempt was precisely to bring public spotlight on collected material, the processes involved, the prevailing assumptions, the trivial and the less trivial details. The extent to which this was done successfully is left with the reader to judge, as is the weighing of the conclusions drawn by this writer in the chapter that follows.
Chapter 6 - Description and analysis of data

Qualitative versus quantitative analysis
- Objectives of the analysis
- Status of the analysis and its outcomes

Practical aspects of the analysis

Pupils' conceptions of electricity prior to teaching
- Current/Electron flow
- Conductors-Insulators
- Lamps-'Burnt-out' lamps
- Switch
- Short circuit

Material produced by the children
- Durability of pupils' conceptions
- Performance by type of exercise
- Concept-based analysis

Quantitative analysis of tests
- Big classes
- Small classes

Qualitative analysis of interviews
- First order qualitative analysis - Broad perspective of data
- Second order qualitative analysis - Case studies

Figure 6.29 Graphic summary of Chapter 6
7.1. Introduction to Chapter 7
7.2. Discussion of the results
7.3. Conclusions
   7.3.1. Metacognition
   7.3.2. Durability of pupils' conceptions
   7.3.3. Pupils' ability to use conceptions across contexts
7.1. Introduction to Chapter 7

...one of the challenges about carrying out investigation in the 'real world' is in seeking to say something sensible about a complex, relatively poorly controlled and generally 'messy' situation (Robson, 1993, p.3).

Following the description and analysis of data, this chapter discusses the outcomes of the research and presents the conclusions reached by this researcher with respect to the research questions pursued and the areas of interest to this thesis. In doing so, the discussion draws from both quantitative and qualitative data. It addresses issues relating to the durability of pupils' conceptions, the three types of exercise used, and the areas covered by the focal points applied in the qualitative analysis of interviews, concentrating on emerging trends or relationships. Comparisons between experimental and comparative group are attempted and the impact of situated metacognition on pupils' performance is placed under scrutiny. In doing so, important points that were discussed in preceding chapters relating to the three key areas of metacognition, durability and context are selectively revisited.

7.2. Discussion of the results

The first word in the discussion of the outcomes of this study inevitably goes to the practice of situated metacognition, which was the experimental approach employed by this researcher. As discussed in Chapter 4, the literature on metacognition is still characterised by some scepticism as to the appropriateness or the feasibility of metacognitive activities for young children, mainly because of the substantial mental requirements placed upon them. Against such a background the employment of metacognition by this researcher (arguably a new type of situated metacognition) was a test not only of the impact of the proposed approach, but primarily of its applicability with primary school pupils, under the real-classroom circumstances described in previous chapters (Chapters 4 and 5). Results relating to the practice of situated metacognition are, therefore, important outcomes of this study in their own right.

The presentation, in the preceding chapter, of numerous examples of material produced by the pupils during the implementation of the metacognitive instances approach, and the discussion of pupils' quotes at different points of classroom discussions, have offered ample evidence of metacognition in action. The fact, for example, that pupils from the experimental group could make comparisons between their prior and post-teaching views, identify scientific
discrepancies in their initial understanding, and acknowledge the usefulness of analogies or examples used during teaching, are taken by this researcher to be clear indications of metacognitive thinking.

Having said so, the intention is not to elaborate on different dimensions of this outcome, rather is one of making the point that metacognition has indeed taken place successfully in the experimental classes. Consequently, the claim of attributing differences in performance between the two groups to the practice of metacognition by the experimental group is reasonably valid. The way in which metacognition has maintained such an impact is one of the issues tackled in the following pages. Having made this point, the discussion can now address the main body of the results.

Analysis of both quantitative and qualitative data suggested that durability of factual knowledge was generally high for the majority of the pupils. This is a particularly interesting outcome, if seen in relation to studies indicating that most information learned in schools drops to a fraction of original learning in a matter of weeks (Hagerman, 1966; Novak, 1998), and the results of the recently conducted Third International Mathematics and Science Study (TIMSS) (Mullis, 1997; IEA, 1998) in which Cypriot pupils' performance was particularly low. One explanation for the high levels of factual knowledge recorded by this researcher could be that the specific subject-unit on electricity was eventually 'marked' in pupils' memories, due to the fact that this was taught by a visiting teacher (most probably with a different teaching style) rather than their normal teacher of science. Although, as was described in the methodology chapter, every effort was made to avoid the appearance of the 'Hawthorne effect' (Chapter 5), the novelty of the teacher may have eventually acted, to some extent, in this direction. The fact, however, that no reason exists why the extent of such influence should be any different for the two groups, in essence suggests that the comparative dimension of this study was not undermined.

Generally high scores achieved in the second and third phase of the research gave some signs of consistency of pupils’ ideas and their ability to report or use these ideas. Such consistency characterised to a greater extent the results from the experimental group, proof of which is the lack of considerable decrease in the group’s overall performance in the three phases of this research. Average performance of pupils from the experimental group (i.e. children who practised situated metacognition) was markedly higher compared to that of pupils from the comparative group, especially given the short time-scale of the intervention. This was the case for both big and small classes, difference in favour of the experimental classes being as high as 9.99% for the big classes (Table 6.3) and 15.62% for the small classes (Table 6.10).
Notably, difference between the two groups was initially small, only to increase over the three phases of the research, for both big and small classes. This is a very interesting outcome that was recently reported in the literature by Blank (2000) who employed a learning cycle model (termed the Metacognitive Learning Cycle) providing formal opportunities for teachers and students to talk about their ideas of science. Her results showed that students who engaged in metacognitive discussions did not gain a greater content knowledge of science, but they did experience more permanent restructuring of their ecology understandings. In interpreting her results Blank suggests that although students in her experimental group did not achieve higher levels of understanding of science, they may have more successfully accommodated the ideas of ecological processes into their long-term memory, an assertion that, as this discussion will show, could be equally valid for the outcomes presented in this thesis.

An important point to make at this stage of the discussion is that the overall stability and occasional increase of group performance raises the question whether children’s understanding of electricity was in any way reinforced prior to testing in Phases 2 and 3. In a preliminary discussion with the teachers of the four classes they were kindly asked not to interfere in any way with the conduct of the research, either during the teaching period or in-between the follow-up phases of the research. Having received such a pledge on behalf of the teachers this researcher has no means to either support or disprove such a claim, since no monitoring of teachers’ subsequent teaching was possible as he had to return to the U.K. The only such indication can be derived from some discrete discussions with children in the follow-up phases, suggesting that none of the teachers attempted to reinforce his/her children’s understanding of concepts of electricity. The fact that the researcher was doing all the teaching himself meant that there would be absolutely no negative impact on the teachers in the event of a class performing badly, and this is thought to have contributed significantly to preventing any such interference on the teachers’ behalf.

Outcomes suggesting a positive impact of situated metacognition on pupils’ conceptions also come from the concept-based analysis of the results. Comparisons of pupils’ performance between Phase 1 and Phase 3 of the research has shown that pupils’ constructed conceptions proved less durable for the comparative group (for all the concepts taught) compared to performance of the experimental group (Table 6.9).

A similar picture with regards to durability of pupils’ conceptions can be drawn from interview data (Chapter 6). Most children from the experimental group consistently exhibited higher performance during the three rounds of interviews, showing that they could move beyond the passive reciting of knowledge to demonstrating ability to manipulate this
knowledge. This difference was more apparent in the case of the small classes as pupils from the small experimental class gave responses that entailed a high degree of detail (see cases discussed in Chapter 6), and were also able to elaborate on examples and analogies used during teaching.

Analysis of interviews has also shown that children’s alternative explanatory ideas were not as consistently used as were scientifically orthodox responses. This is a conclusion reached in the past by Engel-Clough and Driver (1986) who commented that

*This could be interpreted as a hopeful finding for science educators- it suggests that once students learn and use a correct scientific explanation in one context they are more likely to employ it in others* (p.489).

Some cases of inconsistency of pupils’ responses over the three phases of this research direct attention to Strike and Posner’s (1985) notion of *conceptual ecology* in which concepts compete for a certain conceptual niche (Chapter 1). The case could be one of concepts losing status over the period of this research therefore failing to survive in the learners’ conceptual environment. In other words, the loss of status and, consequently, the disuse of conceptions can gradually lead to *conceptual decay* to the benefit of alternative explanations.

Asserting that pupils from the experimental group retained all taught material would have been an unsubstantiated claim not corresponding to reality. In some cases mistakes were made in reporting declarative knowledge and alternative frameworks were evident during some of the interviews, as shown in the preceding chapter. It can confidently be reported, however, that, on average, such problems appeared to a considerably lesser extent than in the case of the comparative group (e.g. Table 6.12), therefore, enabling the conclusion that *situated metacognition* had a positive impact on the durability of pupils’ learning.

Due to the personal mental mechanisms involved in the learning process (even more so in engaging in metacognitive activity), this researcher does not have the means to identify in detail the exact way in which the practice of metacognition maintained an impact on the durability of pupils’ learning. He does, however, assume possible ways in which metacognition may have acted. The first plausible claim to make is that metacognition has acted as the ‘marking event’ (Chapter 2) of pupils’ learning of electricity. By means of metacognitive activities such as classroom discussions, asking questions and taking brief diary-like notes, pupils’ conceptions that were involved in these activities were ‘marked’ and distinguished in pupils’ memories from other pieces of knowledge that were not highlighted in a similar reflective way. Self-questioning, explaining something to a classmate or producing annotated drawing, on the other hand, are believed by this researcher to have made
pupils' learning more conscious, since these activities have demonstrated that the pupils not only held certain understanding, but that they could further communicate this to others. Moreover, encouraging metacognitive reflection on relationships characterising learned material, by means of concept mapping, has helped children to relate their newly-constructed understanding to knowledge they already held, identify links between concepts, and obtain a more global perception of the subject-unit taught. Arguably, this has resulted in making their conceptions of electricity more meaningful, more solid and, consequently, more durable.

With respect to class size, the outcomes of this study could be summarised by saying that for both big and small classes, children from the experimental group on average outperformed their counterparts from the comparative group, and that in the case of the small classes this difference was amplified. This result could be suggesting that group size, or the circumstances under which metacognition is practised, play a substantial role in its success in maintaining an impact on the durability of learners' conceptions of science.

In terms of the CLD model discussed in Chapter 1, it was demonstrated that pupils' conceptions experienced some conceptual decay particularly in the case of the comparative group (Figure 7.1). In the case of the experimental group, on the other hand, conceptual decay was largely retarded since pupils demonstrated more stable (in some cases increased) performance (Figure 7.2). The latter outcome, although surprising at first sight, has previously been recorded in the literature. Tytler and White (1996), for instance, have concluded in the past that over a period of months in which no further explicit thinking takes place in relation to previously studied phenomena, pupils maintain understandings they had generated earlier and show further signs of consolidation and refinement of their conceptions.

![Students' average overall performance - Big comparative class](Figure 7.1)

![Students' average overall performance - Big experimental class](Figure 7.2)
It can, therefore, be concluded that conceptual decay takes place at a slow rate, and contrasts the way in which retention of memorised items, such as unrelated words or numbers, initially drops dramatically (Chapter 2). The explanation behind this major difference between the two cases (that both involve the mechanisms of remembering and forgetting) could lie in the significant role organisation of knowledge and meaning play in the case of conceptions, as opposed to rote memorisation of words.

This said, a point discussed in Chapters 1 and 2 regarding the mechanisms of forgetting of conceptions proves particularly important at this stage of the discussion. Whenever conceptual decay appears to be taking place the case is not necessarily one of loosing elements of knowledge that constitute one’s understanding of a concept. In order to substantiate this claim, reference has to be made to interview-obtained data that generally revealed two cases of forgetting, or of low durability of learners’ conceptions. On the one hand, are cases of pupils who at times gave wrong responses, but when the interviewer rephrased the question or gave what were meant to be helpful hints, the pupil reached a correct answer. Christodoulos, for example, (please see Chapter 6) who was a pupil from the big experimental class, was unable to give clear responses with regards to short-circuit, yet when prompted to rethink his response in terms of electron flow and encouraged to conduct the experiment, he was then able to explain about the route taken by electrons in a short-circuit. What was demonstrated in cases like this one, was that rather than elements of knowledge associated to the scientific conception tested (e.g. propositions, strings, episodes) being lost, these had become inaccessible to the learner, apparently due to a long period of disuse. The fact that the learner managed to reach correct responses, following further questions from the interviewer, showed that the learner needed the right stimuli to retrieve knowledge that s/he was holding in a ‘hidden’ state and which eventually proved to be durable.

On the other hand were cases of pupils who could not reach a sufficiently correct answer, in spite of being offered a second or third chance to reconsider their reply in the way described above. One such example is the case of Petros, a pupil from the small comparative class, who showed inability to give correct answers about the basic concept of electron flow, in spite of repeated prompts from the interviewer (please see Chapter 6). What is being suggested is that in these cases the problem was not one of accessing stored knowledge (since different questions were offering different stimuli that were expected to trigger retrieval) rather it was one of 'loosing' elements of one's knowledge. Of the forty-eight interviews conducted by this researcher, the former behaviour was associated mostly with children from the experimental group, while the latter was more often encountered with children of the comparative group.
Looking at this outcome in relation to the quantitative data of the study and the fact that different learners are more likely to need different stimuli for retrieving knowledge they posses, suggests that the decrease in test performance of the comparative group is a combined outcome of loss of knowledge and unsuccessful attempts for retrieval. Conversely, consistent and in some cases increased performance of the experimental group could suggest that loss of knowledge did not, on average, take place, and the learners maintained successful mechanisms for accessing their constructed conceptions.

Having looked at general dimensions of the data relating to the durability of pupils' conceptions, the discussion will now focus on pupils' performance in the three types of exercises employed during testing. In sum, the majority of the pupils showed high levels of declarative ability for factual knowledge (Type A exercises), high ability to use knowledge in familiar contexts (Type B exercises), and considerably lower ability to utilise knowledge in unfamiliar contexts (Type C exercises), irrespective of group from which they originated. Highest average scores were mainly concentrated in Type B exercises where pupils were asked to apply their knowledge in rather familiar contexts. Interestingly, pupils' average performance in Type A exercises was not much lower from the one exhibited for Type B exercises (Table 6.5). Only in the case of the small experimental class was a difference in average performance between the two types of exercise higher (Table 6.11) yet the small number of participants does not allow any reliable conclusions to be drawn. Returning to the big classes, lowest average scores were exhibited in Type C exercises where pupils had to identify and apply a piece of knowledge to a rather unfamiliar context, or a context with no obvious links to the contexts used in class. This is an outcome that verifies previous findings in the literature according to which lack of familiarity of the context of assessment maintained a negative impact on pupils' performance (e.g. Donaldson, 1978; DES, 1985; Engel-Clough and Driver, 1986; Nunes et al., 1993).

The significantly lower average scores for both big classes in Type C exercises, compared to the other two types of exercises, is an outcome that is indicative of the importance of distance between the context in which learning takes place and the context in which knowledge is expected to be used (Toh and Woolnough, 1994). Test results clearly suggest that the greater the distance the less likely successful utilising of knowledge is to take place.

As noted earlier, difference between Type A and B exercises was, in most cases, not great, an outcome that was, on average, common to all comparative and experimental classes. That is, irrespective of whether the pupils practised metacognition or not. This in essence questions whether a familiar context offers an advantage to the learner, as is often argued in the
literature (e.g. Gick and Holyoak, 1983), in contrast to the 'context-free' recall of knowledge required in Type A exercises. Although generally low performance in Type C exercises is suggestive of the negative impact of unfamiliar contexts on learners' ability to use knowledge, high performance in Type A exercises where no particular context was given, raises some questions. One explanation for having unexpectedly high performance in Type A exercises could lie in that pupils were used to this kind of exercises for assessing their understanding at the end of each subject unit, hence the high ability to recite memorised knowledge. The fact that the majority of the exercises included in the assessment booklet issued by the Ministry of Education and Culture of Cyprus is precisely of this type, supports such a claim. Considerable difference in performance between Type A and B exercises, on one hand, and Type C exercises, on the other, always in favour of the former, is also an outcome that tends to verify the view that even after a new concept is mastered in relation to some phenomena, its extension to other phenomena can involve significant difficulties (Tytler and White, 1996).

Having said so, a particularly important outcome of this study has to be noted. Analysis of pupils' performance by type of exercise suggested that ability to use knowledge in contexts considerably different from the one in which learning took place (Type C) is not associated to variation of learners' performance in either exercises that require simple recall of factual knowledge (Type A), or use of knowledge in contexts similar to the ones employed during learning (Type B). This is a result confirmed by the performance of both groups in all testing phases of this research. In the case of pupils from the big comparative class, for instance, who did not engage in situated metacognition (Table 6.4) although their performance in Type A and B exercises declined with time at similar rates, their ability to use knowledge in unfamiliar contexts (Type C exercises) was, on average, remarkably stable. It can, therefore, be reasonably speculated that once ability to apply knowledge in specific contexts is demonstrated, this is of a more stable nature than is ability to simply recall factual knowledge in a 'context-free' mode.

In sum, the outcomes of this study did not resolve the obscurity in the literature regarding whether a familiar context helps learners utilise knowledge in that context or not. As discussed in Chapter 3, the role of a familiar or a scientific context in assessing pupils' understanding is still undetermined, with findings advocating both a positive and a negative impact from either choice. The reason for demonstrating similar uncertainty in the case of the present study lies in the fact that difference between Type A and B exercises was not great (Table 6.5), something that cannot substantiate the claim that a familiar context can manage a positive impact on pupils' performance compared to lack of such familiarity. The emerging
picture, therefore, is one that does not allow definite conclusions to be drawn with respect to the role of a familiar context in determining pupils' performance.

Although the three contexts used in the test were not used during the interviews, that focused primarily on the durability of learners' conceptions, a point that relates to the preceding discussion is that children appeared more confident when addressing problems with a pictorial representation similar to the ones used during teaching. This shows that in spite of the impact of a familiar context, if any, on the content of the answer given to a problem, a familiar context clearly helps in terms of increasing learners' confidence and ease of reply.

Looking at performance between comparative and experimental group with regards to the three types of exercise, not only did the latter on average outperform the former in all types of exercise (Table 6.6), but also the experimental group showed more consistent (and in some cases increased) performance during the three phases of the research (Table 6.5). It can, therefore, be concluded that the practice of situated metacognition managed a positive impact on pupils' ability for contextual use of their conceptions.

Once again, interpretation of such an impact can only be based on informed speculation, the prevailing impression being that metacognitive activity has acted in the direction of 'bridging' or shortening 'distance' between contexts of learning and testing. In making this claim this researcher is not suggesting that this impact has acted during the administration of tests (i.e. pupils being metacognitive at the time of dealing with a test exercise), rather it is regarded as an impact maintained during construction of conceptions. By revisiting the content and processes of constructing one's knowledge and addressing metacognitive questions relating to the 'why' or the 'how' of the conception(s) being constructed, learners are believed to have become conscious of potential use of their knowledge. For example, by being consciously aware of why a burnt-out light bulb cannot glow (rather than passively and unquestionably obtaining this knowledge) learners were more likely to be in a position to recognise, in a given problem (i.e. new context), that the burnt-out light bulb was causing the breaking of the circuit, which in turn resulted in no electron flow. Put differently, by obtaining a more global perception of their conceptions, learners in essence face new contexts better prepared for what is thought by many as the ultimate purpose of their learning, which is the use or application of this knowledge, if and when this becomes necessary.

Returning to the previously discussed overall superiority in performance of the experimental group in all types of exercise, this outcome could possibly suggest that the positive effect of situated metacognition on pupils' ability to recall and use their knowledge accordingly
maintained an impact in the long term, rather than being restricted to affecting outcomes immediately after the intervention was completed. This is a conclusion supported further by the fact that pupils from the comparative group, who did not practise situated metacognition, clearly demonstrated decreasing performance in both Type A and B exercises over the three phases of the research.

In the case of performance in Type C exercises, a more complex picture has emerged. On the one hand, Type C exercises were the ones in which greatest difference in performance between comparative and experimental group was noted, an outcome that could be suggesting that the impact of situated metacognition was particularly positive for this kind of exercise. On the other hand, questions are raised by the stability in performance exhibited by both groups in Type C exercises (Table 6.5), as to the interpretation of this outcome. This stability cannot be attributed to the practice of situated metacognition since average results of the comparative group (albeit lower) maintained remarkable stability. A reasonable conclusion, therefore, could be that the practice of metacognition had a positive impact on demonstrating ability to use knowledge in Type C exercises initially, but the fact that pupils maintained such ability in the long-term seems unrelated to the practice of metacognition.

Shifting the discussion to outcomes with respect to the scientific concepts taught, both quantitative and qualitative data verified international literature on children’s learning and understanding of electricity, and revealed specific problems with key-concepts for the teaching of this subject-unit. The alternative frameworks of ‘unipolar current’, ‘clashing currents’ or current ‘moving very fast’, which were previously identified by other researchers (Osborne and Freyberg, 1985; Driver et al., 1994b) were also recorded by this researcher. Quantitative concept-based analysis showed that such problems appeared with greater frequency in the case of pupils from the comparative group, whose conceptions of electricity proved less durable than was the case with pupils from the comparative group (Table 6.9). This outcome was confirmed in the three rounds of interviews where pupils from the comparative group would often revert to alternative frameworks in order to explain or justify their responses. The claim, therefore, put forward by this thesis, that situated metacognition facilitates deeper understanding of the concepts taught, is gaining evidence in its favour.

As pointed out earlier, the personal and internal character of mechanisms involved in constructing one’s understanding does not allow this researcher to provide ‘evidence’ as to how metacognition has acted. It is thought, however, that the connections between the two areas, discussed in the theoretical chapters of this thesis, were reasonably evident, the prevailing feature being one of facilitating more meaningful and more conscious learning.
encouraging children from the experimental group, for instance, to reflect on their learning and compare their prior ideas to their current understanding, or by asking them to consider the connection between analogies used during teaching and the phenomena studied, this researcher believes that pupils became more aware of important dimensions of their learning. This, in turn, is a process that can be thought of as making one’s understanding less prone to decay, or less vulnerable to the reappearance of alternative frameworks, hence, it is argued, more durable.

Problems arising from the use of the Greek language were also identified for both comparative and experimental groups, reinforcing the view that the use of a ‘shared language’ between teacher and students is of particular importance (Adey, Shayer and Yates, 1989a). As Coles (1996) put it

_A teacher’s responsibility is to try to understand a child’s language and, in particular for teachers of young children, to understand how we demand a different kind of language in school from that used in the home. There is often a large discrepancy between school talk and talk in the world outside of school_ (p.2).

Such discrepancy, usually accompanied by persistent misconceptions supported by the social environment of the pupils, can act as serious impediment of their understanding. This is an outcome that verifies Novak’s (1998) warning that it is important for teachers to remember that they live in a culture that can be significantly different from that of their students, and that negotiating meaning is in constant need since the same word can bear completely different meanings for teacher and students. Analysis of extensive interview discussions showed that pupils from the experimental group faced such problems to a smaller extent (Chapter 6). It is, therefore, argued that the practice of metacognition helped confronting problems caused by the interaction of the Greek language, by making pupils more aware of the meaning of the terms they were using and of the features of the phenomenon they were studying.

In order to minimise the two problems of dealing with mostly abstract concepts and facing the potential of confusion caused by the impact of the language of instruction, this researcher made extensive use of analogies in his teaching. It can confidently be concluded that the use of analogies such as the ‘ski-lift analogy’ (Georghiades, 1999b) and the ‘chain analogy’ for representing electron flow, or the ‘rising bridge analogy’ to represent the operation of switches made a substantial contribution to children’s understanding of the phenomena studied. Extracts from children’s diaries and views expressed during classroom discussions are supportive of this claim. Following the experience obtained from the conduct of the research, this researcher unreservedly considers himself among the advocates of the use of
analogies in the teaching of science, always within the selective philosophy advocated earlier in this thesis.

Analysis of the forty-eight interviews also verified to a great extent the range of possible outcomes of constructivist-based teaching put forward by Gilbert et al. (1982) (Chapter 1). The reader is reminded that this list comprised a) the ‘unified scientific outcome’; b) the ‘two perspectives outcome’; c) the case of children’s ideas remaining undisturbed by teaching; and d) the ‘reinforced outcome’. Similar variance in outcomes was demonstrated by both experimental and comparative groups, indicating that metacognition did not have a miraculous effect on the application of constructivist teaching – a claim that was after all never put forward by this researcher. This point is highlighted in order to emphasise the view that although metacognition has an important place within the constructivist framework, it cannot be expected to act as the sole solution to the practical problems associated with constructivist teaching. In the final chapter of this thesis it is argued that further enhancement of our understanding of constructivist processes in practice is needed, by means of continuous research. It is further acknowledged that appearance of the last three outcomes on the list by Gilbert et al. (1982) is of course among the less successful features of teaching involved in this research. This result can partly be attributed to the fact that children’s prior experiences had a very strong impact on their performance and the ideas they expressed during the interviews. Ideas such as ‘energy’, for example, seemed to be persistent in their explanations of phenomena associated to electricity, and the fact that no reference to concepts such as ‘charge’ and ‘repulsion’ was made during teaching, contributed to the dominance of their explanations by anthropomorphic features (Chapter 1). This variance in outcomes is seen by this researcher as the result, as well as proof of the realistic design of this study and, consequently, its claims.

Having admitted to the limited expectations that should be placed with the practice of metacognition, there is one important point that needs to be made. The previously discussed outcome of children from the experimental group demonstrating generally greater durability of correct science and greater overall ability for contextual use of their knowledge, could be suggesting that metacognition has acted in the direction of preventing the re-appearance of alternative explanatory frameworks. Analysis of interview data is also supportive of this conclusion, since children from the experimental group who were interviewed, reverted to alternative explanations in their responses with considerably smaller frequency than their counterparts of the comparative group. The point to make, therefore, is that although situated metacognition does not offer a solution to the problems associated with constructivist teaching, it can make a particularly positive contribution towards the prevention of alternative
frameworks reappearing in short time after learning is completed, provided that correct (metacognitively enhanced) science is taught from an early age.

Last, before completing this part of the discussion, two points of a methodological texture have to be addressed, reflecting upon the actual ‘doing’ of this research. First, of particular importance to this thesis is the fact that data collected by means of qualitative and quantitative approaches and the corresponding analysis that followed, have enabled cross-examination of outcomes in a complementary way. In most cases where this was possible, both qualitative and quantitative data converged towards similar conclusions. Cases of some ‘discrepancy’ between the results of certain sections of the tests and the corresponding questions of the interviews also made their appearance, yet these were isolated exceptions rather than the rule. Tests, for example, offered evidence of higher ability on behalf of the experimental group in using conceptions across contexts, while interviews indicated that pupils from the same group were able to elaborate in greater detail on their explanations. Both cases were taken as complementary signs of children from the experimental groups exhibiting deeper understanding, this probably being the result of the practice of situated metacognition. The complementary way in which the two research tools have acted also becomes evident in relation to the discussion of conceptual decay. Although test performance could indicate how durable pupils’ learning proved to be without differentiating between loss of knowledge and loss of access to one’s knowledge, interviews could offer such an insight to a greater extent. In conclusion, therefore, the choice of employing two different in nature data-collecting methods has been successful and contributed to the richness of the outcomes of this study.

Second, the inclusion of class size as an additional variable of the research design again proved a very important choice. This is so because the small classes offered amplified verification of the results of the big classes suggesting that situated metacognition is most successful when practised in small groups. Moreover, the small number of pupils in these classes facilitated better insights into the effect of situated metacognition on pupils’ learning that were particularly useful in shaping the qualitative dimension of the analysis of data.

To recapitulate on the above discussion is to say that children who practised situated metacognition exhibited high long-term performance, in general, and gave signs of high ability for contextual use of learned material, in particular. Evidence of successful metacognitive activity comes from classroom observation and material produced by the children. In the case of the big classes difference in performance was not impressive, something that can be attributed to the short, implanted nature of the intervention that took place during normal teaching hours and while keeping to the curriculum. The fact that
metacognitive stimuli were given mostly in the form of whole-class instruction is believed by this researcher to have contributed to the modest difference in performance. This is a conclusion supported by the outcomes from the small classes where difference in performance was much more evident in favour of pupils from the experimental class, in all three phases of this research. This outcome further suggests that group size or the circumstances under which situated metacognition is practised can considerably determine its success. The methodological choices to incorporate both quantitative and qualitative dimensions in the research and to include class size as an additional variable have, therefore, contributed to the richness of the outcomes of this study.

This concludes the discussion of major outcomes of this research. In order to complete the cycle of this thesis, conclusions with regards to the core areas of metacognition, durability and context are made explicit in the following section. It presents the conclusions reached by this researcher with regards to the research questions that triggered the writing of this thesis, on the basis of the obtained data and the analysis conducted against the back-cloth set by the theoretical grounds of this thesis. In considering these conclusions the reader is urged to bear in mind that these are a reflection of this researcher’s subjective interpretation of the outcomes that were primarily treated as being suggestive rather than definitive.

7.3. Conclusions

7.3.1. Metacognition

1. Metacognition is feasible with Year 5 pupils

The first important conclusion of this research with regards to metacognition is that metacognition is feasible with Year 5 pupils, hence joining forces with scholars who previously advocated this potential (e.g. Rudd, 1992; Gunstone, 1994) and those who supported the early involvement of young children in reflective or philosophical thinking (Lipman, 1985; Fisher, 1995; Costello, 2000). Children’s responses, questions, and ideas expressed during classroom discussions and the material produced by the pupils of the experimental group during the implementation of the metacognitive instances approach (presented in Chapter 6 and in Appendix IV), demonstrated that most children of this age are capable of reflecting upon their learning, to a varying extent and within the limitations of their mental and cognitive development.
This conclusion is considered by this researcher to be particularly important since it provides the stepping stone for further research on metacognition with children of young ages. Even more so, when viewed in relation to the bulk of existing literature, which selectively focused on secondary school or adult populations when it came to studies on metacognition, primary ages being either ignored or excluded as unable to demonstrate metacognitive activity, or to benefit from such activity. It has to be noted, though, that the outcomes of this research cannot sufficiently determine the extent to which the conclusions reached with regards to the practice of situated metacognition with young children are applicable in the case of general, or other forms of metacognition (Chapter 4). More research in this direction is, therefore, called for.

2. Metacognition is best practised in small groups rather than as whole-class instruction

The second conclusion with respect to metacognition is that metacognitive stimuli are best offered in small groups rather than in the form of whole-class instruction. Both arrangements were tested as a result of working in parallel with both small and big classes, and the outcomes of the former were considerably more evident. Classroom observation has led this researcher to the conclusion that children who practised metacognition in the small class gradually engaged more fully in classroom discussions and remembered more taught material (e.g. terms, definitions, examples, applications) from previous lessons, something that was also reflected in pupils' quotes, diaries, annotated drawings and concept maps. This difference in the case of the small experimental class can be attributed to the fact that the small number of pupils enabled better and more frequent feedback during the implementation of the metacognitive instances approach, therefore enhancing pupils' reflection. Also, the majority of the pupils seemed to feel more comfortable when asked to reveal their metacognitive thoughts to a group of 4-5 friends, rather than to an audience of thirty children. Having said so, it has to be noted that this is an arrangement that is time-consuming and hard for the teacher to organise, especially when working in an educational system where the teacher has to ‘deliver’ a predetermined (usually overloaded) syllabus within tight time limits. This is an issue that is addressed in greater detail in the final chapter in recommending potential directions for further research.

3. Situated metacognition can have a positive impact on ‘durability’ and ‘context’

The fact that children who received metacognitive stimuli consistently outperformed their counterparts who did not, is suggestive of situated metacognition having a positive impact on the durability of pupils' understanding and on their ability for contextual use of their conceptions of science.
This research does not offer evidence that situated metacognition managed an impact on actually causing conceptual change learning from an alternative explanatory framework to one of orthodox science, although the outcomes are suggestive of situated metacognition acting in the direction of preventing alternative frameworks from reappearing. The outcomes further suggest that metacognition has an impact on the strength, depth, or degree of consciousness associated with the newly constructed conceptions. The repetitive character of the outcomes over the three phases of this research indicates that this impact is durable over a long period of time that can exceed that of one school year.

With regards to the impact of situated metacognition on pupils' performance, the small experimental class clearly outperformed the corresponding comparative class to a greater extent than the one exerted by the big experimental class against its comparative class, suggesting that class size also affects the extent of such an impact. The short duration of employing situated metacognition is another reason thought to have contributed towards recording modest differences between the two big classes. It is this writer's belief that repeated situated metacognition (i.e. metacognition employed in different subject-units of science) can have a more dramatic impact on pupils' performance in the subject areas taught. In other words, it is possible that metacognitive experience 'builds up' with time in the sense that the learners gradually use numerous metacognitive techniques in different settings, and the positive impact of this activity in a way aggregates. This is a point that is discussed further in the next chapter as a promising direction for further research.

7.3.2. Durability of pupils’ conceptions

1. Use of analogies helps in extending durability, which can vary considerably

Use of analogies or striking examples during teaching for representing difficult concepts proved to be a good way of extending the durability of pupils' conception of the specific phenomena studied. The fact that pupils made very explicit comments acknowledging the usefulness of analogies used (see quotes from classroom discussions and extracts from pupils' diaries), and the fact that most pupils made use of these analogies when interviewed at the end of the school year offer evidence in this direction. In general, and albeit some cases of pupils reporting the analogy as the sole explanation of the phenomenon studied, the use of analogies made a positive contribution to helping pupils construct fuller and more durable understanding by adjusting abstract knowledge to their mental capabilities.

The concept-based analysis of the data also enables the conclusion that durability varies considerably for different conceptions. Put differently, some conceptions are more durable
than other. This said, the data of this research do not allow any generalisations to be made as to the way different categories of conceptions (e.g. conceptions reinforced by experiential knowledge against more 'remote' or rarely used conceptions) varied in their durability.

2. Conceptual decay takes place gradually and at a slow rate
The lack of dramatic changes in pupils' performance over the three phases of this research justifies the conclusion that conceptual decay in electricity takes place gradually and at a slow rate. This is an outcome verified by pupils' overall performance in the three phases of this research, by concept-based analysis of the tests and by means of comparisons between the same pupils' responses in the three interviews. Notably, the negative impact of conceptual decay on learners' factual knowledge and their ability to apply this knowledge in familiar contexts is greater compared to the one maintained on learner's ability to use their knowledge in new contexts. In other words, use of conceptions in unfamiliar contexts is an ability, which, once demonstrated, is less vulnerable to conceptual decay.

3. Durability of pupils' conceptions can be enhanced by means of situated metacognition
Situated metacognition has managed a positive impact on the durability of factual knowledge, this impact being greater when working with small groups of children. In relation to the CLD model it is suggested that situated metacognition can delay the process of conceptual decay. Qualitative analysis of data also suggests that situated metacognition can have a significant positive impact on pupils' ability to elaborate on their responses. In reaching this conclusion, it is not clear whether such ability is acquired during initial construction of the conception -retained thereafter as an integrated part of one's understanding- or whether learners who hold a piece of knowledge for considerable time after learning can then generate explanations based on their current understanding. Last, the outcomes of this research are suggestive of situated metacognition acting in the direction of preventing the reappearance of previously held alternative explanatory frameworks, therefore allowing longer durability of conceptions of orthodox science.

7.3.3. Pupils' ability to use conceptions across contexts
1. The impact of context on pupils' performance is only partly determined.
A first conclusion with respect to pupils' ability for contextual use of their conceptions is that exercises requiring the use of conceptions in settings considerably different from the one in which learning takes place, are difficult for pupils to tackle. The fact that in these cases pupils first have to identify the relationship between their knowledge and the problem at hand and then apply their knowledge in a new setting, directs attention to the debate over the feasibility
of transfer of knowledge that is in need for further research. Children appear to be consciously aware of this problem, something that is reflected in the majority’s views on the degree of difficulty of exercises tackled during this research (Table 6.8).

In examining the impact of a familiar context (Type B exercises) on pupils’ performance, on the other hand, the emerging picture is not very clear because of results showing similarly high performance in cases where no context was given (Type A exercises). Pupils’ confidence and ease of reply are, however, two aspects of their performance shown by interview data to have benefited from a familiar context.

2. **Ability to use conceptions in unfamiliar contexts is stable over a long period of time.**
Test results with regards to pupils’ ability to use their conceptions of electricity in unfamiliar contexts have shown that although their performance in Type C exercises was the lowest, this was characterised by remarkable stability. Notably, the same outcome is common for both experimental and comparative group suggesting that this aspect of pupils’ performance was not affected by *situated metacognition*. The potential, therefore, of studying the reasons behind such stability along with investigating ways of achieving further increase in pupils performance, is particularly interesting.

3. **Situated metacognition can have a positive effect on pupils’ ability for contextual use of their conceptions of science.**
This last conclusion is based on the fact that pupils from the experimental group outperformed their counterparts from the comparative group in all types of exercise. Moreover, variation in pupils’ performance between different types of exercise were significantly less in the case of the experimental group. What this is suggesting is that higher consistency in performance across different contexts exhibited by the majority of the pupils from the experimental group can be attributed to metacognitive instruction having a positive impact on their performance. The repetitive character of the outcomes over the three phases of this research could be suggesting that this impact is durable over a long period of time exceeding one school year, and possibly beyond that. This said, the stable overall performance of both groups in exercises set in unfamiliar contexts raises questions as to the long-term impact of metacognition.

Having laid the conclusions reached by this researcher before the reader, the final step to take is one that, once again, brings to the forefront the strong practical orientation portrayed throughout this thesis. These conclusions provide the stepping-stone for *action* to be taken inside science classrooms, deriving from the implications of the outcomes of this study for the
teaching of science. These implications are addressed in the final chapter of this thesis, along with recommendations for further research.
Chapter 7 - Discussion and conclusions

Discussion of the results

Conclusions

- Metacognition
- Durability of pupils’ conceptions
- Pupils’ ability to use conceptions across contexts

Figure 7.1 Graphic summary of Chapter 7
8.1. Introduction to Chapter 8
   8.1.1. Reflections on possible improvements
8.2. General implications for science education
8.3. Implications for the teaching of electricity in primary science
8.4. Recommendations for further research
   8.4.1. Conceptual change learning
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   8.4.4. Pupils' ability to use conceptions across contexts – Transfer of knowledge

Postscript to the thesis
8.1. Introduction to Chapter 8

Science education is not exempt from the general criticism that research has had little effect on classroom practice. It is significant that it is researchers, not teachers who level this charge: teachers do not reject research, they ignore it (White, 1998, p.55).


Reaching the end of the cycle performed by this thesis, a reminder of the ideas advocated and the way these were implemented in the course of the research presented will help in setting the outcomes of this study in context, and enable the reader to make his/her own judgements with regards to the value worth ascribing to the claims and recommendations made by this researcher.

Central in the arguments raised in this thesis was that the CCL model should move a step further along the route to describing children's learning in science. The core idea behind it is that, moving beyond successful CCL, it is important that pupils be able to use their newly constructed conceptions appropriately when encountering new contexts, and to refer back to these conceptions even after considerable time has elapsed since they were first constructed. In practical terms these two areas are related to the problems of pupils being unable to make use of knowledge acquired in a certain setting to new situations, or pupils who simply forget what they learned in a short time. The research presented by this thesis investigated two main areas, namely pupils' ability to use their conceptions of scientific phenomena (in this case of electricity) in different contexts, and the chronological durability of these conceptions. In doing so, metacognition was introduced as the missing link to the equation that can help treat the two problems.

8.1.1. Reflections on possible improvements

The research endeavour undertaken was not problem-free, nor without mistakes. In retrospect the design of this research, for one, albeit realistic in its objectives and its methodologies, proved rather complicated in the sense that it included too many areas, each of which was complex and multifaceted in its own right. The extensive theoretical sections of this thesis, reviewing a number of distinct, yet often overlapping areas is one direct consequence of this complexity. Given the chance to redesign the whole research this researcher would possibly choose to tackle 'durability' and 'context' in two separate studies, in order to limit the range of thematic areas covered, and enable even more detailed study of these immensely rich fields of inquiry. The fact, on the other hand, that the design employed constructivist teaching in
classes of thirty pupils, while at the same time keeping to the curriculum, proved to be a particular constraint for this research, which would be considered in greater detail in the event of planning it over again.

The simultaneous teaching of four groups (entailing the extra variable of group size) and the conduct of a total of forty-eight interviews resulted in collecting far too much data that, on occasions, had to be treated in a holistic or selective manner. Other problems during this research were associated with the practice of situated metacognition, since the experimental classes were completely unfamiliar with metacognitive instruction. What this meant in practice was that this researcher’s task was not only to teach the subject unit in a way as to keep in pace with the comparative classes, but also to introduce the children to metacognitive activities. Ideally, this researcher would have chosen to extend the period during which children were exposed to the metacognitive instances approach and, if possible, engage more classes in the research. This would have considerably increased confidence in the results and would have enabled generalisations to be drawn in relation to larger school populations. The fact, however, that this research was practically a first attempt to treat these areas warrants its outcomes as a stepping-stone for more selective, focused and in-depth study of related issues.

Any attempt to reflect upon dimensions of the research that could be improved would have to address the subjective nature of the investigation. In spite of employing measures that were meant to reduce subjectivity (such as seeking teachers’ views on the problems addressed by the research; verifying pupils’ responses; and receiving feedback from colleagues on the materials used and the categories employed for the analysis of interviews) it is acknowledged that the reported outcomes rely heavily on one person’s perception and his approach towards the task of conducting this research. Positive scepticism or critique on the reader’s behalf in relation to the ‘validity’ and ‘reliability’ of the claims put forward in this thesis is therefore understandable, and partly provides the driving force behind this researcher’s intention to extend his work in the field by further research in the areas tackled in this thesis.

Minimising research subjectivity is an undertaking that largely depends on the resources available to researchers. Should this researcher have had greater resources at his disposal, a number of improvements could have been implemented. For example, a person could be employed to accompany this researcher to his visits to schools over the first phase of the research, and either observe or ideally video-record the lessons, something that would immensely increase raw data and could provide the evidence in favour or against researcher bias during teaching. The conduct of interviews or the analysis of the transcripts could also be assigned to a third party, ideally avoiding the arrangement in which the researcher knew
which group each child belonged to and was then required to conduct the analysis in a fair and objective way. Having admitted to these possible improvements, the design and conduct of this research should, nevertheless, be judged by the reader in relation to the resources available to this researcher at that time, and in close relation to the realistic philosophy on which it was based.

Other threats to the value of the conclusions reached in this thesis partly relate to methodological choices made in the design of the research. One such example was the decision to use diaries in the experimental group. In spite of the fact that the use of diaries was admittedly the least successful of the four metacognitive activities, this researcher concedes that this may have acted in a way that eventually affected the outcomes of the research. In those cases where some of the pupils managed to reflect on their learning, rather than restrict their diary writing to a descriptive level, the researcher could identify some problematic areas or concepts which the pupils either explicitly admitted, or indirectly indicated in their writings, that they did not understand well. These points were then briefly revisited in the following lesson with both groups in order to help those children who faced difficulties to construct better understanding of the specific concepts. Similar revisiting of points that were not clear to the pupils was attempted in the comparative class, basing such attempts on the feedback that the teacher-researcher received during his teaching by means of discussion, or by observing children’s attempts to tackle different exercises or tasks. What this is suggesting is that although some points that were not clearly understood in the comparative class were treated, it is possible that children from this group may have had further misunderstandings that were not made known to the researcher in the explicit way facilitated by the use of diaries in the case of the experimental group, and therefore overlooked.

As a result of this difference in treatment, a valid criticism of the outcomes of this research might be that the children of the experimental group were practically given more chances to understand a difficult concept than was the case with children from the comparative group. This said, the fact that this ‘unfairness’ in treatment of the two groups was a direct and inevitable result of one of the experimental activities employed by the researcher suggests that this is not a case of biased conduct, rather it is a feature common to most experimental arrangements where one group of participants experience something more or less different than their counterparts from another group. Any critique therefore, on the grounds of unfair treatment of the two groups, although at first justified, should be viewed in close relation to the requirements of conducting quasi-experiments. In hindsight, a different metacognitive activity in replacement of the use of diaries may have been a better choice if it could exclude
the possibility of such a ‘side-effect’.

Another methodological choice discussed in Chapter 5 was that the children of the experimental group were not informed of the new teaching approach followed by this researcher, and metacognitive activities were presented in the natural flow of the lesson as normal activities. This was a choice made in order to minimise the risk of experiencing the Hawthorne effect by ‘concealing’ the novelty of the activities used, an objective that, as this researcher strongly feels, was achieved. It is nevertheless acknowledged that the pupils of the experimental group inevitably had more varied, active and possibly interesting lessons due to the incorporation of a greater number of activities that were presented in a rapid mode. It is therefore possible that differences in performance can be partly attributed to the variation characterising the lessons of the experimental group and not necessarily to the metacognitive requirements of these activities. In order to minimise this risk the researcher made particular effort in maintaining that the lessons for the comparative group were conducted in a similar setting which, albeit less varied, did not lack opportunities for group discussions, active participation in the conduct of experimental investigations and relating of learned material to pupils’ interests and experiences. In other words, the case was definitely not one of presenting varied and attractive lessons for the experimental group as opposed to dull and uninteresting lessons for the comparative group. In retrospect, this problem might have been better confronted by including an equal number of non-metacognitive activities for the comparative group that would eliminate any difference in variation of the lessons between groups. The above criticism shall remain pending until further research is conducted on the metacognitive instances approach that can verify or falsify its claims.

Put aside the difficulties and practical problems encountered during the course of the research, this researcher feels rewarded by what appear to be significant and original outcomes. Prevailing among the outcomes is the conclusion that the practice of metacognition is feasible with primary school children under everyday circumstances, albeit hard and time consuming. It was also demonstrated that situated metacognition can have a positive impact on learners’ ability to use conceptions across contexts and extend the durability of their conceptions.

The contribution made by this thesis is thought by this researcher to be both important and original, not least because existing literature suggests that none of the four areas highlighted in this thesis was examined with focus on the specific problems raised here. Conceptual change learning thoroughly considered both the general process of learning, and learning of particular subject areas in science, yet very rarely was any interest demonstrated on what
follows after CCL has taken place. Studies in metacognition were accommodated mainly within secondary school populations, usually aiming towards improving general thinking skills. Literature on learners' ability to use knowledge across contexts predominantly dealt with transfer of scientific skills, rather than pupils' conceptions, and the notion of durability was minimally explored with studies in consistency been the closest endeavour undertaken. In view of the absence of prior findings with respect to the problems raised in this thesis, its implications for the teaching of science become particularly significant.

The fact that a quasi-experimental design was followed inevitably imposes some limitation in generalising conclusions due to the not 'truly' random selection of participants. Although this restriction is acknowledged as an important principle of research methodology, this researcher will not refrain from putting forward the claim that his results can be generalised. This seemingly unorthodox step is taken because both the design and the implementation of the research enable this researcher to demonstrate that neither the participants were special in any way, nor the circumstances under which the quasi-experiment was performed were unrealistic to any extent. In spite, therefore, of the methodological 'flaw' of non-random sampling and albeit unable to provide thorough statistical evidence, since the design of this research did not allow such processing of data, this thesis suggests that the conclusions reached could equally apply to other groups of children. This claim shall however remain unsubstantiated until research is carried out by other researchers, that will either verify or disprove it. This researcher welcomes research that will address similar questions in the field of science education in order for existing knowledge to be enriched and the claims of this thesis to be placed under scrutiny.

This final chapter discusses the implications for classroom practice deriving from the outcomes of this research and the conclusions reached by this researcher. They are divided in two main sections: a) General implications for science education, and b) Implications for the teaching of electricity in primary science. This is followed by a number of recommendations for further research.
8.2. General implications for science education

Shifting focus towards meta-CCL issues

A first implication of the outcomes of this thesis is that researchers and teachers alike should direct their attention to what happens after learning, or after the teaching process has taken place. In terms of the discussion in the preceding chapters, emphasis should be placed on meta-CCL issues (Chapter 1). The decline in the comparative group’s performance over the period of this research and the problems admittedly faced by the pupils when dealing with exercises that required application of knowledge in unfamiliar contexts, provide sufficient evidence to justify increased emphasis in this direction.

Attention to the ‘output’ of the learning procedure does not suggest that the importance of the ‘input’, or the processes taking place during learning are to be depreciated. Quite the contrary, it is vitally important that interest in the ‘input’ is maintained. The teacher should make explicit the science knowledge children bring into the classroom from home, since this knowledge not only will inhibit or enhance the construction of scientific conceptions, but will also determine to a great extent what is durable and what is potentially being applied in different contexts. The meaning of the language of instruction should also be made explicit and negotiation of meaning between teachers and students (Novak, 1998) should be a prevailing aspect of the teaching/learning process, if problems like the ones encountered in this study by the use of certain idioms of the Greek language, are to be avoided.

It is further suggested that teachers should not establish a setting in which accumulating knowledge is the ultimate purpose, but should provide opportunities for using this knowledge across different settings, portraying a meaningful and purposeful outlook of learning science. In other words, it is important that the teacher maintains links between the context in which learning takes place and a variety of other contexts that are of interest, or of potential use to the pupils. Such emphasis in the teaching sequence would be in agreement with the long and on going efforts for maintaining deeper understanding of transfer of knowledge, which is regarded by a number of scholars as of utmost importance for the broader field of education.

As Singley and Anderson (1989) point out

> One reason why the notion of general transfer keeps rising from the grave is that it is such an attractive proposition for psychologists and educators alike. It is the one effect that, if discovered and engineered, could liberate students and teachers from the shackles of narrow, disciplinary education (p.25).

Attention, therefore, to meta-CCL dimensions of primary science is thought by this writer to be fully justified and, as will be discussed later, in need of further research.
Incorporating situated metacognition in the teaching of science.

Experience accumulated during the course of this research and its outcomes suggest that situated metacognition can have a positive impact on the durability of pupils' conceptions and their ability to utilise these across different contexts. This thesis, therefore, recommends that situated metacognition and, more specifically, the metacognitive instances approach should be considered in everyday science teaching.

The experimental application of this approach showed that it is not an option for teachers who regard firm class management to be among their utmost priorities, for there is an evident conflict between such classroom environment and the practice of metacognition. Metacognition promotes questioning, deeper investigation, drawing links with related subjects, keeping a critical eye, and the conduct of practical experiments to prove or disprove theories, comprising activity that cannot be maintained in a classroom where strict discipline is seen as a quality. The metacognitive instances approach, therefore, places high demands on the teacher with regards to classroom and time management.

The comparative element incorporated in this research between small and big classes has led to the conclusion that the metacognitive instances approach is best employed in small groups while keeping the rest of the class busy with other activities (in a rotating arrangement), rather than as whole-class instruction. The size of the groups, the frequency of offering metacognitive instruction, and the nature of alternative activities for the remaining of the class are dimensions with which classroom practitioners can experiment and eventually select the arrangement that best suits their circumstances and their pupils' needs.

Wide-scale implementation of the metacognitive instances approach

In order for the metacognitive instances approach to find its way into science classrooms this must be made available to teachers who should be given training, support and guidance as to how to implement this in practice. This is particularly important for, the success of other projects in the past was restricted due to significant weaknesses in their implementation by teachers. Baird (1986a), for instance, reported that the behaviour of PEEL teachers maintaining too tight control of the class was one factor limiting the extent of improvement in students' learning, even if the teacher in principle supported the philosophy and objectives of the project. It is also this writer's belief that any attempt to implement the proposals of this thesis would be best made by groups of teachers, since this is important for maintaining colleague support, exchange of ideas, and collaborative decision making, which are essential at the early stages of any approach.
Notably, it is a strong position of this writer that it is not enough only to persuade teachers of the potential benefits of employing situated metacognition in their teaching, rather structural changes in the educational system in which they work are needed, such that will enable teachers to operate under circumstances that truly facilitate implementation of the approach. It becomes apparent, therefore, that a number of implications emerge from this discussion addressing messages to curriculum planners and policy makers at decision-taking bodies such as the Ministry of Education and Culture of Cyprus. Incorporating situated metacognition in everyday teaching should be facilitated by making available some time for this purpose. One way of achieving this would be to reduce to some extent the size of the science curriculum in order to give sufficient time to assimilate metacognitive instruction without the pressure of having to cover too much material, as was the case during this research. Similar problems with limited teaching time were previously emphasised in other studies that employed constructivist approaches (e.g. Joffili et al., 1999), for the construction - rather than the repetition - of knowledge can be a very slow process. This writer regrettably believes that teachers in principle willing to apply this approach in their teaching will reconsider doing so under the conditions currently imposed by the Cypriot science curriculum. What is at first sight a pessimistic, but in essence, realistic position, is also an open invitation to teachers from different educational systems with more flexibility and openness to innovations, to consider, experiment with, and eventually embrace the approach.

The following section looks at implications with respect to the teaching of the subject unit of electricity to primary school children. Inevitably some of the implications listed apply best to the educational system of Cyprus, while others enjoy greater applicability across different contexts.

8.3. Implications for the teaching of electricity in primary science

The fact that the pupils who participated in this research were not taught the concepts of charge, or of repulsion and attraction, meant that they lacked an important basis for founding their understanding of electricity. As a result, they had to rely heavily on memory for passively naming the negative terminal of the battery as the one that pushes electrons and used anthropomorphic images for explaining related phenomena. A first methodological implication therefore would be to teach the concept of charge before embarking on the unit on current electricity.
In planning the subject unit of electricity teachers should seriously take into consideration the two persistent alternative frameworks of electrons 'moving very fast', and electrons moving in a sequential manner that were identified by this and other researchers (e.g. Shipstone, 1985; Driver et al., 1994b). The key role of the concept of electron flow can determine to a great extent pupils' understanding on a number of other concepts of electricity, hence the need for such attention. The case of short-circuit being in causal relationship with water and electric shock are two further alternative conceptions reinforced by children's everyday experience at home, that should also be noted by teachers who should be prepared with appropriate methods for dealing with them.

Being a highly abstract subject area with only the effects of electricity being potentially observable, it is suggested that the use of analogies is particularly helpful in teaching basic aspects of the unit. The three main analogies found useful by this researcher are: a) the 'ski-lift analogy' (Georghiades, 1999b) to represent the movement of electrons; b) the 'rising bridge analogy', to represent the operation of switches; and c) the 'race track analogy', to represent how short circuit is caused. Teachers are of course free to devise their own analogies provided they are confident that the representation of the scientific concepts under study is successful, and that no alternative explanatory frameworks are unwillingly reinforced by the analogy.

The interaction of the Greek language in the two cases of the concepts of 'open / closed circuit' and 'short-circuit' proved highly problematic. This is a point that should be considered by teachers and one that should be highlighted in the textbooks used in Cyprus (both the 'Teacher's guide' and the 'Pupil's book'), for such interaction can be a serious obstacle in children's understanding of basic concepts of electricity. Another language-related problem was children's tendency to use the term 'iron' in a generic way to represent the concept of conductors, or think of iron as a characteristic of conductors. In spite of the fact that an extensive list of materials was used in experiments carried out in class, pupils tended to focus on the object under study rather than the conducting or insulating material, therefore giving answers such as 'the ruler is an insulator', or 'the pencil sharpener is a conductor'. Attention should, therefore, be paid to broadening pupils' experiences of conductors and insulators and the use of appropriate vocabulary.

In order to avoid the risk of presenting a long recipe-like list of recommended action, no further implications will be listed – not least because the ones already noted touch the very core of the areas addressed by this research. The point to make, with regards to the
implications deriving from the outcomes of this thesis, is that these acquire particular importance due to the fact that science is no longer an elite-only endeavour nor a topic of interest to the few, for the impact of science and technology on everyday life is tremendously widespread. An understanding of basic science concepts and the practice of certain scientific skills that can be of use in a layman’s life are by no means a dispensable objective for science education. This, therefore, calls for reflection on the teaching techniques and approaches employed in the past decades and imposes the necessity for teachers and science educators to maintain an open mind towards new suggestions or methodologies that can make a contribution towards more effective science teaching.

Returning to the claim of generalising results and the conclusions reached by this study, put forward earlier in the discussion, a further point needs to be highlighted. Although the problems raised, the theoretical discussion unfolded in the early chapters, the design and implementation of the research, and the claims put forward by this thesis were accommodated within the field of primary science education, this writer regards that the emerging theory revolving round the perceived relationship between metacognition, on one hand, and durability and ability to use knowledge across contexts, on the other, in connection to situated metacognition and the metacognitive instances approach, is potentially generalizable to subject areas other than the one of science, and to levels of schooling other than the primary.

In sum, the metacognitive instances approach introduced in this thesis is not problem-free, nor does it claim to offer some form of a panacea for the teaching of science. It is an approach that is highly demanding for both teacher and pupils, and an approach that may reward its followers only in the long-term. In addition, its application can be particularly difficult in cases where practitioners have little control over curriculum content. Nevertheless, implementation of the metacognitive instances approach has given some very promising signs, which, this writer believes should be explored further. The a priori dismissal of the potentials of the approach can be no wiser in principle than the ‘Paduan professors who refused to look through Galileo’s telescope’ (Harre, 1981 - cited in Robson, 1993, p.62). Throughout this thesis this researcher’s telescope was pointed in the direction of admittedly complex and very broad areas related to human learning. Consequently, the picture presented is only a part of the whole. The concluding section of this thesis puts forward recommendations for further research.
8.4. Recommendations for further research

...research is like a treasure hunt in which we search after small pieces of knowledge but they are not pieces of a jigsaw which will fit into one place... rather, they are like pieces of a kaleidoscope where we get changing patterns of knowledge (Savage, 1990, p.13).

The changing patterns of knowledge provide the driving force for the conduct of research and the ongoing advancement of academia. More often than not, the questions raised are more than the questions reaching a sufficient answer at the end of an enquiry, for

...a lot of research is concerned not with 'finding out something you don't know' but with 'finding that you don't know something' (Philips and Plugh, 1989, p.41).

Being widely accepted as a perfectly natural outcome of research -even more so in the case of studying complex phenomena related to human learning- enables researchers not only to avoid concealing such areas, but to highlight them as potential directions for further research. Identifying such directions is the main undertaking of the remaining of this chapter.

Having looked at four main areas, namely conceptual change learning, metacognition, durability of conceptions and ability to use conceptions across different contexts, it is inevitable that a great number of questions are generated. The list of potential directions for further research is therefore long, emerging from the multilateral focus of this study and the different ways in which the four areas interact with each other. This list is radically shortened by presenting only two research directions for each of the four main areas, considered by this researcher as the most important, or as the ones deserving immediate attention by the research community.

8.4.1. Conceptual Change Learning (Chapter 1)

1. A first research direction with respect to CCL is to attempt an insight into the specific concepts of electricity that proved problematic in terms of short durability and inability to use knowledge, such as 'electron flow' and 'short-circuit'. What is called for is not the holistic study of the nature of these concepts, something that was largely covered in the past (e.g. Driver et al., 1994b; Shipstone, 1998), rather an attempt to devise suitable methods for treating such problematic conceptions. This suggests that the pendulum of CCL-oriented research agendas should move away from children’s ideas and their learning towards the opposite direction, that of teaching for CCL. In doing so, the wisdom acquired during the long period of focusing on the first dimension should not be overlooked but should provide an important referent for grounding feasible, efficient and
philosophically congruent teaching techniques.

2. A second research direction within CCL evolves from this writer’s strong impression that children brought into class their home-generated knowledge of science (in this case, of electricity), mainly reflecting their parents’ understanding, explanatory ‘theories’, and vocabulary. The role of children’s home environment was studied in the past in a rather broad sense and disadvantaged students’ poor academic performance was attributed, among others, to parental apathy or ignorance (Feuerstein et al., 1980). This researcher believes that an extension of research into pupils’ prior conceptions of science should attempt insights into the role of ‘home science’ in developing alternative frameworks, and examine how links between school and home advocated by the flourishing area of promoting the public understanding of science (e.g. Millar, 1993; AAAS, 1995; Alsop, 1998) could make a positive contribution. Closely related to this direction, and in relation to the context of Cyprus where this research was conducted is the problem of the language of instruction and, more specifically, the use of certain idioms or expressions of the Greek language that largely impede children’s learning in science. There are to date numerous studies conducted by internationally acknowledged Greek science educators such as the ones by Psilos et al. (1988) and Vosniadou (1994) placed in a Greek context, yet the individualities of the language of instruction were largely overlooked. It is suggested that research be carried out in different subject areas of physics, chemistry and biology, in an effort to trace these cases, raise awareness among science teachers of Greek pupils and suggest methodological approaches for confronting such problems.

8.4.2. Metacognition (Chapter 4)

1. Researchers’ understanding of the mechanisms and the nature of metacognition to date remains incomplete and controversial living up to its description as ‘a many-headed monster’ (Brown, 1987). More research is needed that would, among others, enhance our understanding on what constitutes metacognition, how it can be identified, and whether it can be taught and how. With the theoretical foundations of metacognition beginning to take shape over the past few years an equally important direction would be to develop and test appropriate material for practising metacognition in science education. Such an attempt will primarily help to avoid the creation of a theory-practice gap, as was the case with the promising constructivist framework (Chapter 1). Eventually this course of action will facilitate the large-scale application of metacognitive instruction in the teaching of science and consequently offer a broader basis for further conclusions on the applicability and usefulness of metacognition in primary science. This researcher, therefore, follows Davidson and Sternberg (1998) in advocating the conduct of research on the use and training of metacognition in natural contexts.
2. *Situated metacognition* has given first signs of a positive impact on important dimensions of science learning, namely retention of taught concepts and ability to use these across different contexts, arguably by facilitating deeper understanding. In order for the *metacognitive instances* approach introduced in this thesis to find its way into the science classroom, more **long-term research** is needed both for verifying this positive impact on taught science, and for investigating whether learners gradually develop a form of *metacognitive fluency* in an accumulative way. It is this writer's belief that should *situated metacognition* be employed on a long-term basis over a number of different subject-units, benefits will extend beyond the science content tackled to a gradual acquisition of *general metacognition* by pupils. This does not suggest moving towards the teaching of general thinking skills or teaching children how to be metacognitive in a context-free manner, for even if different contexts are subsequently used the 'situated' character of the approach is still maintained. What is advocated is offering more opportunities on the same time-continuum for children to get used to, practice and become conscious of the usefulness of metacognitive activity. This researcher also welcomes research that will attempt comparisons between *situated* and *general metacognition* (Chapter 4) on the role each of the two can play with regards to pupils' understanding of school science.

8.4.3. Durability of pupils' conceptions (Chapter 2)

1. Following the introduction of the notion of *conceptual decay* (Chapter 2) in a study that aimed towards prolonging durability of conceptions, a further important step is to investigate approaches that will potentially reverse the decaying process towards more permanent knowledge. In order to do so, the nature of *conceptual decay* will have to be researched in greater depth, along with the nature of concepts that prove durable against that of concepts that exhibit *conceptual decay* more rapidly.

2. A second research direction with regards to durability of pupils' conceptions is to study the notion of *concept-life* investigating how the period that a conception remains in the learner's conceptual repertoire before further interaction takes place affects the success of CCL. In Chapter 2 it was argued that *concept-life* is not a period with fixed ends hence there exists the problem of defining the point at which *concept-life* ends and starts *conceptual decay*. In order to deal with this problem further research that will enhance our understanding of the notion of *concept-life* is needed. This writer suggests that *concept-life* is a period comprised of three smaller time sections as shown in Figure 8.1.
The first section is one of **consolidation** of the newly constructed concept. It is the point where the learner has grasped the meaning of the new concept that appears to be intelligible, plausible and fruitful, yet in need for further consolidation. The new piece of knowledge needs to be further tested, practised and left to ‘mature’ in the learner’s mind. The third section is the period when although some aspects of the learned concept are forgotten, the learner still maintains sufficient understanding of the concept. If left with no further instruction it is at this point when **conceptual decay** commences. If, on the other hand, further instruction is given towards more advanced, related concepts, this can be avoided. The second section of **concept-life** is a time-period that this writer calls ‘**period of optimum conceptual change learning**’ (POCCL). This is the point when the new concept has been consolidated in the learner’s mind and any intervention or new stimuli for further conceptual development (broadening of existing conceptions) will have optimum results since **conceptual decay** has not yet commenced. POCCL is a notion that experience of everyday learning can easily verify. It is widely accepted, for one, that not all learners need the same time in order to ‘learn’ a new concept; they need to read about it, solve relevant tasks, elaborate on its dimensions etc. If this is taken as an axiom of human learning then it can also be agreed that there must exist some abstract or unspecified point of conceptual ‘readiness’ or maturation. This thesis suggests that POCCL is that exact point, varying for each individual. POCCL can hence be defined as **the point in time at which interaction on recently constructed conceptions is most successful in leading to more advanced knowledge**.

The above analysis aimed at demonstrating that research on the notions of **concept-life** and POCCL could result in important outcomes, regarding **the role of timing in the process of CCL** and, consequently, necessitate potential changes in curriculum structure or the teaching frequency of science. It could be investigated, for example, whether running ‘intensive science weeks’ in which teaching would take place every 2-3 days, rather than spreading the teaching of a subject unit over a four- or five-week period (which is the current practice in all
public primary schools in Cyprus) could make a difference on pupils’ understanding and the durability of their conceptions.

8.4.4. Pupils’ ability to use conceptions across contexts – Transfer of knowledge

1. More research is needed with regards to the way familiar or less familiar contexts influence learners’ ability to use knowledge. In doing so, it might be useful, apart from studying learners’ performance to consider their own views as to how or why two contexts are perceived to be different and the difficulties they encounter in their attempts to use their knowledge. Pupils’ ideas, their perceived difficulties or attempts to tackle problems in different contexts, and the techniques they use, are only a few examples of aspects that could potentially be traced. Such insights will enable better understanding of the nature of context and help specify how difference or ‘distance’ between them can be defined.

2. Having looked at ability to use knowledge across different contexts, which is an area very close to the notion of transfer of knowledge, it is this writer’s belief that further research on the nature of transfer is needed that will potentially determine the direction of the debate regarding the feasibility of transfer of knowledge. In doing so, a primary objective should be to establish criteria for specifying what constitutes cases of transfer, and to identify and list the conditions for transfer to occur. Only when the ambiguity surrounding the notion of transfer is resolved can a shift be made towards ‘teaching for transfer’, either with an emphasis on general thinking and learning skills, or on specific content.
Figure 8.2 Graphic summary of Chapter 8

Chapter 8 - Implications for classroom practice

General implications for science education

Implications for the teaching of electricity in primary science

Recommendations for further research

- Conceptual change learning
- Metacognition
- Durability of pupils' conceptions
- Pupils' ability to use conceptions across contexts
Postscript to the thesis

Following the listing of a number of recommendations for further research it becomes all too obvious that -as the reader was warned in the Introduction- this thesis has not offered an end to the story of conceptual change learning. This is by no means to be viewed as a weakness or a flaw, rather it should be seen as a reasonable achievement within the moderate claims made by a realistic research addressing multidimensional and yet developing areas. Even more so, it is an outcome that is compatible to Latour’s (1987) description of the two faces of science as ‘one that knows and one that does not know yet’. Aspects of the ‘not knowing yet’ will always exist and will always offer challenging food for thought and further research.

... to myself I seem to have been only like a boy playing on a seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me (Isaac Newton - cited in Kaku, 1998, p.3).


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Appendix I

a. Outline of the research objectives
b. Teaching aims of the subject-unit 'Current electricity'
OUTLINE OF THE RESEARCH OBJECTIVES

- Examine the feasibility of offering metacognitive instruction to Year 5 primary school pupils by means of situated metacognition and the metacognitive instances approach.

- Investigate any impact of metacognitive instruction on the durability of pupils' conceptions and on their ability to use conceptions in different contexts, over the period of one school year. Examine such an impact in relation to pupils' level of understanding of taught concepts.

- Study the effect of situated metacognition in relation to group size, or the circumstances under which this is practised.

- Study the role of context in relation to pupils' performance by comparing performance in contextually different exercises - a) requiring 'context-free' plain recall of knowledge, b) placed in contexts similar to the ones used during teaching; and c) accommodated in unfamiliar or new contexts.

- Investigate whether pupils' ability to use their conceptions of science across contexts is durable.

- Identify potential differences among taught concepts of electricity with respect to their durability and relate findings to CCL research literature

- Investigate the suitability of using analogies for teaching basic concepts of electricity to primary school children.
AIMS FOR THE SUBJECT-UNIT ‘CURRENT ELECTRICITY’
(As specified in the book ‘First Steps in Science – Teacher’s Book’ issued by
the Ministry of Education and Culture of Cyprus)

LESSON 1 - ‘Simple electric circuit’ (80 minutes)

Aims:
Pupils should be able to:
1. assemble the material they are given (battery, bulb, two wires) to set up an electric circuit,
in such a way that the bulb will light
2. correlate the flow of electric current with the movement of electrons that exist in a free
   state in conductors
3. identify the two terminals of a battery (positive / negative)
4. explain that in order for the bulb in an electric circuit to light, there must exist a conductor,
   that leads from the negative terminal of the battery to the positive terminal
5. distinguish between open and closed electric circuits.

LESSON 2 - ‘Conductors and insulators’ (80 minutes)

Aims:
Pupils should be able to:
1. show experimentally that some materials allow electric current to pass through them
   (conductors) while some other do not (insulators).
2. report that metals are conductors of electric current
3. report at least three insulating materials
4. (a) identify metal parts, and parts that are made from insulating materials, on tools and
   electrical devices presented to them
   (b) explain the use of conductors and insulators on tools and electrical devices
5. report that the danger of electric shock is greater when the human body is wet
6. report at least three examples from everyday life where electricity can cause accidents
   (worn wires, cracked plugs, use of electric heaters in the bathroom etc.).
LESSON 3 - 'Short circuit - Switch' (80 minutes)

Aims:
Pupils should be able to:
1. find out that when two bare wires in a simple electric circuit make contact, this results in a short circuit
2. explain what a short circuit is, and report possible consequences
3. explain the role of the fuse in an electric circuit
4. find out that switches offer an easy way for opening and closing electric circuits.

LESSON 4 - 'The use of electricity' (80 minutes)

Aims:
Pupils should be able to:
1. identify on a plan of an electrical installation, the meter, the distribution box with the main switch and the fuses, the sockets, plugs, the wires and the electrical appliances
2. report at least three forms of energy in which electricity can be converted to, in different electrical appliances (heat, light, sound etc.)
3. solve a number of problems related to simple electric circuit, as encountered on devices given to them
4. identify out of a list of actions which are related to the use of electricity, those which we must avoid because they are dangerous.
Appendix II

a. Lesson plan: Lesson 3 'Short-circuit - Switch'

b. Samples of worksheet*

*(Reproduced by permission of the Department of Primary Education, Ministry of Education and Culture of Cyprus)
LESSON 3 - ‘Short circuit - Switch’

Time: 80 minutes

Aims:
Pupils should be able to:
1. find out that when two bare wires in a simple electric circuit make contact, this results in a short-circuit
2. explain what a short-circuit is, and name possible consequences
3. explain the role of a fuse in an electric circuit
4. find out that switches offer an easy way for opening and closing electric circuits.


Materials:
For each group: 1.5V battery, 2.5V light bulb with bulb holder, length of wire (10cm), 4 wires (16cm each) joint in pairs, scissors, sellotape, glue, 2 board pins, 2 drawing pins, rubber, cork, 3-4 strips of kitchen foil (5cm X 1cm),
paper disk (diameter: 3cm), nail, 2 paper clips, 2 envelope clips.
For the class:
4 1.5V batteries connected in series, 4 wires (15cm), 6V light bulb with bulb holder, kitchen wire-wool, fused plug,
screwdriver, 1-2 switches (the type of switch installed in houses).

Important notes:
Activities marked with an asterisk [*] are intended as means of practising metacognition and refer to activities and questions for the whole class.
Further questioning aiming towards causing reflection of pupils' current understanding and the processes they are following, is also used by the teacher, in groups, while children are carrying out activities (e.g. ‘What is the purpose of this activity? What do you know about electrons in a short-circuit? Why are you using this material to make a switch?).
The questions presented at points of classroom discussion are only indicative of fuller discussions that can be triggered by children’s responses or questions.

Introduction (10 minutes)
The teacher asks questions to revisit the following points from previous lessons:
open and closed circuit
electron flow in a closed circuit
conductors of electricity and insulators

[*] Based on pupils’ responses the teacher draws a concept map on the board, using concepts mentioned by the children. Emphasis is placed on the identification of relationships and connections between concepts, by the pupils. Children are also encouraged to share what they have written in their ‘diaries’ about the topics studied in the previous lesson.

He then tells the pupils that a house in his neighborhood burnt down a few days ago, and that the investigation that followed showed that the fire was caused by a short-circuit. The problem is then set:

What is a short-circuit?

The teacher encourages the children to say what they know about short-circuits (e.g. how they are caused, what their consequences can be etc). He then explains that Exercises 1 and 2 will help them reach an answer to this problem.
Activity 1 (15 minutes)
WORKSHEET 4 is given to the pupils along with the materials listed on the worksheet.
In Exercise 1 pupils of each group are expected to:
   a) set up a closed circuit following the instructions on the worksheet
   b) bring the two wires of the closed circuit together at points where these are covered with plastic
   c) bring the two wires of the close circuit together at the points where these are bare, for 3 seconds

[ * ] Discussion
The pupils are then asked to tell the rest of the class what they observed in their group.
('The light bulb continued to glow when the two wires made contact at a point where they were covered in plastic')
T: Why did the light bulb continue to glow?
('Because there was a closed circuit')

The teacher then draws a similar circuit on the board and asks the pupils to show the route of electron flow.

[ * ] Discussion
T: What happened in the case where the wires made contact at the points where they were not covered in plastic?
('The light bulb went out')
T: Why do you think the light bulb was not glowing then?
('Current was not passing through it...
')
T: What must have happened? [It is expected that pupils will give two explanations]
('Electron flow stopped completely')
('Current was moving but when it reached the point of contact of the two wires it went back to the battery without reaching the light bulb')
T: What was the main difference between the two experiments?
('In the second case the wires made contact at points where they were bare')

The teacher draws again the circuit and the children who support the second explanation show electron flow. He then tells the children that the next experiment will show which of the two explanations is the best one. He asks the pupils to gather close to his desk and performs the following experiment. He sets up a closed circuit, as shown in the figure on the left, and shows that the light bulb glows.
A pupil is asked to show the route followed by electrons inside the closed circuit and explain why it is that the bulb glows.

(Current passes through the wire-wool because it is a conductor of electricity)

Then the teacher joins the two wires so that they make contact at points where they are not covered by insulating material. The children are expected to observe that:

a) the light bulb went out
b) the wire-wool became red-hot and burnt in a matter of seconds

[With this experiment the children are expected to realise that current passed from the first loop in the circuit that did no include the light bulb]

The teacher then asks: ‘Why do you think current takes that route instead?’

Some of the children may guess that this was the shortest way. The teacher makes no comment at this point.

Activity 2 (30 minutes)
The pupils do Exercise 2 from WORKSHEET 4, in which they have to

a) set up a closed electric circuit as in Activity 1
b) place an additional wire that they can find among their materials, as shown in the figure below.

c) observe what happens

[*] d) show on all figures of Activities 1 and 2, the route followed by free electrons in the circuits, and discuss with their partners why this happened.

In order to explain why electrons pass through the second wire, rather than through the light bulb, the teacher presents the following figure on the board.

He then asks the pupils:

'If you were the driver of one of these cars taking part in a race, which of the two routes would you have chosen in order to finish the race first? Why?'

('Upper route: wider, shorter, easier...')
Based on children's reactions he explains that something similar happened in the circuit. Free electrons passed through the second wire which is a shorter and easier route than the one through the light bulb. This route is actually a new, shorter circuit which is called 'short-circuit'. The teacher encourages the pupils to ask questions if there is something that is not very clear about the analogy.

[*] He then suggests that the pupils take 1-2 minutes to think about what they learned to this point, and try to explain to their partners what is a short-circuit and why it is called like this [particularly important Greek]. (Reference is made to the resemblance of the Greek term 'vrahikikoma' (short-circuit') to 'something wet').

Following the teacher asks the pupils:
- **T:** What happened during the experiment with the wire wool?
  - ('The wire wool got red and burnt')
- **T:** Why did this happen?
  - ('It got really hot')
- **T:** How can we explain this?
  - (Children express different opinions)

The teacher explains that in the case of a short-circuit electrons move with greater ease, so greater current passes through the wires. As a result wires get hot.

At this point reference is made again to the house that was set on fire:
- **T:** How could a short-circuit been caused?
  - (Children’s responses)

Following children’s attempts to explain what happened, the teacher shows an enlarged copy of the figure below, and gives pupils the opportunity to attempt a new explanation.

He then explains that in order to prevent the consequences of a short-circuit, for safety reasons, we use fuses inside plugs and electrical appliances. He then unscrews a fused plug and shows the fuse to the pupils. He asks the pupils if they have seen one before and if they know what is the use of it. Following pupils’ responses the teacher explains that the thin wire inside the fuse cuts as soon as more than normal current passes through and the circuit opens, so there is no danger of fire or other damage to the appliances.

The children then complete the conclusion on WORKSHEET 4.

[*] Pupils who finish their work are then asked to draw a case of a short-circuit, showing the flow of electrons and explain briefly what happens in the circuit. A number of drawings are then presented to the rest of the class.

The following questions are raised next:
- **T:** What do we have to do when we want to make the bulb go out?
  - ('We open/break the circuit')
- **T:** How?
  - ('We disconnect one of the wires')
- **T:** Is there an easier way to do that?
  - ('Put a switch in the circuit')
- **T:** Where/when do we use switches?
  - ('When we want to light a bulb, operate an electrical appliance.')
A pupil is asked to turn the light on and off a few times.

T: What happens when we press the switch and the lamp glows?
(The circuit closes and current passes through)

T: What happens when the light bulb goes out?
(The circuit opens and that interrupts current flow)

Children are shown a switch (like the ones used at home) and are then asked to explain what materials are used to make a switch, and how they think it works. The teacher completes their responses by drawing the inside part of a switch on the board and explaining how it operates.

He then tells the pupils that in the next activity they will be making their own switch, which they will place in their electric circuit.

Activity 3 (20 minutes)
The pupils are given WORKSHEET 5 and the materials listed on it. They are left on their own to experiment freely in their groups, and think of a way to make a switch. Pupils can use any of the materials, in whatever way they wish. They are then asked to place their switch in the circuit and demonstrate its use.

(The figures below show different ways for making a simple switch with the materials available to the pupils)

Children from each group present to the rest of the class the switch they made, explaining the role of each of its parts and how it operates.

Last, reference is made to the fuse box that can be found in every electrical installation and the role of the main switch and the fuses is discussed with the children. Pupils are reminded that electricity can be very dangerous and that they should not experiment with sockets, fuses or any other part of the electrical installation at home.

Completion - Evaluation (5 minutes)
The teacher refers to the main points of the lesson by means of questions, like:

- When is a short circuit caused?
- How do we protect electrical appliances from short-circuits?
- What happens to current in a short-circuit?
- What is the use of a switch in a circuit?
- What materials is a switch made of? Why?

Pupils are then asked a) to construct a concept map showing what they learned about short-circuits and switches in today’s lesson; b) to make brief notes about 2-3 things they learned, or about points that they feel are difficult and they did not understand very well. If there is not enough time left either or both activities can be assigned as homework.
PROBLEM: What is a short-circuit?

EXERCISE 1

a) Using the MATERIALS set up a closed circuit, as shown in the figure, so that the bulb glows.

b) Touch for a while one wire on the other at points where there is plastic cover. What did you observe?

c) Push the bare parts of one wire so that it touches the bare part of the other wire. Let them touch only for a 2-3 seconds. What did you observe?
Disconnect one wire from the battery, so that the battery’s energy is not wasted.

Discuss in your group your observations and try to give an explanation.

EXERCISE 2

a) Again connect the wires to the battery, so that a closed electric circuit is made.

b) Connect the short wire to the circuit, shown in the figure. What did you observe?

What did you observe?

a) Use arrows to show the route followed by free electrons in the circuit, now that the short wire is there.

b) Also use arrows to show the route followed by free electrons in the three cases you have examined on the first page of WORKSHEET 4.

Following the discussion with the whole class complete the conclusion using some words or phrases from the balloon.

Conclusion

When two ......................... wires of a closed electric circuit make contact, a new ......................... circuit is created, which does not include the light bulb.

This circuit is called .........................
Current electricity - Lesson 3

Short-circuit - Switch

WORKSHEET 5

Making a simple switch

- In your group you have the device shown

Make a simple switch and place it on the device, so that you can turn the light bulb on and off whenever you want.

Use whatever you want from the MATERIALS and in whatever way you wish.

![MATERIALS](image)

- paper disk
- plasticine
- kitchen foil
1. Match the terms ‘open circuit’ and ‘closed circuit’ with the right figures

[Diagrams showing open and closed circuits]

2. Mark with ✓ the figures that show cases of short circuit

[Diagrams of short circuit scenarios]

3. Answer the questions:

a) Where can switches be found?

b) There is something odd in the phrase ‘close the lights’. What is that?

c) How is it possible that the lamp glows when there is ‘one’ wire? Shouldn’t there be a closed circuit? What do you think?
Appendix III

a. Test administered in the three phases of the research

b. Figures used during the interviews
ELECTRICITY

NAME __________________________ SCHOOL ___________ CLASS ___________

A. 1) Use little arrows to show the flow of electrons in the figure shown:

2) Fill in the gaps: In a closed circuit the terminal of the battery is the one that electrons.

3) When you connect a light bulb with wires and a battery does the light bulb glow instantly, or do you have to wait for quite some time?

How do you explain this?

B. Complete the sentences:

1) When an electric circuit is open, electrons

2) When an electric circuit is closed, the light bulb

3) When the switch is closed, electrons

4) When the television set operates, the circuit is

(4 points)

C. 1) When a light bulb ‘burns out’, what really happens inside the bulb?

2) When a ‘burnt out’ light bulb is connected to an electric circuit, will it glow? Why?

(4 points)

D. 1) Fill in the gaps: Insulators electrons and therefore electric current to pass through them.

2) Name two conductors and two insulators that you know:


(4 points)

E. 1) Short circuit is caused when two uncovered (bare) wires of a closed circuit make contact. The reason is that electrons

2) Explain why short circuit happening at home can be very dangerous:

(4 points)
A1
The diagram below shows an electric circuit. It is made of a battery, wires, two light bulbs (A and B) and a switch (S). What will happen when the switch (S) closes?

Put the correct answer in a circle:

a) Light bulb A will glow first
b) Light bulb B will glow first
c) Both light bulbs will glow simultaneously (together)
d) None of the light bulbs will glow

Justify your answer: ____________________________

(4 points)

B1
Below are a few electric circuits.
a) Write under each case, whether the circuit is open or closed
b) Put V in those cases where the light bulb will glow and X in those cases where the light bulb will not glow.

(4 points)
C1
In the circuit below light bulb B is 'burnt out'. What will happen when the switch (S) closes?

Put the correct answer in a circle:

a) Both light bulbs will glow
b) Only light bulb A will glow
c) Only light bulb B will glow
d) Neither of the light bulbs will glow

Justify your answer: ____________________________

(4 points)

D1
This is a device made by Year 5 children in their Design and Technology class.
After they fixed the wires on the wooden board, the children realised that the wires were not long enough to form a complete circuit. The only materials they have are the ones shown in the list below. Which of these materials can they temporarily use in order to bridge gap AB and see whether their device works?

Write ‘YES’ next to the materials they can use, and ‘NO’ next to the materials which are not suitable for this purpose.

Piece of wood ______
Cotton wool ______
Thin copper tube ______
Plastic ruler ______
Piece of iron bar ______
Pencil ______
Strip of thick paper ______
Strip of cloth ______

(4 points)
E1
Observe carefully the electric circuit shown below and do the exercises that follow.

[Diagram of an electric circuit]

a) When the wires are connected as shown above, will the light bulb glow? ____________________
Why? ____________________________

b) Use little arrows to show the flow of electrons in the circuit.

(4 points)

A2
Below is the inside of John's 'Bright Knowledge' table game. It is made of the board with the questions and answers, some wires, a battery, a bulb and a buzzer.
When John gets an answer right (that is, when he connects one wire to the metal point of a question and the other wire to the metal point of the right answer) which of the following will happen?

[Diagram of the game board]

Put the correct answer in a circle:

a) The light bulb will glow first
b) The buzzer will sound first
c) Both the light bulb will glow and the buzzer will sound simultaneously (at the same time)
d) Neither the light bulb will glow, nor the buzzer will sound

Justify your answer: ____________________________

(4 points)
B2
At the house of the Demetriou family their washing machine is driving them crazy! It nearly never works and causes a lot of problems!
The children are trying to give some explanations, regarding the operation of the washing machine. Can you spot which of these explanations are correct?

Write next to each statement ‘RIGHT’ or ‘WRONG’

a) When the washing machine operates, the circuit is closed
b) When the switch is open, there is flow of electrons
c) When the circuit breaker at the distribution box is activated, the washing machine keeps operating
d) When the fuse inside the washing machine’s plug ‘burns out’ the circuit closes

(4 points)

C2
Andrew’s grandfather has bought him a new game called “Young Scientists”. It is a collection with a lot of materials and instructions for children who like making different kinds of devices. Andrew has made the device shown below. He wants to place it next to his car racetrack in order to illuminate it! However, although he connects the wires to the batteries correctly, the light bulbs don’t glow!
- ‘Are the light bulbs all burnt out?’ he wonders.
- ‘Maybe it is just one of them that is burnt out’ says his mom.
Could Andrew’s mom be right? Justify your answer.

(4 points)
D2
Irene wants to get a new screwdriver as a present for her father who is an electrician. She can choose between the two screwdrivers shown below. Which one do you think she should choose? Explain why.

![Screwdriver with high-quality metal handle](PRICE £3.00)

![Screwdriver with plastic handle](PRICE £3.00)

Answer: ____________________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________
(4 points)

E2
At Kate’s house they have an old electric kettle that they have been using for many years. Kate has recently noticed that the kettle’s wire is worn. The plastic cover has been removed and the little bare wires inside can be seen...

a) What will happen if the two bare wires make contact (touch each other)?
Explain why. ______________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________

b) What else can cause the same effect? ______________________________________________________________________________________
__________________________________________________________________________________________________
__________________________________________________________________________________________________
(4 points)
Question 9

Figure 3

Question 10

A

B

C

Figure 4
Question 14

A

B

C

Figure 5
Appendix IV

Samples of material produced by the pupils during the practice of situated metacognition
I know very well that electrons are not athletes because if there were two light bulbs and one of them was burnt-out they would pass over it and only one of them would glow.

The example with the little seats for those who ski was very good because it helped me understand that all electrons start moving at once, like the little seats for those who ski. Before I thought that the bulb that was closer to the battery will glow first because the others had to wait for energy to travel all the distance inside the wires.
I knew that plastic and wood don’t let current pass and that they are safe but I didn’t know why. Now we learned that insulators don’t have electrons inside them.

I used to think that the light bulb glows wherever you touch the wires but now I learned that it doesn’t glow when you touch them on the glass.
In this lesson we learned about conductors and insulators. Conductors let electric current pass through them. Insulators don’t let electric current pass through them.

I enjoyed them (the lessons) a lot because electricity makes people’s lives easier and the first time our teacher brought a battery, two wires and a light bulb and told us to make the light bulb glow using those materials, and I think that this was a good and great experience for me.
(a) That is where it has the problem
(b) The bulb doesn't glow because electrons are not athletes to pass over it

The light bulb doesn't glow because it has a cut wire and electrons cannot get through
Here the light bulb will not glow because electrons will choose the short route.

(a) This pliers is for cutting wires ... they made it like this so that electricians don't catch electricity
(b) This is made of iron
(c) This is a screw made of iron for rotating when (he) wants to cut wires
(d) This is made of plastic ... they made it like this so that electricians don't catch electrocution
they have electrons

Exous ἐλεκτρονία

they don’t have electrons

Σέν ἐξουν ἐλεκτρονία

passes

άγ wyn

Electricity

doesn’t pass

Σέν άγ wyn

they are safe

Eίναι αὐθαξεμένοι

they are dangerous

Eίναι επιλαίαν ένω

conductor

insulators

δεν περνά ρεύμα - Ανοικτός

current doesn’t pass

κλειστός - περνά το ρεύμα

current passes

Switch

Ανοικτός

κλειστός

dead

καθώς

current passes

καθόταν

current doesn’t pass

Μέ εμπιστευθέντα χεριά

with wet hands

it is dangerous

πλαστικό και σίδερο

plastic and iron

όχι

no

Σύντονος

insulator

conductor

and Μέ υδρόπτε

Turns on lamps

καθώς

current passes

καθόταν

current doesn’t pass

πλαστικό και σίδερο

plastic and iron

όχι

no

Σύντονος

insulator

conductor

κατά τον εορταστικό οικισμό

at the festival