

The Patterns of Physics Problem-Solving From the Perspective of Metacognition

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I hereby declare that my thesis/dissertation entitled:

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- *the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.*
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Date: 16 July 2006

Signed:

Acknowledgement

In the name of ALLAH (The God), the Most Gracious and the Most Merciful.

All praise is due to ALLAH, the Creator of the Universe.

Peace be upon Prophet Muhammad, the final Prophet.

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Abstract

Previous studies in Physics problem-solving have suggested that there are differences between expert and novice Physics problem-solvers in terms of knowledge organisation and application in problem-solving. However, it is arguable that many of these studies are based on activities that should not be considered real problem-solving. Consequently, there is a limited body of research into fundamental aspects of problem-solving among the so-called ‘novices’ available to inform the design of instruction to develop problem-solving ability among ‘novices’. Recent work suggests that metacognitive skills play a vital role in problem-solving. Yet, there are only a few studies looking specifically into the role of metacognitive skills in Physics problem-solving. The research discussed here is an attempt to investigate the patterns of Physics problem-solving among 6 Key Stage 4 (14-16 years old) students in Cambridge through the lens of metacognition. In order to match the students with ‘real’ problems (i.e. that are difficult for them but solvable), 54 students from 2 schools were given a Physics Problems Test (PhyPT) consisting of 6 problems on Linear Motion and followed by 2 questions designed to measure the level of difficulty of each problem. Later, 6 students were selected to undergo a session of individual problem-solving using thinking-aloud and observation by the researcher, followed by retrospective semi-structured interviews. The thinking-aloud was recorded, transcribed and coded using the constant comparative method of Grounded Theory. The analysis of the thinking-aloud protocols was supported by the analyses of data from the interviews, observations and analysis of answer sheets. Though this small-scale project has not reached the stage of theoretical saturation, the use of an open coding technique, constant comparison method and theoretical sampling provide a concrete foundation for generating some working hypotheses about the pattern of Physics problem-solving among these students.

Overview

This dissertation reports from a doctoral research project using Grounded Theory to develop patterns of Physics problem-solving among Key Stage 4 students in Cambridge. However, to fulfil the requirement of the MPhil in Educational Research course, this dissertation reports some early stages of this research, which of course has not yet reached theoretical saturation or established any substantive theory.

In the first chapter, I present the background of Physics problem-solving in general and introduce the concept of metacognition. I also identify two research questions. Then, in the second chapter, I review studies in Physics problem-solving as well as studies in metacognition and problem-solving in general. In addition, the critical consideration of this literature offers a conceptualisation of the focus (problem solving in upper secondary physics learning) that provides the rationale for my research, and informs my theoretical sampling.

In the methodology chapter, I explain my epistemology, theoretical assumption, methodology and methods of the whole study. The exact procedures and justification of all the decisions made in this research process are also discussed in this chapter. The data analysis methods and the analyses of the data collected in this research are reported in detail in Chapter Four, where a model of Physics problem-solving of the students involved in this study is illustrated.

Finally, in the final chapter, I present some implications of my research on the instruction of school Physics problem-solving and on future research. I also suggest in brief, the future development of my doctoral research in the future. The research process using Grounded Theory has not yet achieved saturation and it is my intention that this will continue as a part of the doctoral research next year.

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In memory of my mother, Voon Mui Fah

1.0 INTRODUCTION

‘Education’ referred to experiences or instructions which nurtured the capacities (the concepts and skills, the mental operations and dispositions) for subsequent problem-solving and enquiry.

(Pring, 2000, p. 14)

One of the vital goals of education is to enable people to utilise their knowledge in problem-solving. Whitehead (1970) made this point when he stated that education is the acquisition of the art of knowledge utilisation. Dewey (cited in Pring, 2000) believed that worthwhile learning enables people to adapt successfully to new situations, to identify and deal with problems as they arise. Cumulative learning ultimately results in the establishment of capabilities that allow an individual to solve a wide variety of novel problems (Gagne, 1985). According to Greeno (1978), a major objective of instruction, especially in mathematics and science, is to strengthen students’ problem-solving skills. Furthermore, Larkin & Reif (1979) believed that Physics education must address the crucially important task of teaching students to become proficient problem-solvers. Hence, problem-solving is an essential component of education.

In Physics education, according to Bascones et al. (1985), “learning Physics is equated with developing problem-solving abilities, and achievement is measured by the number of problems which a student has correctly solved on a test.” (p.253). In the 2005 A-Levels Examinations, while most of the subjects’ pass rates increased, Physics is one of the three subjects (with French and German) that decreased (Ross, 2005). A decline of 2% in the Physics pass rate made this subject among the most difficult in school. Consequently, it is not surprising to see that, the 2005 Science (Physics) GCSE (The Times, June 2005) had the least candidates¹ relative to other science subjects (chemistry/biology).

According to Osborne et al. (2003), students perceive science, particularly physical science as a difficult subject. Bascones et al. (1985) reported that Physics was one of the most difficult subjects in secondary school curriculum. According to Larkin &

¹ The total number of candidates for Science (Biology) was 56522, Science (Chemistry) was 53428 and Science (Physics) was 52568; Science (Double Award) was 988900 and Science (Single Award) was 89348.

Reif (1979), most students find it considerably easier to acquire knowledge about Physics than to attain the abilities for applying knowledge flexibly in order to solve diverse range of problems. In addition, it has become increasingly difficult to teach Physics problem-solving (Larkin, 1980) as until now there has not been a single effective general methodology of Physics problem-solving (Husen & Postlethwaite, 1994; Mestre, 2001; Reinhold & Freudenreich, 2003).

1.1 Overview of research in Physics problem-solving

Research on developing an effective general instruction for Physics problem-solving started at least 40 years ago. Garrett (1986) reported that research in Physics problem-solving was started in 1961 by Dean in order to investigate Physics problem-solving techniques in secondary school. However, research in this area only started to evolve after the late 1970s with the works of Simon & Simon (1978), Larkin & Reif (1979), Larkin et al. (1980), Chi et al. (1981), Larkin (1981), Chi et al., (1982) and de Jong & Ferguson-Hessler (1986). Most of the research during that period was to identify the differences between expert and novice Physics problem-solvers. Later work by Savage & Williams (1990) and Heller & Heller (1995) is to establish Physics problem-solving models. Recently, the trend in Physics problem-solving research has shifted to identifying the factors that can increase problem-solving ability (Gerace, 2001; Harper, 2001; Kanim, 2001; Duke & Pritchard, 2001; Zou, 2001; Gerace et al., 2002; Park & Lee, 2004; Kuo, 2004). The overview of this trend is described in the next three paragraphs.

Reviewing the research in the 1980s, Mestre (2001) concluded that ‘experts’ have extensive knowledge that is highly organised and used efficiently in problem-solving. The ‘experts’ also approach problem-solving differently from the ‘novices’. The ‘experts’ categorise problems qualitatively and according to major principles whereas the ‘novices’ categorise problems quantitatively and according to superficial attributes of the problems (i.e., the objects that appear in the problem statement) (*ibid*).

There are two significant Physics problem-solving models established by Savage & Williams (1990) and Heller & Heller (1995). Savage & Williams (1990) recommended modelling for Physics problem-solving to solve mechanics problems; whilst Heller & Heller (1995) suggested the ‘Logical Problem Solving Model’

comprising of five stages (focusing the problem, explaining the physical principle or law, planning the solution, executing the solution and evaluating the answer).

One of the earliest Physics problem-solving studies concerning metacognition has been reported by Amigues (1988). Henderson et al. (2001) and Kuo (2004) explored the beliefs and ideas among lecturers about their students learning of Physics problem-solving. They both reported that metacognitive skills play a role in Physics problem-solving among undergraduates. These studies will be discussed in detail in the next chapter.

1.2 Metacognition in Physics education and problem-solving

From these three decades of research, the trend in studies of Physics problem-solving seems to have focused on cognition and subsequently metacognition. Seroglou & Koumaras (2001), through their framework of Physics teaching, argue that Physics education has shifted from the dimension of cognition in the 1960s to that of metacognition in the 1980s, and will move on to the era of emotional and philosophical dimensions after the metacognitive dimension has elapsed.

It has been argued that metacognitive skills should be taught to students to help them solve Physics problems (Mestre, 2001). According to Flavell (1979), metacognition refers to knowledge and cognition about cognitive phenomena. Following are some examples of how a person is said to apply the metacognitive skills (Flavell, 1976): When he/she realised that:

- a) learning A is harder than B.
- b) he/she must recheck C before accepting C as the answer or fact.
- c) he/she must jot down D so that it is not forgotten.
- d) he/she must ask someone else about the truth of E.

Kluwe (1982) said that the activities of metacognition can be divided into two categories which are: (a) the thinking subject has some knowledge about his/her own thinking and that of other persons; and (b) he/she may monitor and regulate the course of his/her own thinking. An example of the first category is an individual's knowledge about his/her shortcomings in memorisation. This is the knowledge of metacognition (*ibid*). As for the second category, it refers to an individual's cognitive activity having as

its object his/her own cognitive enterprise, aiming at efficient and appropriate thinking. An example of this is the change of speed of information processing under time pressure or the allocation of one's processing resources in order to focus on the relevant features of a situation. Some refer this as metacognitive *strategies* (Flavell, 1979) and others as metacognitive *skills* (Brown, 1978). In this dissertation, it refers to metacognitive skills.

In problem-solving, Greeno (1978) said:

In addition to knowing the concepts and propositions given in a text, students must also have knowledge of how to apply those concepts and propositions to find the solutions of problems. This "how to" kind of knowledge is in the general category of "skills,"...

(Greeno, 1978, p. 13)

The above mentioned skills, in my view, are the metacognitive skills needed to find the "how to" kind of knowledge. It is the cognitive activity of one's own cognition as stated by Kluwe (1982). These metacognitive skills have been listed variously as regulating, monitoring and orchestrating one's thinking (Flavell, 1976); planning, monitoring, evaluating, predicting and awareness of one's thinking (Brown, 1978); or regulating, monitoring and evaluating one's thinking (Jausovec, 1994; Vos, 2000).

Manning & Payne (1996) raised the issue of the various meanings and interpretations of metacognition. The definitions of metacognition may differ according to the context used, such as that of memorisation (Flavell, 1979), reading and comprehension (Flavell, 1985; Marzano et al., 1988), learning (Veenman et al., 1997), teaching (Manning & Payne, 1996), problem-solving (Kluwe, 1982; Vos, 2001) and others. However, in the interest of remaining within the word-limitation of this dissertation, these will not be discussed at length. In this dissertation, I will adopt the definition of metacognition used by the only secondary school Physics problem-solving study (Amigues, 1988), that is, metacognition refers to *knowledge about one's own cognition*.

The role of metacognition in problem-solving has been demonstrated by many researchers (DeGrave et al., 1996; Kuppasamy, 1992; Schoenfeld, 1992; Swanson, 1990; Foong, 1993; Fernandez et al., 1994; El Hmouz, 1998; Nooriza, 2001; Halina, 2003, to name a few), mostly in the context of mathematical problem-solving. Yet, there are few studies into the relationship between metacognition and Physics problem-solving among

secondary schools students. Most research on metacognition and Physics problem-solving focuses on university students (Heller & Heller, 1995; Henderson et al., 2001; Kuo, 2004).

If metacognitive skills appear to be relevant in Physics problem-solving among first-year university students, then it seems likely that these skills may play a role in helping secondary school students when solving Physics problems. The present study is an initial attempt to investigate the role of metacognitive skills in assisting secondary school science students to solve Physics problems individually.

1.3 Statement of the problem

This research will investigate the role and the pattern of metacognitive skills in Physics problem-solving among Key Stage 4 (i.e., 14-16 years old, hereafter KS4) students in Cambridge, United Kingdom.

1.4 Research questions

1. What is the role of the metacognitive skills in each step of Physics problem-solving?
2. What kind of pattern(s) in Physics problem-solving can be identified from the perspective of metacognition?

2.0 LITERATURE REVIEW: Towards a General Physics Problem-Solving Instruction

If one of the aims of Physics education, as explained earlier, is to produce proficient problem-solvers (Larkin & Reif, 1979), then Physics problem-solving research should first identify factors that will improve the problem-solving skills amongst students. In this chapter, I will discuss some important studies in Physics problem-solving that worked towards this aim. I will also report some studies of metacognition in general problem-solving and point out the use of thinking-aloud in these studies.

2.1 What is a Problem and Problem-solving?

Before I present the studies in the area of Physics problem-solving, it is important to clarify the definitions of problem and problem-solving.

... “problem” refers to a situation in which an individual is called upon to perform a task not previously encountered and for which externally provided instructions do not specify completely the mode of solution. The particular task, ... is new to the individual, although processes or knowledge already available can be called upon for solution.

(Resnick & Glaser, 1976, p. 209)

Dewey (1910) said that a problem occurs when an individual is confronted with a difficulty. Rowe (1985) defined problem-solving simply as the meeting of challenges. It means answering a question for which one does not directly have an answer available (van Someren et al., 1994). If we know exactly how to get from point A to point B, then reaching point B does not involve problem-solving.

Ray (1955) suggested that the problems utilised in a problem-solving research should be:

- a. reasonably complex (require several responses, allow trial and error)
- b. clear (description and classifiable as successful or unsuccessful)
- c. made available two or more procedures (allow discovery and prediction)
- d. scorable along a continuum.

According to the above definitions of ‘problem’, a problem in the context of my study should be difficult and unfamiliar to the solver but solvable and has at least a clear goal. An easy task in which an individual finds it easy and already knows how to

generate a solution will be called an *exercise*. Consequently, the process of finding an answer by completing an exercise is not problem-solving because,

In some educational dogmas and practices, the very idea of training mind [sic] seems to be hopelessly confused with that of a drill which hardly touches mind at all – or touches it for the worse - since it is wholly taken up with training skill in external execution. This method reduces the ‘training’ of human beings to the level of animal training.

(Dewey, 1910, p. 52)

According to Schunk (2000), not all learning activities in schools involve problem-solving because technically, when students become so skilful in problem-solving that they can reach the solution automatically, the actual process of problem-solving does not occur. It is possible for a student to carry out mechanical resolution, leading to a correct solution without any understanding (Gil-Perez et al., 1990).

Most researchers working on problem-solving (Dewey, 1910; Ray, 1955; Newell & Simon, 1972; Mayer, 1991, to name a few) agree that a problem occurs only when someone is confronted with a difficulty for which one does not directly have an answer available. However, difficulty is not an intrinsic characteristic of a problem because it depends upon the solver’s knowledge and experience (Elshout, 1987; Garrett, 1987; Gil-Perez et al., 1990). Hence, a problem might be a genuine problem for one individual but might not be for another. In short, problem-solving refers to the effort required in achieving a goal or finding a solution when no automatic solution is available (Schunk, 2000).

One has to distinguish between (1) the situation when an individual has relatively specific knowledge that makes problem-solving easy; and (2) another situation in which an individual must resort to more general knowledge and procedures to solve a problem (Greeno, 1980). Technically, the latter situation is real problem-solving. However, in most of the research before the 1990s, the informants considered as ‘experts’ were among those who are experienced and familiar with the Physics ‘problems’ and have been studying or teaching Physics for quite a long while (Simon & Simon, 1978; Larkin & Reif, 1979; Larkin et al., 1980; Chi et al., 1981; Larkin, 1981). These studies actually reflected the Physics knowledge of an expert in Physics, rather than an expert in Physics *problem-solving*. As a result, the expert frameworks constructed by these studies failed

to produce a general procedure that can help the ‘novice’ in solving Physics problems. Nevertheless, these studies served as a foundation in Physics problem-solving research, especially in the methods and techniques of analyses, which will be explained in the next section.

2.2 Early research in Physics problem-solving: ‘Expert’ versus ‘Novice’

As explained in the section 1.2, most of the early studies in Physics problem-solving focused on the differences between ‘expert’ and ‘novice’ problem-solvers. According to Mestre (2001), in order to improve Physics problem-solving among students, most of the studies attempted to understand the advantages that ‘expert’ problem-solvers have and transformed these advantages into Physics problem-solving instructions. Researchers assumed that by teaching problem-solving procedures of the ‘experts’ to the so-called ‘novice’ students, the students will be able to achieve the knowledge framework of experts.

The comparison of the differences between ‘expert’ and ‘novice’ was the main purpose of the studies in Table 2.1. However, these studies were not able to identify differences in problem-solving ability as the tasks were only genuine problems for the ‘novices’, but not for the ‘experts’. This is because, by looking at the column ‘Sample’ in Table 2.1, the ‘experts’ in these studies are individuals with considerable knowledge, experience and training in Physics and consequently the process of reaching a solution is both easy and automatic for them. In contrast, the ‘novices’ have less knowledge, experience and training in Physics, meaning that they are actually facing ‘real’ problems.

Table 2.1: Summary of early research in Physics problem-solving.

Author(s) & year	Purpose(s)	Sample	Procedure(s)
Simon & Simon (1978)	Individual differences between a more experienced solver and a less experience solver in kinematics.	‘Expert’: had strong mathematical background and wide experience in solving kinematics questions ‘Novice’: had taken a single course in college Physics many years previously and had an adequate background in algebra.	Solved 25 kinematics textbook problems using thinking-aloud; analysed quantitatively and qualitatively.
Larkin & Reif (1979)	To produce a Physics problem-solving model of ‘expert’ and ‘novice’ each in the topic of mechanics	‘Expert’: Physics Professor who has recently taught a mechanics course ‘Novice’: undergraduate who has just completed his first university-level course in mechanics	Solved 5 mechanics textbook problems using thinking-aloud; analysed qualitatively to produce an expert and a novice model.
	To teach an ‘expert’ model to a group of students in a small-scale experimental instruction to determine the success of the model.	10 first-year Physics course volunteers: 5 were taught the ‘expert’s’ model & 5 were taught the ‘novice’s’ model, within same topic & same amount of time.	Small-scaled experiment; Both groups solved 3 electric circuit problems using thinking-aloud; considered successful if an answer was obtained within time limit.
Larkin et al. (1980)	To investigate the production systems of ‘experts’ and ‘novices’ in Mechanics.	‘Experts’: 10 Physics Professors and 1 Physics advanced graduate student. ‘Novice’: 11 first-year university-level Physics students	Solved 2 dynamics problems using thinking-aloud; 4 codes: a) statements of principles; b) instantiations of principles; c) algebraic combinations; d) statements of values
	To build two computer simulations representing the ‘expert’ and ‘novice’.	‘Expert’ simulation used knowledge development model (working forward) ‘Novice’ simulation used means-ends analysis (working backward)	Compared with the human models and made modification.
Chi et al. (1981)	To investigate the differences between ‘expert’ and ‘novice’ in categorisation and representation of problems.	‘Experts’ – advanced Physics PhD students, Physicists. ‘Novices’ – first-year Physics undergraduates, college students.	4 studies: 1 & 2: categorised problems according to the solutions. 3. explained solutions to problems in 3 minutes; analysed into network depictions & production systems 4. talked-aloud solutions of 20 problems and explained the features that cued the choice of solutions.
Larkin (1981)	To build computer simulations that represented the ‘expert’ and ‘novice’	‘Experts’: 10 Physics and 1 Physics advanced graduate student. ‘Novice’: 11 first year university-level Physics students	Solved 5 mechanics problems using thinking-aloud; analysed into solution paths.

In Simon & Simon’s (1978) and Larkin et al.’s (1980) studies, the ‘experts’ spent less time solving ‘problems’ because they, as experienced solvers in kinematics

problems, must have undergone extensive training. According to Neves & Anderson (1981), practice can help shorten the time used to solve ‘problems’.

If we assume that a relatively constant amount of time will be spent on problems, then in the initial stages of practice some good solution will not be discovered because they involve too much search time. As the search process with a problem becomes faster, more and more of the search tree can be explored...

(Neves & Anderson, 1981, p.83)

So the ‘experts’ already have all of the ‘search trees’ needed to solve most of these ‘problems’. It is more likely that ‘experts’ can also solve the problems in less time as they have developed automatic processing through a lot of practice (Shiffrin & Schneider, 1977). Larkin et al. (1980) claimed that the ‘experts’ combined principles, collected necessary information and generated new information all in a single step. They explained that,

...after writing an equation, these solvers (skilled) rarely explicitly mention the values of its variables, but simply proceed to solve the equation, using these values. Thus apparently these solvers already know the values of the variables as they write the equation...

(Larkin et al., 1980, p.338)

Another study by Larkin (1981) further strengthens my argument. Larkin (1981) built a computer simulation programme which had the ability to store production systems (a production is a condition-action pair of the form “If...then...”) that have been used to solve problems correctly, giving the simulation “a kind of” learning mechanism similar to human’s learning ability. The simulation was called ABLE and was built in a primitive mode that only contained a list of mechanics principles and symbols. A ‘barely ABLE’ (most primitive form) used general algebraic means-ends strategy to represent the workings of a ‘novice’ found in previous studies (Simon & Simon, 1978; Larkin et al., 1980). The learning mechanism of ABLE was to store all of the correct production systems and transform them into a solution path cued by a characteristic pattern of known quantities. The new solution path was the new information or knowledge that would be stored and used every time the cue appeared to ensure shorter time and steps in problem-solving. The more developed (with new knowledge) ABLE was called ‘more ABLE’.

Larkin (1981), through her research (see Table 2.1), found that the ‘barely ABLE’ represented the working of ‘novices’ and the ‘more ABLE’ represented that of ‘experts’.

The ‘more ABLE’ had being trained with a number of similar problems until it was capable of building solution paths according to particular cues in problems. Thus, the organisation of domain-specific knowledge (e.g., in this study - mechanics) associated with problems situations was more clustered resulting in faster execution of the solution. Hence, this study actually inferred that a solver only becomes ‘expert’ after being exposed to a wide range of training and experience in solving similar problems. This, according to Greeno’s (1980) type (1) ‘problem-solving’ (as in section 2.1), is not problem-solving because the individual has relatively specific knowledge that makes ‘problem-solving’ easy.

Some studies found that ‘experts’ used ‘working-forward’ or ‘knowledge development’ strategy while ‘novices’ used ‘working-backward’ strategy or ‘means-ends analysis’ (Simon & Simon, 1978; Larkin et al., 1980; Larkin, 1981). ‘Working forward’ strategy implies that the solver operates from the given in the problem (initial state) to the goal (the desired answer) while ‘working backward’ strategy operates from the goal to the initial state (Schunk, 2000). The means-ends analysis used by the ‘novice’ in Simon & Simon’s (1978) study was described as a more ‘primitive’ approach where there is no immediate solution. The ‘novice’ created subgoals for each problem resulting in more time taken to solve each problem. I would argue that, by using such a procedure, the ‘novice’ was really solving a problem because he/she encountered problems with no immediate solution that forced him/her to turn to means-ends analysis. Furthermore, means-ends analysis is described as one of the popular and powerful problem-solving heuristic strategies (Mayer, 1991; Schunk, 2000). It involves the ability to investigate a wide range of possibilities since there is no immediate solution in mind. The ‘experts’ worked forward purposefully because they knew precisely what to look for, since they had already encountered similar ‘problems’ before. The ‘novices’, however, had to work backward in order to look for the possibilities that might help them reach the solution. This kind of comparison only reflected the differences of knowledge and experience in answering Physics question, and so did not help identify the skills to solve Physics problems.

In addition, Chi et al., (1981) reported that there are also differences between ‘expert’ and ‘novice’ in terms of knowledge organisation. In Study 3 (see Table 2.1), the network depictions of the ‘experts’ are richer and are associated with basic physical principles as well as some procedural knowledge. Hence, they claimed that the ‘experts’ have a lot of tacit knowledge that can be used to make scientific inferences and to select various principles that can be applied to a problem. This organisation of knowledge among the ‘experts’ is not surprising because, as explained in the ‘more ABLE’ (Larkin, 1981), richer production systems and solution paths can be produced and stored through practice. It maybe appropriate to say that the categorisation of knowledge about problems can imply the knowledge differences between someone who is more experienced and has mastered Physics knowledge (i.e., professor, advanced graduate, physicist) and someone who is not (i.e., first year undergraduate, college student). This, however, does not represent real problem-solving as defined earlier.

In Larkin & Reif’s (1979) study, it was found that the ‘expert’ had organised his/her knowledge into coherent methods that integrated related principles in a functional unit that could be easily executed while the ‘novice’ did not show this knowledge organisation (similar to Chi et al., 1981). After their small-scaled experimental study (see Table 2.1), it was reported that 3 respondents from the ‘expert’ group solved all the problems while 2 respondents solved 2 problems. As for the ‘novice’ group, 4 respondents solved no more than 1 problem while 1 respondent solved all the problems. It must be remembered that in their research, a problem was considered solved successfully if the respondent could give a correct answer within a time-limitation. As explained earlier from the quote by Neves & Anderson (1981), ‘experts’ (trained and experienced) will always use less time compared to ‘novices’. Thus, the criterion of time-limitation should not be used to judge the problem-solving ability of someone who is faced with a ‘real’ problem.

2.2.1 Summary: End of ‘Expert’ versus ‘Novice’

The final aim of these studies was to understand how an ‘expert’ solved Physics problems and attempted to design a general Physics problem-solving instruction that can be taught to students. If problems appeared to be relatively easy for the ‘experts’, the

‘experts’ in the studies in Table 2.1 were not really solving problems. Rather, they were answering questions or doing exercises in a domain-specific knowledge area with which they were very familiar. The instruction would only be “drilling” (as explained by Dewey, 1910) the students with more training in storing sets of solution paths and production systems that could be retrieved whenever a cue for a particular problem occurred. Thus, while this studies serve as good methodological premises from which to begin my investigation, their comparison of ‘expert’ and ‘novice’ solvers failed to produce a general problem-solving instruction that could be taught to students to improve their problem-solving skills. The failure to produce a general method of Physics problem-solving also has been noted by Husen & Postlethwaite (1994) in their review of Physics problem-solving before the 1990s.

Furthermore, Gil-Perez et al. (1990) suggested another way of looking into this problem. Instead of researching the advantages of expert problem-solvers to produce a problem-solving instruction, researchers can try to investigate students’ difficulties in confronting ‘real’ Physics problems and indicate ways to overcome these difficulties. By researching the characteristics of students’ problem-solving patterns, a general instruction guideline can be produced in order to meet various patterns of Physics problem-solving found among the students.

2.3 Later research in Physics problem-solving: Another way

Although there is no explicit argument found in recent literature about the reason(s) for the failure to produce a general problem-solving instruction, most of the researchers after the mid-1980s did not follow the previous research trend to compare ‘expert’ and ‘novice’ in problem-solving. They favoured studying Physics problem-solving among students from the same age-group and in particular factor(s) that affected Physics problem-solving (Bascones et al., 1985; Amigues, 1988; Robertson, 1990; Henderson et al., 2001; Kuo, 2004). Robertson’s (1990) study described in Table 2.2 further strengthens my argument that if a student has done a wide range of exercises on a specific area of Physics, he/she can subsequently generate a solution for a question that is familiar to him/her without necessarily understanding it.

Table 2.2: Summary of later research in Physics problem-solving.

Author(s) & Year	Purpose(s)	Sample	Procedure(s)															
Bascones et al. (1985)	To assess effectiveness of Ausubelian instruction versus the traditional instruction.	76 ninth-grade students in a Venezuela secondary school.	1 year of statistical experimental study: 1. Traditional group 2. Ausubelian group Pre- & post-tests: 1. problem-solving ability (reasoning) 2. verbal comprehension 3. numerical ability 4. attitude towards science 5. attitude towards problem-solving															
Amigues (1988)	To investigate how peer-interaction which evoked metacognition and sociocognitive confrontation can help promote better problem-solving in electrical diagrams	58 tenth-grade students in France	Experimental study; <table border="1" data-bbox="787 615 1393 835"> <thead> <tr> <th>Groups</th> <th>Analysed errors (3 electrical diagrams)</th> <th>produce a functional electrical diagram (problem-solving)</th> </tr> </thead> <tbody> <tr> <td>Group1</td> <td>Individually</td> <td>Individually</td> </tr> <tr> <td>Group2</td> <td>Individually</td> <td>Pairs</td> </tr> <tr> <td>Group3</td> <td>Pairs</td> <td>Individually</td> </tr> <tr> <td>Group4</td> <td>Pairs</td> <td>Pairs</td> </tr> </tbody> </table> Post-test: Individually produce a functional electrical diagram (same problem after 15 days). Conversations of 8 pairs of students' analysis of errors of 3 electrical diagrams were recorded and interpreted.	Groups	Analysed errors (3 electrical diagrams)	produce a functional electrical diagram (problem-solving)	Group1	Individually	Individually	Group2	Individually	Pairs	Group3	Pairs	Individually	Group4	Pairs	Pairs
Groups	Analysed errors (3 electrical diagrams)	produce a functional electrical diagram (problem-solving)																
Group1	Individually	Individually																
Group2	Individually	Pairs																
Group3	Pairs	Individually																
Group4	Pairs	Pairs																
Robertson (1990)	To prove that deep understanding of Physics concepts will result in better problem-solving skills.	20 first-year Physics course college students (paid volunteers).	Solved 3 problems using thinking-aloud, solved 4 familiar problems and 3 transferred problems silently; Coded the protocol into 6 categories: 1. basic description of the problem 2. theoretical description of the problem 3. exploratory analysis 4. metacognitive statements 5. problem solution 6. assessment Performed multiple regressions to see which factor (index (understanding); mathematics score; verbal score; Physics score (from examinations in the course); familiar problems; sex) best predict the performance of transfer problems.															
Henderson et al. (2001)	To know what the Physics instructors' ideas are about their teachings and learning of Physics problem-solving among undergraduates	30 Physics lecturers	Answered a 'goal survey' questionnaire to rate 2 most important goals (out of 16 goals) of first year Physics course; Interviewed 6 of the lecturers to understand their ideas of how students can learn best in Physics problem-solving and how they can teach problem-solving.															
Kuo (2004)	To understand the Physics instructors' conceptions about their students' problem-solving processes	30 Physics lecturers	In-depth interviews with the lecturers to generate concept maps of how their students solve Physics problems.															

The transfer problems in Robertson's (1990) study are problems that are structurally but not conceptually unfamiliar to the solver; he/she cannot produce standard algorithms without an understanding of the concepts. It is clear that the transfer problems are unfamiliar problems which share similar characteristics with the problems explained in section 2.1. In Table 2.3, the near to zero correlation of transfer problems with familiar problems (.015); the negative correlation between transfer problems and Physics examinations' results (-.166); and the high correlation of familiar problems and Physics examinations' results (.409), indicate that questions in examinations are familiar problems (which students often encounter) but transfer problems are difficult problems. Thus, one can conclude that the transfer problems used in this study channelled the students toward real problem-solving.

Table 2.3: Correlation matrix showing the relationships between transfer performance and predictor variables (Robertson, 1990)

	Transfer problems	Index	Maths Scores	Physics Exams	Sex
Index	.762**				
Maths Scores	-.343	-.514*			
Physics Exams	-.166	.032	.358		
Sex	.045	-.007	-.063	.207	
Familiar Problems	.015	-.095	.393	.409	-.321

* $p < .05$, ** $p < .001$

From Table 2.2 it is clear that, in the studies undertaken after the 1990s, there was no comparison between expert and novice, but instead the purpose of the research was to investigate particular factor(s) like understanding (Bascones et al., 1985; Robertson, 1990), metacognition (Amigues, 1988) and lecturers' beliefs (Henderson et al., 2001; Kuo, 2004). However, the experimental studies (Bascones et al., 1985; Amigues, 1988) which employed statistical analysis for a small sample size failed to show that understanding of Physics concepts is the major factor that influences Physics problem-solving.

In Bascones et al.'s (1985) study, "Ausubelian" instruction promoted cognitive development and meaningful learning of Physics concepts rather than the verbatim memorisation of definitions used in traditional instruction. The students' problem-solving ability was tested using 8 different Physics problems and their reasoning patterns

were measured by a rubric form (0-15 points) that assigned points for specific behaviours shown by the students. From the ANOVA and correlation statistics generated, both of the groups showed improvement. The “Ausebelian” group performed significantly better than the traditional group, but none of the students in the Ausebelian group reached the mastery level of problem-solving ability (9.00) after a *one-year-long period* of instruction. On average, there was only a 1.09 increase from the result of pre-test on problem-solving ability (3.78). This post-test result of 4.97 out of 15 does not imply a level of good problem-solving ability after the one-year-instruction (the effect size should be considered in the calculation of significance). There might be several possible reasons: (1) the “Ausebelian” instruction may not have been very effective in increasing problem-solving ability; or (2) without an investigation to understand the problem-solving patterns of the students, the researchers may have assumed that the “Ausebelian” instruction was suitable and effective for all of the students; or (3) statistical comparison may have been too general to represent the effectiveness of the instruction (e.g., only looking at the overall means rather than the individuals. 7 out of 36 of the “Ausebelian” group scored more than 6.00 on the problem-solving ability test); or (4) perhaps the problem-solving ability was measured by reasoning pattern while the “Ausebelian” instruction was designed to improve understanding (a lack of construct validity).

In Amigues’ (1988) study, the quantitative results were inconsistent across the groups. However, it was found that the students in pairs performed better in analysing errors in electrical diagrams, while students who worked individually performed better in producing functional electrical diagrams. From the qualitative analyses of the conversations, it was found that the interactions that encouraged self-monitoring, self-regulation, evaluation and verification helped the problem-solving. These elements of metacognition are of particular interest to my research. In Amigues’ (1988) study, the conversations within the pairs resembled the interpersonal interaction. In an individual case, it is assumed that this kind of conversation or dialogue would manifest itself as an intrapersonal interaction in the student him/herself. Flavell (1987) explained this as the person variable under the three subdivided categories of metacognitive knowledge (the other two are task variables and strategy variables). In the person variables, there are another three subcategories: intra-individual (knowledge or belief about one’s own

thinking), inter-individual (knowledge or belief about other's thinking) and universal (knowledge or belief about universal aspects of human cognition or psychology). If a student can be encouraged to talk to him-/herself during the process of problem-solving, the thinking (cognition) or the thinking of his/her own thinking (metacognition) can be assessed.

The studies by Henderson et al. (2001) and Kuo (2004) showed the importance of metacognition in Physics problem-solving. The lecturers in Henderson et al.'s (2001) research believed that a "sign of maturity" is the most difficult category of problem-solving skill that students must learn. This "sign of maturity" was described as metacognitive skills or reflective practice (i.e., realising that the final result is too large; playing around to see what approaches might be valuable). Kuo (2004) generated 2 final models (a linear & cyclical) of undergraduates Physics problem-solving perceived by the instructors. The linear model implied that the instructors believed that students understand the general Physics principles and concepts of the problem and that they do not need to backtrack while solving the problem. According to the cyclical model, instructors believed that checking is required because the correct decision is not always made by the students. Some elements of metacognitive skills in both of these models were extrapolated during interviews. However, there were a lower percentage of metacognitive elements in the linear model because in the cyclical model, students must intellectually retrace their steps, and go back and forth, before they come to the correct answer. In this research, Kuo (2004) categorised the metacognitive statements expressed by the instructors into 3 main metacognitive skills: planning, monitoring and evaluation. Planning involves metacognition that is related to starting a solution to a problem; monitoring involves metacognition that is related to checking the progress of a solution to a problem; and evaluation involves metacognition that is related to checking the reasonableness of a solution to a problem (*ibid*).

2.3.1 Summary

Over the past 30 years, the emphasis within the literature examining Physics problem-solving has shifted away from analysis of cognitive to metacognitive. This trend is consistent with the Physics teaching's framework suggested by Seroglou &

Koumaras (2001). Indeed, it was also suggested by Mestre (2001) that metacognition should be taught to school students in order to improve their problem-solving skills. However, it is the contention of this dissertation that without an understanding of how students use metacognitive skills (consciously or unconsciously) in solving Physics problems, it would be difficult to design and implement effective metacognitive instructions of Physics problem-solving among secondary school students. Furthermore, as one of the aims of Physics education is to inculcate better problem-solving skills, there is a need for research with an emphasis on *genuine* problem-solving; as opposed to doing exercises or answering questions.

2.4 Research in metacognition and problem-solving: How metacognition help problem-solving

A number of studies have addressed metacognition and problem-solving in either general or specific subject areas (see section 1.2). Table 2.4 shows some studies that use ‘real’ problems among secondary school students.

Table 2.4: Summary of recent study in metacognition & problem-solving.

Author(s) & Year	Purpose(s)	Sample	Procedure(s)	Finding(s)
Yeap (1998)	To observe the patterns and metacognitive behaviours in mathematical problem-solving	10 Year-7 students in Singapore	Solved a mathematical problem using thinking-aloud while being observed by the researcher and interviewed later.	Metacognitive experiences are more important in determining the success of the problem-solving.
Stillman & Galbraith (1998)	To understand metacognitive behaviours of students in solving real world mathematical problems.	22 Year-11 female students in a school in Australia	Solved a mathematical problem in pair using thinking-aloud, followed by interviews to elaborate their problem-solving processes.	Students spent less time in orientation activities but more time in organisation, execution and verification activities.
Goos et al. (2002)	To investigate the metacognitive activities of students in solving mathematical problems.	Pairs of students in 5 different schools in Australia	Naturalistic longitudinal study. Video- & audio-taped targeted pairs of students in classrooms during problem-solving activities, followed by interviews.	Transactive discussion of metacognitive new ideas and assessment appears to be a significant factor in successful collaborative problem-solving.
Kramarski et al. (2004)	To compare the cooperative-metacognitive instruction on solving authentic mathematical problems	91 seventh-grade students in Israel	Experimental study (6 weeks); 2 metacognitive instruction groups & 1 non-metacognitive instruction group; individual pre- & post-tests (1 authentic task & some standard tasks).	Cooperative-metacognitive instructional students were significantly outperformed the cooperative instructional students for both authentic and standard tasks.

In Yeap's (1998) and Stillman & Galbraith's (1998) studies, the problems are unfamiliar and new to the students (according to Park & Lee (2004), real-world problems are unfamiliar and difficult for secondary school students); in Goos et al.'s (2002) study, the problem-solving activities took place after the students had been taught a new topic, hence the problems used were new to them; and in Kramarski et al.'s (2004) study, an authentic task is defined as a problem where no ready-made algorithms are available to solve the problem whereas a standard task has ready-made algorithms. Thus, 'real' problem-solving was being observed in these studies using quantitative and qualitative methods. All the studies reported the importance of metacognition in assisting secondary school students in solving mathematical problems. This opens up the possibility of exploring, in similar manner, the metacognitive aspect of problem-solving in Physics among secondary school students, which remains understudied.

2.5 Research using thinking-aloud: How to observe metacognitive skills and problem-solving in Physics

In this section, I will discuss the methods used by some researchers in observing Physics problem-solving and metacognitive skills in their studies. From the summary of Science problem-solving research by Garrett (1986), there have been four methods used to investigate Physics problem-solving between 1950s and 1980s. These are experimental/statistical research (4 studies), case study (1 study), individual interview (1 study) and protocol analysis (7 studies). With the exception of one study that used statistical measurement (Bascones et al., 1985) and two that used interviews (Henderson et al., 2001; Kuo, 2004), most of the studies reported in section 2.2 and 2.3 produced thinking-aloud protocols (Simon & Simon, 1978; Larkin et al., 1980; Chi et al., 1981; Larkin & Reif, 1979; Larkin, 1981; Robertson, 1990; Amigues, 1988).

While thinking-aloud method is a useful method in observing problem-solving (van Someren et al., 1994; Gilhooly & Green, 2002), it is also a very useful method for research in metacognition (Rowe, 1991). This is demonstrated by some recent studies shown in section 2.4 which applied thinking-aloud to observe the metacognitive behaviours (Yeap, 1998; Stillman & Galbraith, 1998; Goos et al., 2002). In some studies in metacognitive skills, the use of thinking-aloud protocol generated more categories of

metacognitive skills in addition to the two that were introduced by Flavell (1976) (monitoring and regulating). For instance, mathematical problem-solving studies carried out by Garofalo & Lester (1985) and Stillman & Galbraith (1998) generated four categories of metacognitive behaviours: (1) orientation (strategic behaviour to assess and understand a problem); (2) organisation (planning of behaviour and choice of actions); (3) execution (regulation of behaviour to conform to plans); (4) verification (evaluation of decisions made and of outcomes of executed plans). Science problem-solving studies conducted by Mettes (1987) and Veenman & Spaans (2005) established four categories of metacognitive skills in learning and problem-solving: (1) orientation (preparing for the task, analysing problem, constructing goals, building mental model); (2) planning/systematic orderliness; (3) evaluation (regulation and control of the process, monitoring and checking); (4) elaboration (connecting existing knowledge with incoming information, linking process).

An important aspect of the above studies is that their use of thinking-aloud is not limited to a certain age-group. The theoretical explanation of the use of thinking-aloud has been reported by Ericsson & Simon (1980) and Gilhooly & Green (2002). Among the adults, spontaneous thinking-aloud can be observed when they are on their own or in a noisy environment; whereas among children, it can be observed when they encounter difficulties in problem-solving or understanding (Gilhooly & Green, 2002). Thus, the use of thinking-aloud protocol is an appropriate method to observe both Physics problem-solving and metacognitive skills in my study. The ‘validity’ of this method will be further explained in section 3.5.1.

2.6 Summary

In this chapter, I have explained the limitations of the studies before the 1990s. With the recent development of research about metacognitive skills in problem-solving, some researchers in Physics problem-solving have also turned their attention to this factor, which might shed light on the production of a general problem-solving instruction. I have also shown how metacognitive skills help secondary school students in solving problems in other knowledge domains and have suggested that thinking-aloud is a method that is suitable for my research.

3.0 RESEARCH METHODOLOGY

In the previous chapters, I have explained clearly the reason for conducting this research and also the formulation of my research questions. In this chapter, I will explain the selection of methodology that will generate suitable research design to answer my research questions.

3.1 Methodological approaches

The selection of research methodology in educational research can be approached from perspective of personal value (Greenbank, 2003) and research question (Thomas, 1998). I will first explain my personal value in educational research. According to Greenbank (2003), when a researcher is deciding what research method to adopt, inevitably the underlying ontological (the nature of the world) and epistemological (ways of knowing the world) position of the researcher will influence his/her choice. This personal value about what is the 'right' thing to do will give priority to a certain kind of explanation and assumption about human beings. Hence, my personal value about educational research is embedded in the profession as a teacher:

In my experience, when teaching a simple topic of Physics to a class of 30 students, with the same teacher (me), classroom, materials and time, not all students can answer the same questions and their achievement differs in time. When the unsuccessful students were asked for the reason for the failure to give correct answer, again, their feedback differs. Sometimes, when I asked them to explain the reason, they suddenly realised why they were wrong and with a little help, the students improved gradually. But sometimes, the students could not explain why. I came to realise that there is hardly a single truth in human behaviour (at least among my students) and what is called reality is time-bounded. In order to understand a situation in-depth, sometimes I have to work together with the student, who would provide me with information to let me understand the real situation. My action to explore the situation sometimes can influence the students.

Rodwell (1998) suggested that there are two major paradigms in social science: positivist and interpretive paradigms. However, most social scientists attribute quantitative methods to the positivist paradigm and qualitative methods to the interpretive

paradigm (Henwood, 2002). Yet, one can combine both quantitative and qualitative methods within one paradigm, while still attending to the rigour requirements arising from the epistemological assumptions of each position (Rodwell, 1998). From the explanation of my personal values in education, my epistemological assumption is interpretive paradigm that proposes multiple realities; emphasises on the mutual relationship between knower and known; time- and value-bounded (*ibid*). In relation to this, Cohen et al. (2000) said that the central endeavour in the context of the interpretive paradigm is to understand the subjective world of human experience. Weber's 'understanding' (*verstehen*) goes further by asking not only why an action has taken place but also why a certain 'behaviour pattern' continues to be followed (Secher, 1962).

It is precisely the exploration of patterns of problem-solving that my research aims to understand. The nature of the research questions is thus not to confirm hypotheses. Obviously, my research does not fall into the confirmatory perspective (Biddle & Anderson, 1986) that presumes to establish objective information about social behaviour that can be generalised. The research questions would be best answered from the discovery perspective, which generates richer and deeper findings. In-depth investigation and interpretation of individuals, in fact, make (traditional form of) generalisation impossible because of the uniqueness of each individual (Pring, 2000). For Schofield (1993), generalisability is best thought of "as a matter of the 'fit' between the situation studied and others to which one might be interested in applying the concepts and conclusions of that study" (p.221). In the interpretive paradigm used in this research, understanding is more important than generalisation (Crotty, 1998).

Furthermore, my research questions are rather broad; this is because:

1. There is no precedent research or theory explaining the role of metacognitive skills in Physics problem-solving among the secondary school students individually (recall that Amigues (1988) reported Physics problem-solving in *pairs*). There are a number of studies (in section 2.4) explaining the role of metacognition in problem-solving among secondary school students, unfortunately not in Physics. This makes a discovery perspective, rather than a confirmatory perspective, more suitable.

2. These are provisional research questions formulated in an attempt to explain the role of metacognitive skills in Physics problem-solving among the secondary school students that will be further developed through this research.
3. The metacognitive skills involved in Physics problem-solving are yet to be determined as there are several sets of metacognitive skills suggested by various researchers (see section 1.2).

The broadness of the research questions requires an *open-ended* approach. Therefore, the theoretical perspective² of my study is *naturalistic inquiry* (see section 3.2) introduced by Guba & Lincoln (1985) who said,

A major distinction must be made between types of studies in which the investigator “knows what he or she doesn’t know,” and therefore can project means of finding it out, and situation in which the investigator “does not know what he or she doesn’t know,” in which case a much more open-ended approach is required. ... Naturalistic inquiry is almost always in the latter position...

(Guba & Lincoln, 1985, p. 209)

This research is almost tantamount to “not know what I don’t know” concerning the metacognitive skills involved in Physics problem-solving among secondary school students. This principle of openness does not mean that researchers always begin empty-handed or empty-headed (*ibid*). The researchers have their own theoretical assumptions and structures (as in the literature presented in Chapter 2), which direct their attention to concrete aspects but should remain ‘blind’ to the structures in the field under study (Flick, 2002).

A methodology suggested by Naturalists (Guba & Lincoln, 1985) that accommodates the openness of an investigation is Grounded Theory (hereafter GT, see section 3.3). Furthermore, my research intends to discover, in-depth, the pattern(s) of problem-solving and seeks to understand the role of metacognitive skills within this/these problem-solving pattern(s). It is appropriate to use GT since it draws from data, and is likely to offer insight, enhance understanding, and provide a meaningful guide to action (Strauss & Corbin, 1990).

² The philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria (Crotty, 1998)

3.2 Naturalistic inquiry

The term “naturalism” has a long and distinguished heritage (Kornblith, 1999) and is elastic in its use (Strawson, 1985). According to Hammersley (2002), originally naturalism refers to the paradigm in natural science that aligns with realism and deductivism. However, in the mid-1960s, naturalism had been redefined radically by Alfred Schutz (Beynon, 1989). Schutz argued that the attention of research on human life should be focused on the natural state of settings where the interpretations and “rationality” of the actors explored therein.

Meanings are held to guide behaviour and shape people’s actions. However, the same stimulus can mean different things to different people and even to the same person on different occasions. Individuals do not merely respond to, but interpret circumstances, and the research enterprise must, as a consequence, focus on motives, beliefs and attitudes, as well as behaviour, in real-life physical and temporal contexts.

(Schutz, 1964; cited in *ibid*, p.125-126)

Naturalism was redefined as a reaction to the positivists in social science who argued that only under the paradigm of positivism, can one produce scientific research that could be generalised, tangible and explain the real causes and effects of a social phenomenon. Hence, Beynon (1989) argued that through systematically deploying multiple data sources and unravelling the complexity of processes, meanings and interpretation, can direct to generating substantiating hypotheses thus opening up the possibility of new theory. Guba & Lincoln (1985) also responded to the positivists by proposing five axioms of naturalism that are in contrast with positivism:

- a. Realities are multiple, constructed and holistic.
- b. Knower and known are interactive, inseparable.
- c. Only time- and context-bound working hypotheses are possible.
- d. All entities are in a state of mutual simultaneous shaping, so that it is impossible to distinguish causes from effects.
- e. Inquiry is value-bound.

These axioms are parallel with my personal value (in section 3.1), where there are multiple realities; generalisation is time- and context-bound (thus working hypotheses are more appropriate to refer to as this kind of generalisation); and interpretation of a social

situation depends much on me as a researcher (thus inquiry is value-bound). Therefore, in this research, I creatively, although not dogmatically, follow the 14 characteristics of naturalistic inquiry outlined by Guba & Lincoln (1985) and Erlandson et al. (1993) in order to shape my research design in producing a natural setting that allows me to observe the Physics problem-solving process:

1. the study must be set in their natural settings as context is heavily implicated in meaning (as opposed to experimental settings in laboratories);
2. a human (the researcher) is the research instrument;
3. the utilisation of tacit knowledge is inescapable;
4. qualitative methods sit more comfortably than quantitative methods with the notion of the human(researcher)-as-instrument;
5. purposive sampling enables the full scope of issues to be explored;
6. data analysis is inductive rather than a priori and deductive;
7. theory emerges rather than is pre-ordinate, a priori theory is replaced by grounded theory;
8. research design emerges over time (and as the sampling changes over time);
9. the outcomes of the research are negotiated (construction of realities);
10. the natural mode of reporting is the case study;
11. nomothetic (search for general law) interpretation is replaced by idiographic (study of individual) interpretation;
12. applications are tentative and pragmatic;
13. the focus of the study determines its boundaries;
14. trustworthiness (see section 3.7) and its components replace more conventional views of reliability and validity.

(modified from Cohen et al., 2000, p. 138)

3.3 Grounded theory

GT is a research methodology introduced by Glaser & Strauss (1967) that opposed the trend of verification of the ‘grand’ social theories that was popular at that time. GT is suggested as an alternative that could strengthen the mandate for generating theory (i.e., it follows a discovery not a confirmatory perspective, see section 3.1). They argued that the trend of verification of (less relevant ‘grand’) theories had neglected the discovery of new social theories. According to Glaser & Strauss (1967), GT is one that

will *fit* a situation being researched, and will *work* when put into use. By “fit”, they meant that the categories must be readily (not forcibly) applicable to and indicated by the data under study. By “work” they meant that those categories must be meaningfully relevant to and be able to explain the behaviour under study (parallel with the generalisation suggested by Schofield (1993) in section 3.1). The essential part is whether the data under study can explain the *behaviour* under study. GT is thus derived from data rather than preceding them (as opposed to conventional inquiry). It is not deductive but patterned. Furthermore, it is open-ended and can be extended indefinitely (Guba & Lincoln, 1985).

Strauss & Corbin (1990) explained that GT is action/interaction-oriented. The researcher attempts to derive a general, abstract theory of a process, action, or interaction grounded in the views of participants in a study (Creswell, 2003). This process involves multiple stages of data collection, refinement and interrelationship of categories of information. Two primary characteristics of this methodology are: constant comparison of data with emerging categories, and theoretical sampling of different groups to maximise the similarities and the differences of information. I will explain the constant comparative method in the next chapter and theoretical sampling in section 3.4.

According to Denscombe (1998), there are five premises underlying GT. Firstly, the analysis of data is, broadly speaking, a ‘pragmatic’ one. They gave guidelines and rules of thumb, not methodological rules to be followed on all occasions. Secondly, the analysis of data should be geared towards generating new concepts and theories. The key word is analysis, where the GT approach is directly concerned with how the researchers organise, code and make sense of the research material. Thirdly, theories should be ‘grounded’ in empirical reality. According to the principles of GT, research involves a constant checking of the analysis (theories, concepts) against the findings and a constant refinement of the theories and concepts during the process of research. Fourthly, researchers should start out with an ‘open-mind’ (as explained in section 3.1). Fifthly, the selection of people, instances, etc. reflects the developing nature of the research and cannot be predicted at the start. Hence, the researcher will not be able to specify at the outset exactly how large the sample will be. The process of research will involve the continual selection of units until the research arrives at the point of theoretical saturation.

It is only when new data seems to support the analysis rather than add anything new that the theory is saturated and the sample size is 'enough'.

3.4 Selection of participants

The population of the research is KS4 students in the Cambridge area and participants were drawn from it. These students are chosen because this is the final stage of secondary education before they either opt to continue their study or enter the field of employment. Since problem-solving is an essential aim of education, at the final stage of secondary education, it is assumed that the students have gained some adequate skills in problem-solving.

As explained earlier, the sample size cannot be specified until the research has already been undertaken. The theoretical sampling in GT is also directed by the evolving theory; it is a sampling of incidents, events, activities, populations, etc. (Strauss & Corbin, 1990). All sampling in GT is done with some purpose in mind (Guba & Lincoln 1985). The selection of sample is based on theoretical assumption. In this study, there are two ways of forming theoretical sampling: from literature and data. According to Strauss & Corbin (1990), in GT, technical literature (i.e., reports or articles from previous research) can direct theoretical sampling. It can give ideas about where might be the direction to uncover phenomena that are important to the development of a theory. Hence, there are three criteria in selecting theoretical sample (as discussed in the previous chapter): (1) students who encounter 'real' problems, (2) which are difficult and have no immediate solutions and (3) are interested in engaging with the problem-solving.

3.5 Methods

GT strongly focuses on the interpretation of data no matter how it is collected (Flick, 2002). Here, the question of which method to use for collecting data becomes secondary and according to Guba & Lincoln (1985), the methods used in naturalistic inquiry may also change in the process of theory definition. The final procedure reported in this dissertation is not exactly the same as initially proposed due to some changes after the field work, but this is appropriate when using GT approaches. It is opened for the researcher to design and choose a variety of methods and techniques in collecting the

data, with some consideration of the 14 characteristics of naturalistic inquiry suggested in section 3.2.

In order to achieve the natural setting of a Physics-problem-solving-situation and the theoretical sampling, ten Physics problems were constructed according to the characteristics of problem suggested in section 2.1. With reference to provide a Physics-problem-solving setting, naturalistic research tends toward low manipulation and low imposition of units because of the importance of the context (see characteristic (1) in section 3.2). One must not judge the natural setting as completely untouchable. In contrast to a laboratory setting, it is not a “created” and highly manipulated as in experimental research (Erlandson et al., 1993). Willems (1969) gave some examples of natural and less natural settings,

For example, tonsillectomies might occur more frequently than paralysis-inducing accidents, but would not necessarily be judged more natural...a visit to a dentist involves a high degree of human instigation and arrangement, but probably would not be judged less natural than a tornado, at least for the purpose of research.

(Willems, 1969, p.46)

In this study, the setting would be considered ‘unnatural’ if the student is asked to solve problems using special mediums (i.e., computer, abacus) or is interrupted with instructions from the researcher (i.e., asking the student to check the answers, giving hints, etc.).

Furthermore, these Physics problems do not serve as an instrument but as a *tool* for the researcher to enable the theoretical sample being selected and problem-solving process being observed. This tool will be discussed further in section 3.6.1. The naturalists conduct interviews, observations and analyses of documents in order to collect data (Erlandson et al., 1993). In my study, I choose the thinking-aloud method (see section 3.5.1), retrospective semi-structured interview (section 3.5.2), observation (section 3.5.3) and analysis of answer sheets (section 3.5.4). Thinking-aloud is the core method, supported by the retrospective semi-structured interview, observation and analysis of answer sheets to ensure that the data is ‘grounded’ and to strengthen the trustworthiness of the data using triangulation (see section 3.7).

3.5.1 Verbal reports

There are mainly three types of verbal reports that can be used to collect data about the process of an individual performing a task: introspective, concurrent and retrospective (Ericsson & Simon, 1980). The introspective method requires the respondent (at the intermediate points) to stop and report on “internal” processes as they occur; while the retrospective method requires the respondent to complete a task totally or partially, and then describe the strategies used (Rowe, 1985). The concurrent method requires the respondent to verbalise spontaneously the cognitive process while doing a task without any prior question to answer (Ericsson & Simon, 1980).

The first two types of verbal reports need the respondent to make reports that answer some specific questions before or after the task. According to Nisbett & Wilson (1977), this will not give reliable data as the respondent needs to reflect upon the questions in order to verbalise the answers while doing the task. In the introspective method, the respondent is constantly being interrupted while performing the task as he/she needs to remind him/herself of the questions and report the answers about what he/she is doing (*ibid*). This also increases the burden on the respondent’s working memory while performing the task, thus making the process of completing the task slower or less efficient. In the retrospective method, the respondent has time to reflect on what he/she is doing before reporting the process, thus giving rise to unreliable reports (*ibid*). This method also, if involving a substantial delay, can cause the respondent to forget the process of the task that he/she has done, resulting in an invalid report.

On the other hand, the concurrent verbal report is a method introduced by Ericsson & Simon (1980) to answer the doubts about the reliability of introspective and retrospective verbal reports (Nisbett & Wilson, 1977). To overcome the limitations of those reports, Ericsson & Simon (1980) used the framework of information processing theory in problem-solving in order to suggest that the concurrent verbal report does not burden the respondent’s working memory and does not report more than what is happening in the respondent’s mind. This is possible if he/she is given sufficient training in verbalising cognitive processes spontaneously.

The framework of information processing theory in problem-solving can be closely likened to the operation of a computer. Newell & Simon (1972) postulated that

human thinking in problem-solving operates as an information processing system of a computer. A commonly used model in cognitive science involves three major components: sensory register, working memory (short-term memory) and long-term memory (Schunk, 2000). In this model, the sensory register maintains very briefly a stimulus event, providing time for recognition, classification and either storing or ignoring the event (Frederiksen, 1984). The working memory holds the inputs and output of the thinking process (Newell & Simon, 1972). It operates under the consciousness of an individual and has limited duration and capacity (Schunk, 2000). It can only hold around seven units of meaningful or “chunked” items (Miller, 1956). The inputs in working memory that are rehearsed will be stored in the long-term memory, or otherwise will be lost. The long-term memory is a repository of permanent knowledge skills (Frederiksen, 1984) and is considered to have no limitation in storing information (Ericsson & Simon, 1980). Information is stored in the form of inactive nodes representing an item or a “chunk” of related items in the long-term memory. Only activated nodes are contained in the working memory (Frederiksen, 1984).

When solving a problem, the sensory register will register the attentive information into the working memory. Through controlled processing (Schneider & Shiffrin, 1977), one or more related nodes of information in the long-term memory will be activated and executed in the working memory in order to work out the solution (Frederiksen, 1984). According to Shiffrin & Schneider (1977), besides controlled processing, one can also execute automatic processing where the activation of a set of nodes is controlled by a particular input configuration without the respondent’s attention. For example, a person can sing or hum his favourite song while driving in a busy street. However, this requires a lot of training (*ibid*).

The aim of training thinking-aloud before the data collection is to make the verbalisation of the cognitive process an automatic process. This will ensure that the working memory of the respondent is not burdened with another task besides the problem-solving task (Gilhooly & Green, 2002). In introspective method, training can also help the respondent to familiarise with the specific questions. However, introspective method requires more training than thinking-aloud (*ibid*) because thinking-aloud aims to make what is already in the mind verbalised spontaneously, while

introspective method aims to ensure that the questions are registered into the working memory and answered automatically.

Furthermore, in contrast to retrospective method, thinking-aloud does not give the respondent time to make interpretations or reflections upon his/her thinking (Chi, 2000). Thus, it is more natural. The 'reliability' and 'validity' of the thinking-aloud method are best secured compared to the other types of verbal reporting methods. Hence, for the purpose of my study, thinking-aloud is the best method of collecting verbal reports aimed at observing problem-solving process among KS4 students.

Thinking-aloud has been used by some researchers in Physics problem-solving and metacognition (as in Chapter 2). This is a useful method to make inference of the cognitive process (Rowe, 1991) and can provide some information about learning and problem-solving (Newell & Simon, 1972). Chi (2000) said that thinking-aloud requires the respondent merely to state the objects and operators that he/she is thinking of at that moment of the solution process. The respondent says out aloud everything that comes into his/her mind while working on a task.

In this research, some exercises were given to the students to do thinking-aloud before their statements were recorded to ensure that the process of verbalisation could be executed automatically (van Someren et al., 1994). This training is usually given to respondents before the study begins so that during problem-solving they can think-aloud in an ongoing manner (Rowe, 1985). According to van Someren et al. (1994), the training takes, at most, 15 minutes, and if after that the respondent still finds it hard to verbalise, it is better to stop because he/she is unlikely to provide useful protocol. This is because he/she cannot execute verbalisation automatically and this will affect the process of problem-solving (becomes 'unnatural'). In this study, the students were instructed to talk-aloud about anything that comes across their minds: feelings, questions, self-conversations or any sayings when solving the problems.

Another important aspect that a researcher needs to consider when applying the thinking-aloud method is the selection of problems. The problems chosen for the purpose of thinking-aloud should not be so difficult that the respondent cannot give a complete protocol of the problem-solving process. At the same time, the problems should not be solved by the respondent in an automated manner (van Someren et al., 1994). This is

because automatic process usually will not be reported as the respondent does not pay attention to it (Nisbett & Wilson, 1977). Hence, it is essential to determine that the problems given are 'real' problems. To do this, van Someren et al. (1994) recommended that, after the completion of the problem-solving process, the researchers can ask the respondents to describe the difficulties of the problems (through a retrospective interview, which I adopted in my study).

According to Rowe (1991), metacognitive skills are difficult to measure. Various kinds of instruments and methods are needed to ensure more reliable results. Therefore, in my study, retrospective semi-structured interviews, observation and analysis of answer sheets were used, in addition to thinking-aloud, in order to observe the metacognitive skills in problem-solving. Thinking-aloud allows observation during the task performance while the retrospective method can elicit more information on fragments of the thinking-aloud that sounded incomprehensible, incomplete or odd (van Someren et al., 1994). In the research reported here, the retrospective semi-structured interview was used immediately after the problem-solving to ensure that the students could give direct information about the problem-solving processes from the short-term memory (Rowe, 1991). Some questions about the thinking process and the solution given were asked to clarify the thinking and behaviour of the students when they were solving the problems. The retrospective semi-structured interviews and thinking-aloud were recorded using a digital recorder.

3.5.2 Retrospective semi-structured interview

In semi-structured interviews, questions are normally specified, but the interviewer is free to probe beyond the answers to seek clarification and elaboration (May, 1997). It is called retrospective semi-structured interview because the interview is carried out immediately after the respondent has finished solving a problem thus ensuring that he/she remembers the motive behind his/her procedure (Rowe, 1991). According to Erlandson et al. (1993), the questions can range from being predetermined to very open-ended. The purpose of the interview is not just to understand the problem-solving behaviour but also to strengthen the trustworthiness of this research. In this study, a set of questions specified by Charles et al. (1993) is used (Appendix F). However, some

questions raised from observations were asked to clarify students' actions and to ensure that my interpretations based on my observations were confirmed by the students (Appendix F).

3.5.3 Observation

This is a non-participant observation where the behaviour and interaction continue as they would without the presence or interruption of a researcher (Adler & Adler, 1998), as promoted by naturalists (Erlandson et al., 1993). As metacognition cannot be observed explicitly through behaviour, the main purpose of observation in this study is to prepare questions for interview aimed at clarifying students' specific steps in problem-solving. Questions were written down during observation. Short field notes were also taken to help provide information to clarify some aspects of the thinking-aloud protocols such as when students said the words 'this' and 'that' (which cannot be determined through protocols).

3.5.4 Analysis of answer sheets

Analysing documents is one of the methods suggested in naturalistic inquiry (*ibid*). However, the analysis of answer sheets in my study does not employ the documentary research proposed by Hodder (1998) where the writer cannot be observed or interviewed. The answer sheets were analysed and compared to the recordings of the thinking-aloud, enabling the study of the problem-solving visually. Therefore, it supports the interpretations of the thinking-aloud protocol.

3.6 Research procedures

There are four phases in this study which started with pilot testing of the tool, followed by selection of participants, data collection and data analysis. The later two phases being alternated according to GT procedure.

3.6.1 First phase: 'Pilot testing'

The aim of this phase was not to pilot test the tool per se, but to ensure that I have the appropriate tool for selecting theoretical sample since I am not familiar with the

ability of problem-solving among the students in Britain. In this phase, ten Physics problems focusing on the topic of ‘Forces and motion’ were constructed in an open-ended format by referring to the National Curriculum of the Key Stage 3 (KS3) and KS4 (DfEE & QCA, 1999). This was done to ensure that all of the students in KS4 can understand and solve the problems in KS3’s syllabus if not the KS4’s. This topic was chosen because it involved most of the five fundamental quantities of Physics such as length, mass and time. By giving problems from this fundamental topic of Physics, I am concerned with the problem-solving process rather than the mastery of Physics knowledge, although this does not imply that Physics knowledge is less important.

Following each problem was a set of structured questions about the perceptions of the problem solved by the student. The questions posed aimed to confirm the characteristics of the problems as in section 2.1. Examples of the questions following the Physics problems are:

- a. Do you think this is difficult for you? Please explain.
- b. Do you have any immediate solution for this?

This set of Physics problems was piloted among 3 KS4 students individually. After they had completed the pilot ‘test’, they were interviewed to examine the appropriateness of the problems and questions. It was found that 10 open-ended problems were too many to be answered by students in one session and the questions that followed should be limited to only two items. The equations and units conversions provided in the test were sufficient to give enough information for the students to solve the problems. The last version of the Physics Problems Test (hereafter PhyPT) is as in Appendix B. There are only six problems, arranged from the easiest to the most difficult (according to the pilot testing), followed by 2 retrospective questions asking about the difficulties of the problems and the availability of the solution. In addition, a question designed to ascertain the interest of the students in Physics was also included in Page 2 of the PhyPT. The information about the students sought on Page 2 was intended to help the researcher detects which students meet the criteria for the theoretical sampling.

Model solutions of the six problems are provided in Appendix C, but these are not the only possible solutions. Although most of the problems involve simple algebra, a correct interpretation of Physics concepts is also needed to reach the final answer. For

example in Problem 2, the students may be able to calculate the speed for each runner using simple algebra and equation given in Page 3. However, the wrong interpretation of speed will not give the correct answer of the fastest runner. In order to ensure that the students were engaging in the process of problem-solving, there was no time-limitation placed on this test.

3.6.2 Second phase: Selecting the theoretical sample

To have a variety of students, as promoted in GT (Strauss & Corbin, 1990), I selected a community college (School C) and a village college (School V) in Cambridge area which agreed to participate in this study. Appendix A showed the formal letter that I wrote to the schools' Principals and Heads of Science Department in January 2006. Permission was granted by both schools through email and by phone.

After the pilot testing, the second phase of the study was to select theoretical sample. The first visit to School C was on 10th February 2006 where the PhyPT was solved by a class of 26 Year-11 students (12 males and 14 females). As there was no time limitation, the students finished the test in 15 to 49 minutes. The first visit to School V was on 3rd March 2006 where the PhyPT was conducted in a class of 28 Year-10 students (12 males and 16 females). They completed the test in 24 to 46 minutes. Most of the students could solve the first three problems. Problems that involved acceleration (4 to 6) were abandoned by the majority of the students. Hence, Problem 3 was used as the benchmark for the selection of the theoretical sample. A student was selected for the third phase of the study if he/she is interested in Physics and could solve problem 3 correctly, but perceives the problem as difficult and has no immediate solution (as indicated from the retrospective questions). Table 3.1 shows the 6 students selected for the third phase of the study.

Table 3.1: Theoretical sample for the third phase of the study

Student	Name (Assumed)	School	Year	Gender
A	Angie	C	11	Female
B	Betty	C	11	Female
C	Colin	C	11	Male
D	Diane	C	11	Female
E	Eddie	V	10	Male
F	Fiona	V	10	Female

3.6.3 Third phase: In-depth investigation

In the third phase of the research, an in-depth investigation was carried out using the thinking-aloud method and retrospective semi-structured interviews individually to identify the patterns and the role of metacognitive skills in the process of Physics problem-solving among KS4 students. The students were asked to solve some Physics problems that have the similar level of difficulty as Problem 3 (see Appendix D). The level of difficulty of the problem is important to ensure that the problem is difficult enough to engage the student with real problem-solving but not so difficult that complete protocols cannot be obtained (as explained in section 3.5.1).

The students were given the same first three problems as in PhyPT to give an exercise for thinking-aloud and to see if the students can remember the problem (metacognition is concern with regulation of one's memory). Problems 4 & 5 have the similar level of difficulty as Problem 3 (the benchmark) with the same concept of Physics and equation use. A possible set of solutions to the problems can be seen in Appendix E. Problems 4 & 5 were designed after the analysis of the second phase, according to the practice of GT in which the methods and tools change according to the ongoing data analysis (Glaser & Strauss, 1967; Strauss & Corbin, 1990).

The first thinking-aloud session was on 24th February 2006 involving Angie (all are assumed names) and Betty. Angie was asked to solve 5 problems using thinking-aloud but the thinking-aloud of the first problem was not recorded since this was an exercise. Due to unavoidable time-constraint, Betty solved 4 problems and only 3 protocols were recorded. Observations were made and retrospective interviews were carried out after each problem solved. After the initial analysis of the data led to two emergent patterns, I was more focused on what to observe and ask. Hence in the second session with Colin and Diane on 3rd March 2006, the time taken for each student was shorter. There was a need to record the thinking-aloud of the exercise problem (Problem 1) to provide richer and more data. This was due to the time-constraint because of which the student could not solve 5 problems (producing 4 recorded protocols) like Betty, at least the protocol of Problem I could produce a pattern that could be compared in the analysis. In the second session, Colin solved 4 problems while Diane solved 3 problems as she repeated the exercise to familiarise herself with the thinking-aloud. On 9th March

2006, another session of thinking-aloud was carried with Eddie and Fiona, who both solved 4 problems. The writing up of technical reports for the schools and detail analysis were conducted until the school's Spring Holiday. After the Summer Term had started, it was not possible to revisit students in School C as they were preparing for examinations. The overall research procedure is summarised in Figure 3.1.

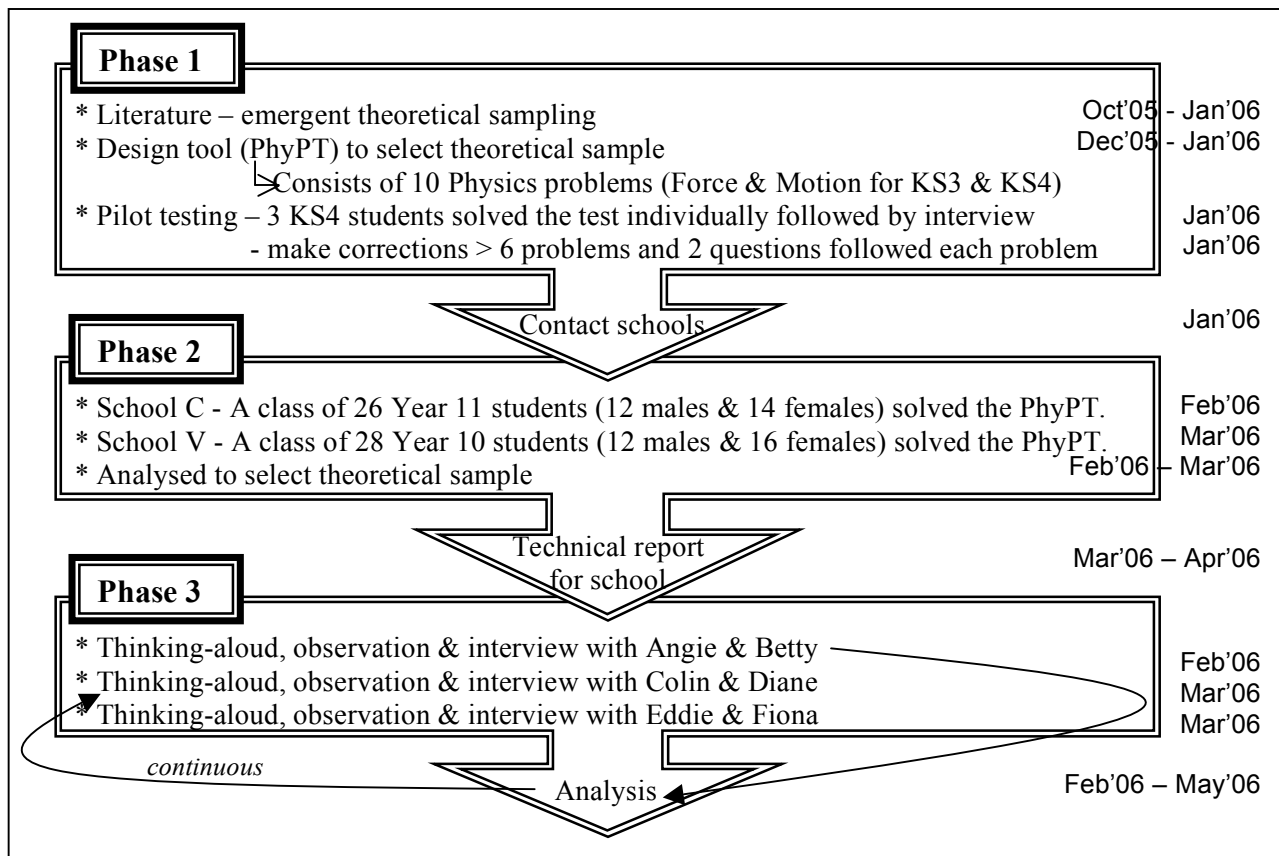


Figure 3.1: The data collection procedure and timeline.

The data collected includes the thinking-aloud protocols (see Table 3.2), retrospective semi-structured interview transcripts, answer sheets for both the PhyPT and during thinking-aloud session and observation field-notes.

Table 3.2: Problems (see Appendix D) recorded and solved by each student.

Student	Problems					Total protocols
	1 (exercise)	2	3	4	5	
Angie	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
Betty	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	3
Colin	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
Diane	twice					4
Eddie	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
Fiona	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4

*Notes: = solved; = solved & recorded

3.7 Trustworthiness

Onwuegbuzie & Daniel (2003) made the criticism that most researchers in qualitative research failed to provide evidence for judging the dependability (i.e.: reliability) and credibility (i.e.: validity) of findings. It is assumed that these criteria are only applicable for quantitative research. However, Maxwell (1992) said that validity is one of the key issues in the legitimacy of qualitative research. In naturalistic inquiry, the conventional criteria used to evaluate internal validity, external validity, reliability and objectivity are replaced by the criteria of credibility, transferability, dependability and confirmability, or in short, the trustworthiness of naturalistic research (Guba & Lincoln, 1985). It is different because naturalistic inquiry has multiple truths, rather than single reality found in conventional paradigms that are rooted in objectivism. Table 3.3 shows some techniques suggested by Guba & Lincoln (1985) and Erlandson et al. (1993) to establish the trustworthiness of naturalistic research.

In my small-scale study, not all the techniques in Table 3.3 can be used to establish the trustworthiness due to the time-constraint. In naturalistic inquiry, the only instrument is the researcher who is in the settings when respondents are being observed. It is impossible for another individual to report exactly the same observation as the researcher. Therefore, to establish dependability and confirmability, all the recordings, codings, answer sheets and transcripts (which are not included in the appendices) are made available for auditing. To establish transferability, a *proper* (within word-limitation) thick description (see Table 3.3) of the finding will be reported in Chapter 4. Finally, in establishing credibility or internal validity, triangulation is used.

Table 3.3: Criteria to establish trustworthiness in naturalistic inquiry.

Criterion	Technique	Procedure
Credibility	Prolonged engagement	Spending enough time in the context.
	Persistent observation	Focusing on an issue in detail.
	Triangulation	Using multiple methods, sources, researchers or theories.
	Peer debriefing	Exposing oneself to a disinterested peer in a manner paralleling an analytic session.
	Negative case analysis	Process of revising hypotheses with hindsight.
	Referential adequacy	Collecting holistic data (i.e., videotaping) to enable interpretation being tested for adequacy.
	Member check	Checking the analyses, interpretations and conclusions among research members (stakeholders).
Transferability	Thick description	Bring the readers to the context.
Dependability	Audit	Enable auditing when required.
Confirmability	Audit	Enable auditing when required.

Triangulation is one of the popular solutions to the problem of assuring the validity of research (Schostak, 2002). The idea is that, if a number of different methods or sources of information are used to tackle a question, the resulting answer is more likely to be accurate (Smith, 1996). Triangulation involves the use of different methods and sources to extend or check the integrity of inferences drawn from the data (Ritchie, 2003). Denzin (1989) presented four types of triangulation: data, investigator, theory and method.

Data triangulation refers to the use of different data sources (*ibid*). It is to collect the same data at different times, places and persons, which is quite similar to the theoretical sampling of GT (Flick, 2002). Theoretical sampling is selecting participants on the basis of concepts that have proven theoretical relevance to the evolving theory. To ascertain the proven theoretical relevance, the concepts are repeatedly present or notably absent when comparing incident after incident (Strauss & Corbin, 1990). The different incidents provide the differences in time, places and persons. Thus, the data collected can be compared and contrasted, giving the data triangulation.

Investigator triangulation employs different observers to detect or minimise biases that result from the researcher as a person (Denzin, 1989). This is inapplicable to this research that only has one researcher. Theory triangulation refers to approaching the data with multiple perspectives and hypotheses in mind to assess the findings (*ibid*). Finally, the method triangulation is used in my research by employing thinking-aloud,

retrospective semi-structured interview, observation and analysis of answer sheets for each student.

3.8 Ethical consideration

As my research involved school students individually, ethical consideration is made following the guidelines provided by the British Educational Research Association (BERA, 2004). Permission to conduct the research was asked from the school Principals through formal letters (see Appendix A). To reduce discomfort to the schools and students involved (BERA, 2004, paragraph 18), the schools were given the full authority in deciding the time to conduct this research. A thorough criminal background check by the Criminal Records Bureau, United Kingdom has been done in order to obtain an Enhanced Criminal Record Certificate (disclosure no.: 001127087243) providing irrefutable evidence that I do not have a criminal record. This is needed for the third phase of my research in which I met the students individually without the supervision of a teacher.

Two ethical issues in naturalistic inquiry are confidentiality and informed consent (Erlandson et al., 1993). The issue of informed consent has been explained partly in the previous paragraph. Parallel with the voluntary informed consent criterion in paragraph 10 and 11 of BERA (2004), the students involved in the third phase of the study were given a brief explanation of the research before its commencement. They were told about the recording of the thinking-aloud and who would be listening to it. They were also informed about what they should do, how long it takes and were given the option of withdrawing if they thought that leaving the class for 30 minutes would be a disadvantage for them. All of the students in this study were willing to participate. As for confidentiality, the schools' and students' names were not reported in this dissertation (BERA, 2004, paragraph 23). Initials were used for the schools (C or V), while the students reported were given assumed names that are listed alphabetically in 5-character long.

3.9 Summary

In this chapter, I have explained strong reasons for the choice of methodology, methods and participants. I have also reported the research procedures, phase by phase, and established the trustworthiness of my research. Finally, some considerations of ethical issue in educational research have also been discussed briefly to ensure that, the correct measures were taken to preserve the rights participants.

4.0 DATA ANALYSIS

In this chapter, I will explain how I have practised the use of coding systems and constant comparative method of the GT to produce problem-solving patterns of the six students. Then, I will present the analyses of open-coding for each student in each problem individually. After making axial-coding, some problem-solving patterns of each student were generated and after selective-coding, a general pattern of problem-solving among these students was produced. The analysis started with open-coding but may alternate among the three stages of the coding.

4.1 GT data analysis techniques

According to Guba & Lincoln (1985), in GT, data analysis is open-ended and the issue is to find the best means to “make sense” of the data in ways that will facilitate the continuing unfolding of the inquiry and lead to a maximal understanding (*verstehen*) of the phenomenon being studied within its context. In the early stages of the research, a rough definition and explanation of the particular phenomenon is developed and then is examined in the light of the data that are being collected throughout the study (Cohen et al. 2000). The process of redefinition and reformulation is repeated until the best explanation is reached that embraces all the data, and until a generalised relationship has been established that embraces the negative cases.

There are six characteristics of a GTist (Strauss & Corbin, 1990) which can be practiced during the process of analysing the data:

1. the ability to step back and critically analyse situations
2. the ability to recognise the tendency toward bias
3. the ability to think abstractly
4. the ability to be flexible and open to helpful criticism
5. sensitivity to the words and actions of respondents
6. a sense of absorption and devotion to the work process.

This research will also follow the coding systems suggested by Strauss & Corbin (1990) and the constant comparative method by Glaser & Strauss (1967) before the emergence and saturation of a theory or pattern that may be sufficient to explain the role of metacognitive skills in Physics problem-solving in the context of the KS4 students

under study. According to Strauss & Corbin (1990), it is difficult for a beginner in GT to conduct the coding and constant comparative method because of the lack of practice and theoretical sensitivity. The latter refers to a personal quality of the researcher and is developed through experience and reading in a relevant area (*ibid*). Hence, it can only be developed over many years (Glaser & Strauss, 1967). So, as a beginner in GT, it may be a challenge to perform the characteristics of GT completely, but every effort has been made to understand the procedures through reading.

4.1.1 Constant comparative method

Glaser & Strauss (1967) have outlined the constant comparative method in four stages (p. 105):

- a. comparing incidents applicable to each category
- b. integrating categories and their properties
- c. delimiting the theory
- d. writing the theory.

This method happens in all stages of data analysis to compare categories, either to merge them (if similar), separate them (if different) or rearrange them (if it is a subcategory). While doing constant comparison, the property, dimension and condition will be compared to redefine the category which will be recorded on a memo (see Appendix G for example of definition of codes) (*ibid*). The more similarities encountered, the more consistency within a category may be confirmed, thus providing confidence for the researcher that a substantive theory has been saturated (Strauss, 1987). If more differences are encountered, a further theoretical sample is needed. In GT, substantive theory can only explain a phenomenon in one particular context, while formal theory can be generalised into a wider context (Strauss & Corbin, 1990). One must reach the saturation of substantive theory before proceeding to the development of a formal theory. This initial substantive theory is similar to the working hypothesis suggested by Guba & Lincoln (1985), where generalisation is only applicable to certain instances that match the condition of the context under study. In my research, there is an emergence of a substantive theory, but this has not reached the stage of theoretical saturation.

4.1.2 Open-coding

According to Strauss & Corbin (1990), open-coding is the process of breaking down, examining, comparing, conceptualising and categorising data. This is the first step of the analysis where actions or interactions are labelled using researcher's own phrases into as many categories as possible (Glaser & Strauss, 1967). This is to ensure the openness of the analysis, which will lead to the discovery of more categories. The names of the categories can be provisional and can change after axial- and selective-coding (Strauss, 1987). Appendix G shows the categories created during the open-coding stage.

4.1.3 Axial-coding

After a variety of categories have been created in open-coding, in axial-coding, connections are made between categories by using constant comparative method (Strauss & Corbin, 1990). During this stage, researchers may be able to hypothesise and develop denser categories (Strauss, 1987). Appendix H shows the categories and subcategories emerged from axial-coding.

4.1.4 Selective-coding

Selective-coding refer to the process of selecting the core category, systematically relating it to other categories, validating those relationships and filling in categories that need further refinement and development (Strauss & Corbin, 1990). It is usually undertaken after the stages of theoretical sampling. Through the integration of categories and relating them with a core category, a story line can be generated (*ibid*). In this research, a model tells the story line after the selective-coding.

4.1.5 Data analysis procedure

After the thinking-aloud and interviews were transcribed into word processing documents, they were read through to help me generate some categories that might be relevant to each sentence of the protocol prior to the beginning of the coding. I also reread the books by Glaser & Strauss (1967) and Strauss & Corbin (1990) to ensure that I could fully understand, apply and practise the coding procedures and the constant comparative method suggested by them. For each set of the protocol, I coded twice

separately (open-coding) and then I made a comparison of the two sets of categories. Wherever there were different categories for the same line, I replayed the recordings and chose the category which was more relevant. After that, for each set of protocol, I combined the categories through similarities in their attributes in order to generate a more general category or a subcategory (axial-coding). In this way, I was able to see emerging patterns for the problem-solving process of the student for each problem. A comparison within the student's own protocols was made to generate a general pattern for each individual. The patterns were then rechecked by comparing the coding for each problem within the student and a general pattern for the student was extrapolated. The final step was to compare the patterns *between* the students. An overall pattern of Physics problem-solving among these six students was being generated through the integration of the categories (selective-coding).

4.2 The patterns of Physics problem-solving of the students

In this section, I will describe the patterns of Physics problem-solving of every student. All the thinking-aloud protocols, interviews transcripts and answer sheets of the students are arranged as in Table 4.1. The term 'problem' is used to refer to the problem solved while the term 'question' refers to an interview question (in abbreviation Q). The definition of each code is found in Appendix H.

Table 4.1: Location of appendices for the thinking-aloud protocols, interviews transcripts and answer sheets.

Student	Appendix
Angie	I
Betty	J
Colin	K
Diane	L
Eddie	M
Fiona	N

4.2.1 Angie

Angie (Appendix I) solved 4 problems (see Table 3.2), excluding the warm-up problem. The first two problems were perceived as easy. She first read the problems and then interpreted the meanings of the problems (Problem 2: line 10-11; Problem 3: 17-22).

After she had understood the problem, she started to choose which equation to use (Problem 2: 12; Problem 3: 27-33). In planning the steps, she arranged the equation and then checked if her planning was right. After it had been confirmed, she would start to make a calculation and then interpret the answer.

When she was solving a more difficult problem, she presented a slightly different pattern. She used her memory when she knew that she was facing a more difficult problem. Before I gave her Problem 4, she said, “oh this is getting harder”, then she glanced at the question and immediately she said,

- 1 Oh I think I know this question because I remember it
- 2 I think I have done it
- 3 Oh, oh no, not this one but it has something to do with cycling

The use of memory in problem-solving occurred again after she had finished reading the problem (Problem 4: 10-12; Problem 5: 14-16). She remembered that Problem 4 was not in the test given during the second phase of the study and Problem 5 was similar to Problem 2 and 3, so she tried to remember how she did it. And then she interpreted the problems and planned what should be done to solve them. The planning (Problem 4: 13-21; Problem 5: 17-25) led to calculations (Problem 4: 22-38; Problem 5: 26-40) and then she stopped to check if the answer for the first calculation was logical (Problem 4: 39; Problem 5: 41) before she planned for the next steps (Problem 4: 40-48; Problem 5: 42-54). The cycle repeated until she reached the answer asked for the question. At the end, she interpreted her mathematical answer into something meaningful for her (Problem 4: 115-120; Problem 5: 85-87). She always made sure that she checked and reflected upon the answers in each step (Problem 4: 39; 68; 87-92; 100-106). As a general summary for Angie, her Physics problem-solving pattern is as portrayed in Figure 4.1.

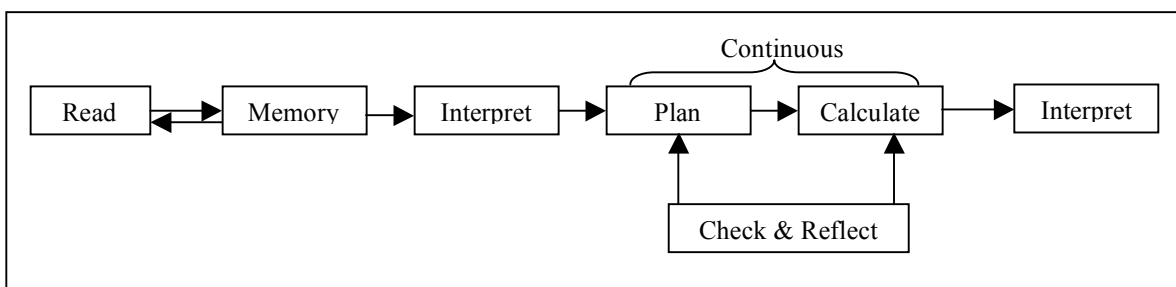


Figure 4.1: Pattern of Physics problem-solving for Angie.

Most of the quotations that I have extracted above appear to be metacognitive elements where Angie thought about her own thinking, calculations, answers and memory. This is obvious in the steps of remembering the problem, interpreting, checking and reflecting her answers and calculations. Furthermore, this also appears in the stage of planning (Problem 4: 15-16; 43-48; 74-76; Problem 5: 16-19; 43-45).

4.2.2 Betty

Betty (Appendix J) solved 3 problems (see Table 3.2), excluding a warm-up problem. All the problems were perceived as difficult (see Q2 & Q39). She first read the problems and then planned how to solve them. In Problem 2, after she had finished reading the problem, she said,

10 Well I'm going to sort them out

and in Problem 3 and 4, she planned her solution (Problem 3: 9-20; Problem 4: 14). These were not immediate solutions, but rather tentative planning. She carried out the initial plan and then made interpretations of what she had done, then made reflections to check her results before she proceeded with further planning. In Problem 2, after she had carried out her plan to 'sort out' the information (arrange the information), she said,

28 So I can see who is the fastest
 29 And I can see that
 30 Cause they are different distances (made interpretation)
 31 So I need to um...
 32 Work it out in proportion (another planning)
 33 So it...
 34 Um
 35 I need to work out the velocity

This also happened in Problem 3 after she had finished calculating the time for all three runners (Problem 3: 63-69) and in Problem 4 after she had calculated the speed of the cyclists (Problem 4: 34-41). Following the completion of the second plan from which she derived an answer, she would check and reflect the answer to ensure that it made sense. Her constant checking and reflecting upon the answers can be seen in all the problems, notably in the middle (Problem 2: 20-22; 41-42; Problem 3: 40-48; Problem 4: 39-40; 88-89; 128; 140) and after the calculations (Problem 3: 76-90; 96-97; Problem 4: 52-55; 65-69). In her answer sheets for Problem 3 and 4 (Appendix J), there were several

corrections that she made to her calculations and answers. She said that she always checks whether her answers are logical or not (Q28 & Q37). Finally, she ended her problem-solving with an interpretation of her answer (Problem 2: 63; Problem 3: 98-99; Problem 4: 153-154).

Betty said that she would always go back to read the last sentence of the problem to ensure that she had all the information and answered the question properly (Q21-Q23). In the protocol, it is obvious that she reread the last sentence of the problem before she came to the answer. For example in Problem 3, she had obtained an answer, but when she reread the last sentence of the problem, she said,

96 Oh no wait
97 I don't because I have to beat 0.1 second

And in Problem 4, she read back the problem after completing all the calculations (Problem 4: 147-148). The pattern of Physics problem-solving for Betty is summarised in Figure 4.2.

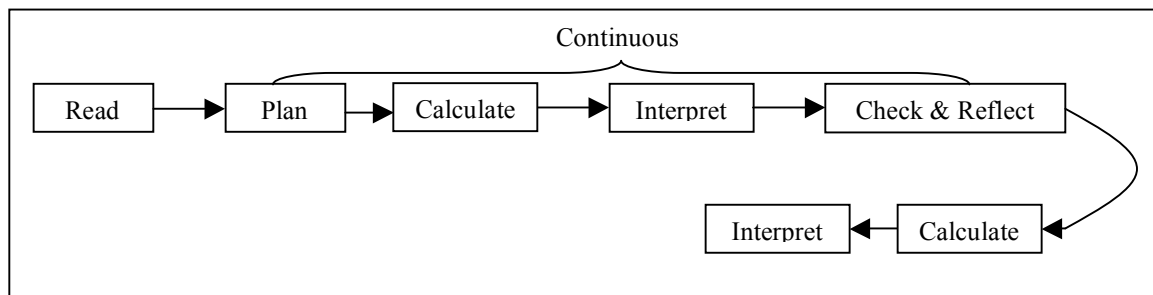


Figure 4.2: Pattern of Physics problem-solving for Betty.

Like Angie, Betty also showed a lot of metacognitive elements in planning, interpreting, checking and reflecting her answers and calculations. Table 4.2 shows examples of the metacognitive statements in those steps in Problem 3 and 4.

More metacognitive statements are evident in the most difficult problem (Problem 4 – see Q39). After she has just finished reading the problem, she said,

6 Hard this [problem]

Knowing that the problem was difficult, she reread it and looked for important information to help understand it.

Metacognitive statements also appeared when she was facing difficulties (Problem 4: 73-76; 86-92). When the difficulty was overcome, she said,

- 103 That's pretty fast isn't it
 104 Cause I thought I need to find my velocity
 105 Oh
 106 Metre per minute square
 107 Not second

Table 4.2: Examples of metacognitive statements of Betty.

	Problem 3	Problem 4
Planning	16 If Cynthia is running at 3 metres per second 17 Then 18 I think I'll do a 100	17 If I work out my velocity 18 Then I can 19 Um 20 Oh no way 21 If I work out my velocity then I can um 22 Then I can work out how long it would take for me to do 9 kilometres
Interpreting	43 Because by looking at it 44 I can see 45 Already if I divide 100 by	47 What is 30 48 Um 49 30 is 50 30... 51 Seconds 52 I think
Checking	40 I don't think that is actually right	85 800 divided by 2 86 Ou... 87 I do it... 88 No that is distance 89 So that is time
Reflecting	82 Now I'm stuck 83 And I don't know what to do	73 I don't know if this the only way of doing it 74 900 metres in 3 minutes 75 So 300 76 Yeah I can do it

Metacognition seems to help Betty solve the difficulties that she faced. She could use metacognitive skills to evaluate the difficulty of the problem, hence she executed another way to try to solve it. She also tried to ask herself if there was another way to solve the problem, understand her situation and question her answer and method of problem-solving. However, this does not prove that the metacognitive skills she used contributed to the success or failure of her problem-solving.

4.2.3 Colin

Colin (Appendix K) solved 4 problems (see Table 3.2). All of them (except the warm-up problem) were perceived as difficult (see Q1, Q2 & Q27). He first read the problems and then planned how to solve them (Problem 2: 12-13; Problem 3: 11-12; Problem 4: 15-25). Like Betty, Colin also made tentative plans after he had finished reading the problem. He then executed the initial plan and made another plan. For example in Problem 3, he rewrote the information from Problem 2 and then said,

17 And then I need to
18 Convert that into the time

After the calculation, he said,

46 And then if I add them up
47 I should get

After another calculation, he planned again (Problem 3: 57-61). He always ensured that he arranged all the important information after he had made his initial plan (Problem 2: 14-18; Problem 3: 13-15; Problem 4: 8-12). He constantly reminded himself of the information at hand. In Problem 3 (line 58-59) and Problem 4 (line 15-16), he reminded himself that he had the value of time and distance. For Colin, this was an important strategy because he could refer to the information quickly and link all the information to figure out a plan or solution (see Q7, Q10 & Q35). By looking at the answer sheets, it is clear that Colin wrote down all the information that was important to him.

He sometimes tried to understand the meaning of his answer (Problem 2: 44-48; Problem 3: 48-52; Problem 4: 42-44). After he had executed all his plans and came to an answer, he would check his steps (Problem 2: 50-52; Problem 3: 68-72; Problem 4: 67-74). This is also important because if there was an answer that did not make sense to him, he said that he would be in a state of “can’t think properly” (see Q6 & Q7). He would read back the problem and ensure that his answer solved the problem logically (see Q18). The pattern of Physics problem-solving for Colin is summarised in Figure 4.3.

Colin showed metacognitive statements while he was planning, arranging information, checking and interpreting the meaning of his answer. These can be seen in the quotes of his statements in those steps (as presented throughout this section).

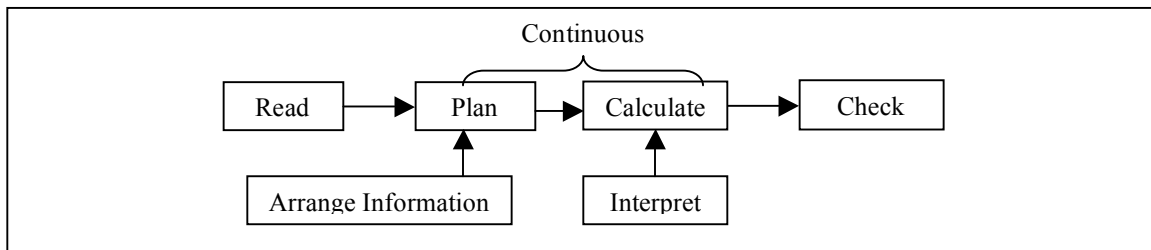


Figure 4.3: Pattern of Physics problem-solving for Colin.

4.2.4 Diane

Diane (Appendix L) solved 3 problems (see Table 3.2). The first two problems were perceived as easy (see Q1). She first read the problems and then started to calculate without any planning as if she knew the solutions. By looking at the answer sheets of Problem 2 (Appendix L), there were only three lines of calculation. She said that she immediately knew the solution after she read the problem (see Q2 & Q3). This shows that Problem 2 was not a ‘real’ problem for Diane and this explains the reason why she could execute the solution immediately without planning. However, she said that she had never seen this problem before (see Q4) – note that this problem was in the PhyPT in Phase 2 (see Appendix B, question 2). She did not need to recall the solution since it could be executed automatically. During the calculation, she checked her answers (Problem 2: 29-30; 40). After the calculation, she interpreted the mathematical answers to resolve the task. The pattern for Diane when solving easy Physics problems is: read > calculate (checking) > interpret.

Diane perceived that Problem 3 was a little difficult (see Q5) and showed a similar pattern of problem-solving to Colin’s. She first read the problems and then started to plan how to solve it (see Q7) and perceived that the record of the race was important information. So she started to arrange the important information (Problem 3: 7-17), like Colin. She then made a calculation and stopped to reflect on her steps (Problem 3: 29-35). She was unsure of the steps she planned, so, she rechecked the calculation (Problem 3: 36-38). When she came to the final answer, she reread the problem to make sure that the answer was reasonable and made sense (see Q11 & Q12). When she reread the problem, she interpreted the meaning (Problem 3: 42-49). The steps in her answer sheet for Problem 3 also are not as tidy as in Problem 2 where she did

several scribbling marks on the sheet. Her calculation at the bottom of the sheet, which she crossed-out, was to check her calculation (Problem 3: 21-24). The pattern of Physics problem-solving for Diane can be summarised in Figure 4.4.

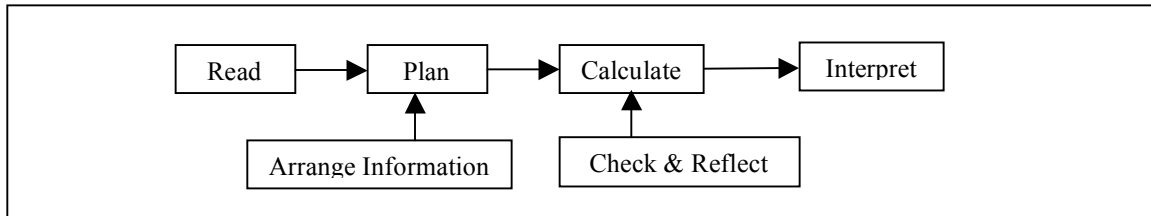


Figure 4.4: Pattern of Physics problem-solving for Diane.

Diane did not show many metacognitive statements during problem-solving. She said that she seldom talks to herself when she is solving a problem (see Q27). Metacognitive statements were found when she was planning (Problem 3: 12-13; 18-19), reflecting (Problem 2: 22; Problem 3: 30-35) and checking (Problem 2: 29-30; Problem 3: 43-47) during calculation.

4.2.5 Eddie

Eddie (Appendix M) solved 4 problems (see Table 3.2). He perceived that all of the problems are difficult (see Q4, Q20 & Q32). Like the students above, after he had read the problems, he started to make tentative plans to solve the first parts of the problems (Problem 2: 12-15; Problem 3: 9-13; Problem 4: 7-12). He would then carry out his tentative plans, either calculating or arranging information, and proceeded to make the next plan (Problem 2: 26-27; Problem 3: 19; 25-27; Problem 4: 22-23; 47-51). He ended his calculations with an interpretation of his final answer that he derived (Problem 2: 41; Problem 3: 31-45; Problem 4: 147-152).

In Problem 3 and 4, he constantly checked his answers and reflected upon his current situation of problem-solving process. This was because he felt that his answers were not very logical (see Q25, Q26 & Q37). In Problem 3, he repeated “100 metres in 20 seconds” 3 times (Problem 3: 35-41) because he was unsure of the meaning of this mathematical answer. In Problem 4, whenever he obtained a mathematical answer, he stopped to check and reflect upon it (Problem 4: 29-31; 36-42; 92-104; 122-135). The pattern of Physics problem-solving for Eddie is summarised in Figure 4.5.

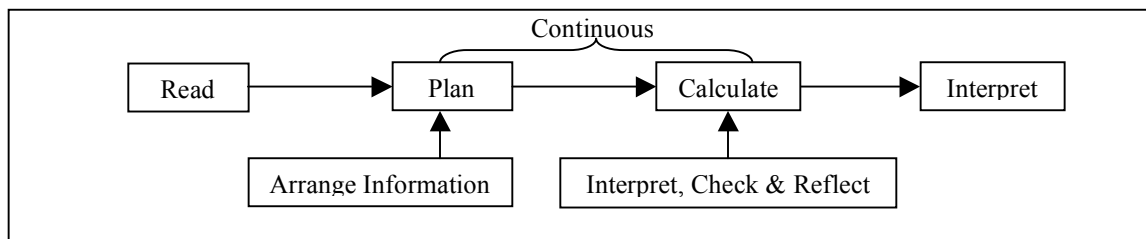


Figure 4.5: Pattern of Physics problem-solving for Eddie.

Eddie also showed a lot of metacognitive elements in planning, checking and reflecting his answers and calculations. Table 4.3 shows examples of the metacognitive statements in Problem 4. More metacognitive statements were found in the most difficult problem (Problem 4), when he was unsure of his answer,

122 Just check that now if I got that different from the first time

And when he was sure of the checking, he said,

126 Yeah so I think I got that right

Table 4.3: Examples of metacognitive statements of Eddie.

	Problem 4
Planning	10 Well I'll try to find the common one 11 Which is I'll do 2 multiply by 3 which equals 6 22 So, I'll convert 6 minutes into hours 23 It would be easier (see also examples in 50-51; 59-60; 86 in Appendix M)
Checking	36 Seems to much 37 To be able to do in 1 hour 38 That's definitely too much to do that in 1 hour 99 So it doesn't make sense 100 So I'm just got to go back to the stage where
Reflecting	29 It seems quite a lot to me 30 Per hour 31 But I think I've got it 32 So I'll carry on 96; 132-134.

Metacognition seems to help Eddie to stop and think about his answer and recheck it. When the problem was more difficult, he would be more careful in reading

the problem, take more time in interpreting the meaning of the answer and check to see if it made sense (see Q29, Q30 & Q33). However, this does not prove that the metacognitive skills he used contributed to the success or failure of his problem-solving.

4.2.6 Fiona

Fiona (Appendix N) solved 4 problems (see Table 3.2), including the warm-up problem. She perceived that Problem 2 was easy but not Problem 3 and 4 (see Q1, Q5 & Q30). After she had read the difficult problems, she started to interpret the meanings (Problem 3: 9-13; Problem 4: 7-12). This appears to be similar with Angie, who tried to understand the meanings of the problems before she started to plan (Problem 3: 11-15; Problem 4: 7-11). Then she planned (Problem 4: 12) and executed the plan. In both of these problems, she identified an equation and rearranged the variables to find the intended variable (the time) (Problem 3: 17-29; Problem 4: 26-29).

Next, she calculated and then checked her answers (Problem 3: 39-44; Problem 4: 40-45). The checking helped her to identify errors or think of another way to solve the problem. In her answer sheet for Problem 3 (Appendix N), she tried two ways to ensure that she used the correct equation (in full terms and in symbols) and two ways to calculate “Jenny’s” time ($100/5.4$ and $100/(100/18.5)$). Hence, she had the ability to think of another way to solve the same problem. In the interview (see Q34), when her solution was being questioned, she quickly suggested another solution.

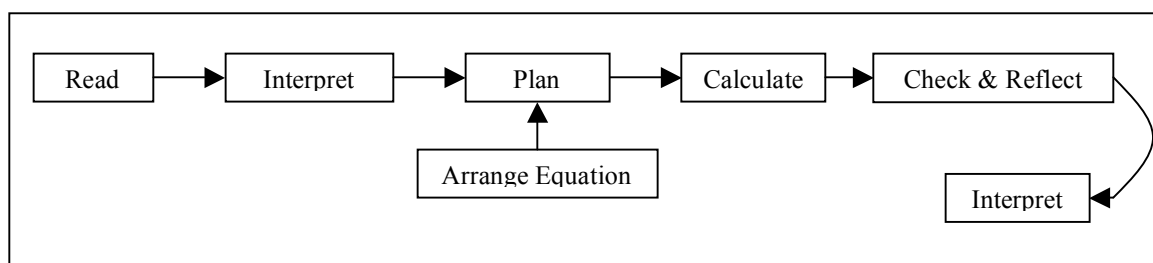


Figure 4.6: Pattern of Physics problem-solving for Fiona.

Fiona constantly checked her answers during calculations (Problem 3: 55-60; 76-81; 98-99). Finally, she ended her problem-solving by interpreting the meaning of the final answer to ensure that it made sense to her (see Q25 & Q26). Figure 4.6 illustrates Fiona’s pattern of Physics problem-solving.

Fiona demonstrated a lot of metacognitive statements when she was checking and reflecting her answers (see Table 4.4). In Problem 3, she could not make sense of the time taken by ‘Cynthia’ (see Problem 3 in Appendix D) who Fiona thought was the fastest runner among the three runners in Problem 2 (Appendix D) because ‘Cynthia’ had the smallest value calculated in Problem 2. After double-checked the answer in Problem 3, she finally realised that her mistake was lay in the fact that she did not put the unit of “speed” for the answers in Problem 2, which caused her to think that the values were time (see Q8). She changed the units into ‘m/s’ in Problem 2 after she has realised her mistake. She said,

- 115 Ou!
 116 Jenny
 117 No, um
 118 Sophia
 119 If I write down the unit I would have understood it

Table 4.4: Examples of metacognitive statements of Fiona.

	Problem 3
Reflecting	36 To make it more accurate you have to do 43 Oh, no, that would be right 44 Ok, um 45 So I'll do the same for Sophia (see also examples in 72; 78-80; 95; 102-103; 111; 119 in Appendix N)
Checking	41 I'm not sure if that right 42 I'm gonna do it again 55 I think I've done this wrong 56 Cause 57 Um 58 I got a 59 Cynthia takes the most amount of time 60 Which is wrong 63; 65-67; 76; 81; 85-87; 98-99.

4.3 A more general pattern

By comparing the patterns of all the students, a more general but complex pattern of Physics problem-solving can be generated as in Figure 4.7. It is complex because the research has not reached the state of theoretical saturation needed to generate a more

refined and generalisable pattern. There are three parts of the pattern that are firmly established and three parts that are not.

The core and simplified pattern of problem-solving can be seen as reading the problem, followed by planning and then calculation. These are the three parts of the patterns that have been found in all the students (denoted by double-lined arrows in Figure 4.7). It can be interpreted as a linear pattern of the problem-solving.

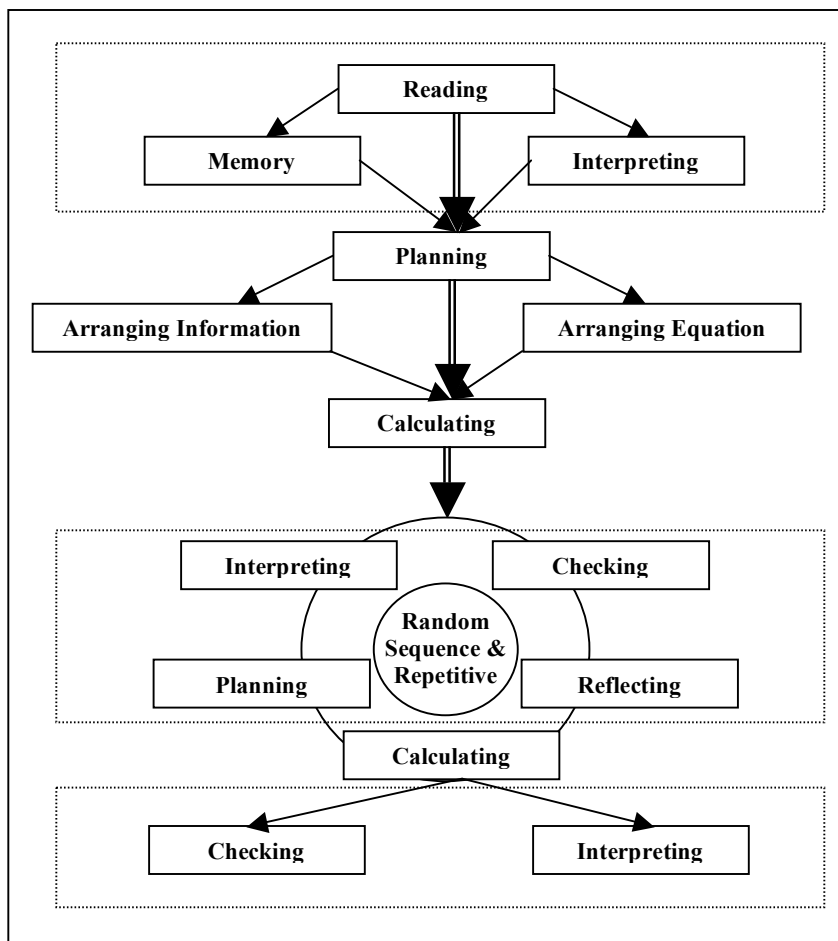


Figure 4.7: A more general pattern of Physics problem-solving of the students.

The three dotted-boxes in Figure 4.7 are areas that showed variations among the sample. Most of the students made plans after reading the problems, but two students showed other actions consistently (i.e., Angie - memory; Fiona - interpreting). After the first calculation, the sequence of actions that followed varied among the students. Angie and Eddie tended to reflect and check their calculations before proceeding to plan the next steps. They then went on to the next calculations, followed by either checking or

interpreting the answers. Betty preferred to interpret the meanings of her answers and check the calculations before she proceeded to the next planning. Colin, Diane and Fiona usually checked their answers and proceeded to the next planning or continued to make the next calculations. Finally, in the third dotted-box, all the students ended their problem-solving with interpretations of the meanings of the final answers, except for Colin who finished the problem-solving with a check on his calculations. Colin appeared to be consistent in checking his calculations at the end.

4.4 Metacognitive skills

Metacognitive elements are found in several steps in the pattern represented in Figure 4.7. Figure 4.8 shows the steps with metacognitive elements in shaded-boxes. The use of the metacognitive skills of memory is shown consistently by Angie. In Problem 5, when she remembered that the problem is similar to Problem 2 and 3 (Appendix I – Problem 5: 16-19), she tried to use the similar strategy to solve the problem. Almost all the students showed metacognitive statements during planning and goals setting. They self-talked about what to do (e.g.: Appendix J – Problem 2: 10-11) and used “if...then” sentence structure in this step (e.g.: Appendix M – Problem 3: 10-13). In the step of interpreting, metacognitive skills play a role in self-questioning about the meanings, trying to make sense and looking for a logical reason for the mathematical answer.

In the step of checking, metacognitive skills play a role in identifying errors and ambiguities in the calculations and answers. While in the step of reflecting, the students stopped and tried to monitor the progress of problem-solving and understand the current situation by self-questioning (e.g.: Appendix I – Problem 3: 81-86) or pondering (Appendix J – Problem 3: 76-86). In the final step of problem-solving, metacognitive skills helped the student (Colin) to check the final answer by reminding himself to do the checking (Appendix K – Problem 3: 68-69). From this study, metacognitive skills can be defined as the skills employed to think of one’s thinking and they are explicit during self-questioning and self-talk.

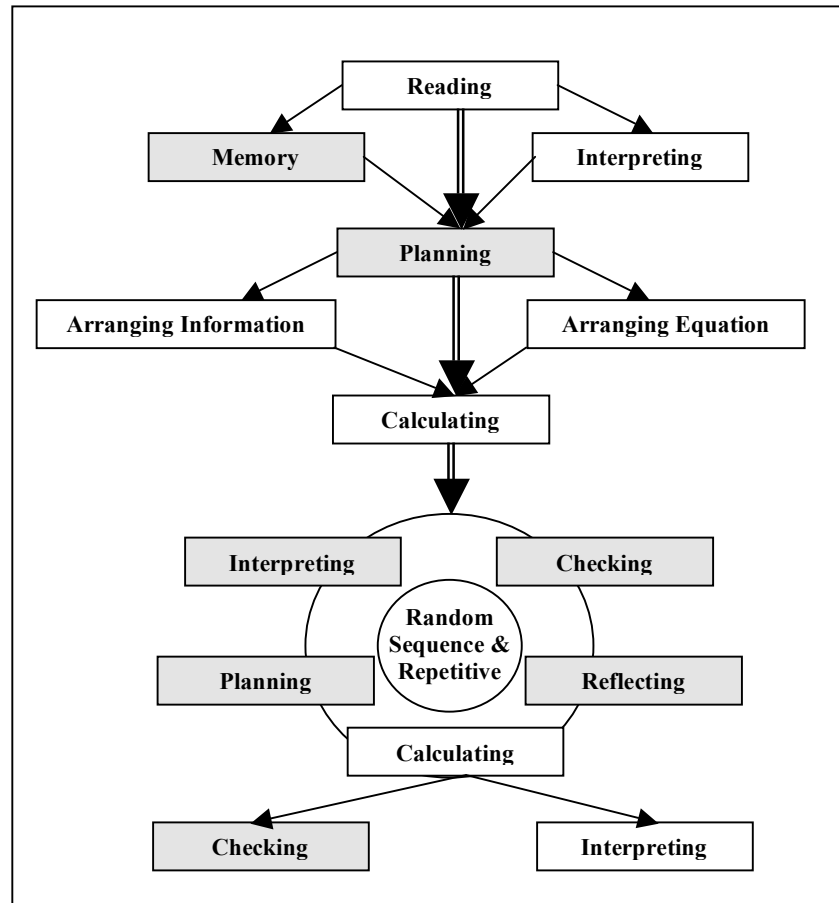


Figure 4.8: Metacognitive skills found in the pattern.

4.5 Summary

In this chapter, I have described the use of coding system and constant comparative method in analysing the data and explained the findings by referring to the appendices. A pattern of Physics problem-solving (Figure 4.7) has been generated and explained. However, This model needs (a) to be tested against more data to find out if it includes all patterns that might find among the population, and across a wider range of Physics problem-solving, and (b) to be explored whether the variations are only dependent on individual differences, or depend on problem-features/context, and develop an understanding of why and when (conditions) different paths of the model are used. Nonetheless, the role of metacognitive skills in Physics problem-solving is shown in Figure 4.8 – memory, planning, reflecting, checking and interpreting. Thus, I have addressed the two initial research questions (refer section 1.4) to the fullest extent within the time-limitation of this study.

5.0 CONCLUSION

In this chapter, I will draw conclusions from this study as a whole and recommend some implications for teaching and future research as well as suggest how this study can be pursued further during my PhD study next year.

5.1 Discussion

The aims of this research were to understand the patterns of Physics problem-solving and the role of metacognitive skills in problem-solving among KS4 students. Figure 4.7 illustrates an initial pattern of Physics problem-solving among these students. Although this is not a confirmed model, it can be used to compare to some problem-solving models in science and mathematics outlined in Table 5.1.

Table 5.1: Comparison of established problem-solving model with the findings.

Author(s), Year, Subject	Model	Comparison	Remarks
Dewey (1910) [Science]	Problem's location and definition	Interpreting	Not in all the students
	Suggestion of possible solution	Planning	Most of the students only suggested one solution
	Development by reasoning of the bearings of the solution	Interpreting	Shown by all the students
	Further observation and experiment leading to its acceptance or rejection	Calculating, Checking, Reflecting	The checking at the end only showed by one student
Polya (1945) [Mathematics]	Understand the problem	Interpreting	Not in all the students
	Devise a plan	Planning	Most of the students only suggested one solution
	Carry out the plan	Calculating	Shown by all the students
	Look back	Checking	The checking at the end only showed by one student
Heller & Heller (1995) [Physics]	focusing the problem (visualise the problem)		Not found in the pattern
	explaining the physical principle or law	Interpreting	Not in all the students
	planning the solution	Planning	Shown by all the students
	executing the solution	Calculating	Shown by all the students
	evaluating the answer	Checking	The checking at the end only showed by one student

When compared to the above problem-solving models, the core pattern of Physics problem-solving can be identified as interpreting > planning > calculating > checking.

However, in my research, interpreting and checking are not carried out by every student. All the students went through the step of planning and calculating. This suggests that interpreting the problem and checking the answer are two steps that need to be strengthened among students in order to increase their problem-solving ability.

Metacognitive skills can be found in the steps of planning, reflecting, checking and interpreting. These are similar to Mettes (1987, see section 2.5) who suggested four categories of metacognitive skills (orientation, planning, evaluation and elaboration). The use of memory at the beginning of problem-solving as demonstrated by Angie is a part of orientation. In the step of checking and reflecting, which are similar to evaluation, the students monitored and regulated the problem-solving process. Finally, interpreting is similar to elaboration.

In the research by Stillman & Galbraith (1998) which implemented real problems (see section 2.4), they claimed that metacognitive skills helped the students in problem-solving. Table 5.2 makes a comparison of my findings with theirs.

Table 5.2: Comparison of findings of Stillman & Galbraith (1998) and this research

Where metacognitive skills help students (Stillman & Galbraith, 1998)	Related processes identified in this research
Understanding the problem	Read the problem, jot down key words.
Organisation of information	Arranging information
Cued ancillary data from long-term memory	Remembering
Developing and executing plans	Planning
Monitoring progress	Reflecting
Verifying final results	Checking

They reported that students pay little attention in verification (similar to my findings where only Colin performed verification of final results). Although there are similarities between my findings and the established findings, this cannot be called as substantive theory because my research has yet to reach the stage of theoretical saturation.

5.2 Implications for Physics problem-solving instruction

Although this research has not reached the stage of theoretical saturation, the data analysis and discussion above suggest that the students seldom perform the steps of

interpreting problems, making orientation, and checking the final answer. Most of the students are good at planning and appear to be ‘working forward’ (see section 2.2). Thus, in the instruction of Physics problem-solving, students can be reminded to make an interpretation of the problem using Physical Laws, try to visualise the problem and explain it qualitatively (Heller & Heller, 1995). Once the final answer is obtained, it is also essential to remind the students to check the calculations and answers from the beginning (also recommended by Stillman & Galbraith (1998)). Most of the students only interpreted the final answer and accepted it if it sounded logical (made sense) to them.

As for the metacognitive skills, I did not show any clear evidence of how the metacognitive skills found in my research assisted or affected the success of Physics problem-solving since this is not a causal study. From the outset of my study, I aimed to explain the *role* of metacognitive skills in the steps in Physics problem-solving. Yet, other researchers (Heller & Heller, 1995; Mestre, 2001) have suggested that metacognitive skills should be taught in Physics problem-solving instruction.

5.3 Implications for future research

There are still a number of areas in the model of the Physics problem-solving pattern represented in Figure 4.7 (dotted-boxes) which need further investigation. This small-scale research is the starting point for a doctoral study aimed at establishing patterns of Physics problem-solving among students, and suggests the strengths and weaknesses in their problem-solving methods. This is to enable the design of Physics problem-solving instructions for different patterns and levels of ability. Although further theoretical sampling and prolonged observation of students will be required to establish theoretical saturation or provide negative cases, some working hypotheses or potential substantive theories, may be generated from the data analysis completed thus far:

- a. There are several orders of steps in the middle dotted-box in Figure 4.7 that may generate more patterns of problem-solving.
- b. Both the checking and interpreting at the end of the problem-solving process are useful to generate correct answers.

- c. Metacognitive skills in reflecting about one's situation are useful to suggest errors, alternatives and strategies that can help enhance the problem-solving ability among the students.
- d. Metacognitive skills assist the students in becoming better problem solvers especially in planning, reflecting, checking and interpreting.

As explained in section 3.3, a GT generated must fit and work with both the data and behaviour under study. The above working hypotheses fit the data but again further research is needed to determine if they work when put into use. This will be one of my foci in my doctoral study, along with generating more working hypotheses and categories from further theoretical sampling.

From this study, I have also asserted a framework of real problem and genuine problem-solving (see section 2.1) that is useful for future studies in problem-solving in order to overcome the limitations of the studies reviewed in section 2.2. I also have explained in length the theoretical background and appropriateness (see section 3.5.1) of the use of thinking-aloud in research that observes problem-solving and metacognition. At this point, it has been found to be the most suitable method for research that is governed by the theoretical framework of naturalistic inquiry. The above implications should be considered as important by future researchers who are interested in understanding students' problem-solving process in natural settings.

5.4 Summary

This small-scale, naturalistic inquiry using GT is designed to understand the patterns of Physics problem-solving from the lens of metacognition. Due to time-constraints, I was only able to conduct one stage of theoretical sampling and have yet to reach theoretical saturation. This work will be continued in my PhD study where more students and topics will be selected. In this MPhil study, the practice of using techniques from GT, in sampling and data analysis, has helped to increase my theoretical sensitivity to ensure the generation of richer and denser categories. Nevertheless, through careful research and detail analyses of the existing literature, this study has demonstrated in a thorough and clear manner the importance of using 'real' problems in researching metacognition in Physics problem-solving processes among secondary school students,

which has – until now – been vastly understudied. Furthermore, this study has succeeded in generating a model of Physics problem-solving that will be the foundation of further essential research.

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