Between Rhetoric and Reality: The Use and Effectiveness of Practical Work in Secondary School Science

Ian Zoller Abrahams

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University of York

Department of Educational Studies

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Abstract

Many, both inside the science education community and beyond it, view practical work as an essential feature of science education. Questions have however been raised by some science educators about its effectiveness as a teaching and learning strategy. This study considers the effectiveness of practical work using the two-level model of effectiveness proposed by Millar et al. (1999) linked to Tiberghien's (2000) two-domains model of knowledge as an analytical framework.

The study is based on twenty-five multi-site case studies and employs a condensed fieldwork strategy. Data was collected, using tape-recorded interviews and observational field notes, in a sample of practical lessons undertaken by pupils in English comprehensive schools during Key Stages 3 and 4.

The findings suggest that whilst practical work is effective in getting pupils to do what is intended with physical objects it is relatively ineffective in getting them to think about their data using the intended scientific ideas. Nor is practical work usually designed to help pupils make links between observables and explanatory ideas. This suggests that the cognitive challenge of linking observables and ideas is largely unrecognised by teachers and those science educators who propose practical work. The findings also indicate that whilst practical work generates short-term engagement it is relatively ineffective in generating motivation to study science or longer-term personal interest, though it is often claimed to do so. This suggests that those involved with science education need to be better able to identify practical tasks which require pupils to make links between observables and ideas, and to structure such tasks to assist this kind of thinking and to recognise the limitations of practical work in the affective domain.

TABLE OF CONTENTS

Chapter 3: Research methodology

Chapter 4: Case study reports

Chapter 6: What pupils learn about objects, materials and ideas

Chapter 7: The role of practical work in the affective domain

Chapter 8: Conclusion

LIST OF TABLES

Page Number

List of Tables

LIST OF FIGURES

Page Number

List of Figures

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Chapter 1

Introduction

> According to Plato, the world can be divided into the abstract world of ideas or thoughts, and the concrete world of physical realities. He was not very successful in finding connections and relations between these two worlds. What Plato had forgotten was to include the laboratory; the missing link between the abstract world of thought and the concrete world of physical realities. The role of the laboratory is to connect the two worlds together. (Brodin, 1978 p. 4)

1.1 Preamble

One of the features of science education that sets it apart from most other subjects taught in school, perhaps *the* distinctive feature, is that it involves practical lessons that are, in general, undertaken in specifically designed and purpose built laboratories (White, 1988). The term 'practical lesson' is used here to mean any lesson in which the pupils are involved in manipulating and/or observing real (as opposed to virtual) objects and materials, and it is this manipulation and observation that will be referred to as 'practical work'. By characterising this type of activity on the basis of what pupils do, rather than on where they do it, it seems more appropriate to refer to it as 'practical work', rather than 'laboratory work' (or 'labwork'). Yet, having made this distinction, we might also recognise that most practical work in school science does take place in the laboratory (Millar 1987), so most school 'practical work' is also 'laboratory work'. Indeed the House of Commons Science and Technology Committee (2002), when discussing resources for practical work, make no reference to any practical work other than that undertaken in the laboratory.

Practical work is, from my own experience as a science teacher, not only widely, but also frequently, used in the teaching of science in English secondary schools. One possible reason for this, as Donnelly (1998) has suggested, is that many science teachers see the frequent use of practical work as an essential part of what it *means* to be 'a science teacher'. That practical work "seems the 'natural' and 'right' thing to do" (Millar, 2002 p. 53) means that many teachers see its use as the basic *modus operandi* for the teaching of science. The risk that this presents is that the use of practical work can become so routine that teachers cease to assess critically whether it is always the most appropriate way of achieving a specific learning outcome.

My own interest in practical work was kindled when a head of department challenged my decision to demonstrate current and voltage in parallel circuits using a teacher demonstration, rather than allowing the pupils to carry out the practical task for themselves. Whilst the precise details of the discussion between us have long since been forgotten, the general thrust of his argument was that for pupils to learn it was essential for them to be allowed to do and discover it for themselves. He was a highly experienced teacher, I a new entrant to the profession, and so for a number of years I taught parallel circuits through the use of a class practical. Despite my pupils appearing to enjoy practical work I became increasingly concerned about the effectiveness of practical work as a means of developing conceptual understanding. This concern arose from the fact that in practical lessons most of my time (as well as that of my pupils) was devoted to procedural issues such as collecting, setting up and successfully operating equipment in order to generate the desired data and/or phenomena, to such an extent that conceptual development was either marginalized or, in some cases, squeezed out of the lesson altogether.

But the effectiveness of practical work was not my only concern. Despite the fact that I, and my colleagues in the science department, saw practical work as a source of pupil motivation - a view supported, for example, by Jakeways (1986), Ben-Zvi et al. (1977) and Henry (1975) - and therefore used it as often as possible, the number of our pupils choosing to study science in the post-compulsory phase of their education was at best static (biology) and at worst steadily declining (physics and chemistry). That this was in no sense a situation unique to the school in which I was teaching can be seen from the fact that although there is a frequent and widespread use of practical work in English schools (Millar, 2004; Bennett, 2003; TIMSS, 1999) the absolute number of pupils choosing to pursue science at 'A' level is in steady decline (Osborne et al., 2003). This decline, so the House of Commons Science and Technology Committee (2002) reports, is most pronounced in chemistry and physics: the two science subjects that offer the most practical work during Key Stages 3 and 4.

My interest aroused, I undertook an MA in Education. However, rather than resolving my concerns about the effective and affective value of practical work, that study illustrated to me, through the disparate views expressed within the educational literature, the extent to which these issues had not yet been resolved. Moreover, whilst some literature was informed by research there was nevertheless "a large amount of literature which can best be characterised as opinion-based rather than research-based. Tied to these opinions or assumptions are the goals and objectives science educators consider desirable for science teaching and learning" (Blosser, 1981 p. 7). The only firm conclusion that I was able to reach was that there was little useful research-based information on the general effectiveness and affective value of practical work that could be used to help teachers within the context of their own teaching practice.

1.2 The purpose of the research

The purpose of this research, in contrast to some of the previous topic-specific studies that have looked at the *comparative* effectiveness of using two different approaches to teaching the same topic (see for example Thijs and Bosch, 1995; Watson et al., 1995; Chang and Lederman, 1994; Atkinson and White, 1981), is to investigate the effectiveness and affective value of practical work in a manner that will, it is hoped, provide teachers with useful generic information on the effectiveness and affective value of practical work that they can use to inform their own practice. As Langeveld (1965) has pointed out "Educational studies… are a 'practical science' in the sense that we do not only want to know facts and to understand relations for the sake of knowledge, we want to know and understand in order to be able to act and act 'better' than we did before" (p. 4). Indeed the problem with these previous studies is that they do not provide useful generic information but only specific information on the teaching of a specific topic within a specific subject to pupils of a certain age and academic ability. This study has sought to avoid these problems and, in so doing, provide useful generic information on the effectiveness of practical work by looking at how it is used in biology, chemistry and physics in the teaching of a wide range of topics to pupils of various ages and academic abilities.

This research has two broad themes. The first relates to the general effectiveness of practical work as used in biology, chemistry and physics lessons across the compulsory phase of secondary education (Key Stages 3 and 4). This is because, as a science teacher, it seems both reasonable and highly relevant to ask whether, given its disproportionately high cost and the relatively large proportion of the teaching time that it occupies, practical work is an effective use of both teaching time and available resources. The second theme relates to the issue of whether practical work has an affective value (in addition to its cognitive value) and, if so, in what sense this manifests itself. From a science teacher's perspective there are two useful measures of the affective value of practical work. The first, very obvious measure is whether pupils choose to pursue science beyond the end of Key Stage 4 and, if so, which of the sciences they prefer to study. The second measure is whether those pupils who choose not to pursue science post-compulsion (and there can be many reasons for this other than a lack of motivation) have developed, during their compulsory science education, a positive view of science and its value to them personally and to society.

1.3 The structure of the educational system in English schools

This study was carried out in state maintained comprehensive schools in England and it may be useful, before proceeding to an overview of the thesis, to briefly describe the structure of the educational system in English schools.

All pupils in English state maintained schools are required to follow a National Curriculum for the eleven years of their compulsory education with these being divided up into four unequally spaced Key Stages. Education in primary and junior school corresponds to Key Stages 1 and 2 respectfully. Key Stage 3 covers the first three years at secondary school (Years 7, 8 and 9) at the end of which pupils (and/or their parents) select the subjects they want to continue to study during the two years (Years 10 and 11) that constitute Key Stage 4 and which ends with the pupils sitting their first public examinations (GCSE's) at the end of Year 11. Although pupils have some choice as to the subjects to study during Key Stage 4 it remains a statutory requirement that they continue to study Science along with English and Mathematics until the end of Year 11. All science teaching has, since 1989, been controlled by the National Curriculum and is based around four attainment targets – three relating to 'science content' and one to 'scientific enquiry'.

In terms of who teaches what science subject the current system in England is one in which science is taught to pupils in Key Stage 3 as a combined subject with the same teacher often teaching all of the various biology, chemistry and physics components to the same pupils. In this respect it can be seen that, on average, non-subject specialists are teaching two thirds of Key Stage 3 material. Whilst science in Key Stage 4 is designed to be taught as three separate subjects, each of which is taught by a subject specialist, Millar (1987) has pointed out that shortages – particularly in the number of physics teachers – have inevitably meant that physics lessons in some schools are being taught by teachers who lack any formal qualifications in physics.

1.3 Overview of the thesis

Following on from this chapter, Chapter 2 reviews some of the literature relating to science education. The review focuses initially on the findings of three large national surveys that have investigated the nature and purpose of practical work in England. Having discussed the findings of these studies, this chapter then considers a number of key historical episodes that have been influential in changing the views of teachers and policy makers regarding the role and value of practical work in the teaching of science. Chapter 3 starts by discussing issues of research methodology and explains why it was decided to use twenty-five multi-site case studies employing a condensed fieldwork strategy, before moving on to consider the finding of an initial pilot study and the effect that these findings had on the subsequent design of the main study. The theoretical framework that is used is then discussed, as too is the way in which it provides a useful way of thinking about the effectiveness of practical work, that, in turn, leads to the three research questions that this study sets out to answer. Finally details are provided about the school selection process and the reasons for choosing to focus this study on the use of practical work only in Key Stages 3 and 4. Chapter 4 then presents details about each school, teacher and lesson observed so as to enable any particular case study to be located within the broader framework of the study as a whole. It also provides illustrative examples of three case study reports, chosen to exemplify one or more specific features of practical work that were seen to affect the effectiveness of several of the tasks observed. Chapters 5 and 6 are each devoted to answering one of the two research questions that relate to different aspects of the effectiveness of practical work. Whilst the findings of these two chapters combine to provide a better understanding of the overall effectiveness of practical work, each can be read independently of the other. Chapter 7, which investigates the affective value of practical work, starts with a detailed discussion of the psychological literature on motivation and interest. It then shows, by reference to the literature and comments made by teachers within this study, that the meaning of the terms 'motivation' and 'interest', at least within certain educational contexts, bears little resemblance to their meaning in a strict psychological sense. The chapter then goes on to present an analysis of the collected data from the case studies that, in turn, provide a useful way of understanding why pupils can both claim to like practical work and also express a firm intention to drop science at the end of Key Stage 4. Chapter 8, the final chapter, provides a summary of the three previous 'findings' chapters, followed by a discussion of certain aspects of the rhetoric/reality divide that emerged from this study. Then, with the benefit of hindsight, the possible influence of the study's design on the findings is considered, leading to a discussion of the reliability and validity of the main conclusions. The chapter ends by considering the study's contribution towards educational knowledge and understanding and its implications for teaching, as well as offering some tentative suggestions as to how practical work might be made more effective and possible areas for useful future research.

Chapter 2.0

Literature Review

2.1 Introduction

To date, despite the large amount of literature relating to practical work in science, there is relatively little incontrovertible data about the actual nature, purpose or effectiveness of practical work in secondary schools in England and Wales. Indeed after two hundred years of debate Millar (1987) can still reasonably ask "But what is this practical work for, and what learning does it promote? Its very taken-for-grantedness means that this question is often not asked; we find it hard to imagine school science without a strong practical emphasis. We reply simply that 'science is a practical subject' and leave it at that" (p. 113).

2.2 The nature and purpose of practical work: Previous large-scale national surveys

Surprisingly there have been only three large-scale studies into the nature and purpose of practical work in school science teaching throughout England and Wales (Kerr, 1964; Thompson, 1975; Beatty, 1980). These three questionnaire based survey studies all attempted to provide an insight into the nature and purpose of practical work at a specific instant of time and, despite the changes that have occurred within the school curriculum, the findings of all three are still frequently quoted. One point that should be noted here because of its direct bearing on the nature of this thesis is that both Kerr (1964, pp. 43-46) and Thompson (1975, p. 36) report finding discrepancies between the rhetoric surrounding the use of practical work and the reality suggested by the findings of their surveys. Likewise Beatty and Woolnough (1982), laying part of the foundation for this current thesis, also draw attention to the fact that their "analysis [of the Beatty (1980) survey data] may not necessarily reflect what is taking place in the laboratory and the question which must be posed is 'are they doing it?'. *Only by closer scrutiny of the work in schools can the nature of actual practice be determined*" (p. 30. Italics added). It is to these three studies that I now turn.

2.2.1 The Kerr Study 1963

Following a grant by the Gulbenkian Foundation in 1960 Kerr undertook the first extensive survey in order to inquire into the nature and purpose of practical work within the framework of grammar school science teaching in England and Wales.

The study involved 151 schools, 56% boys' schools, 26% girls' schools and 18% co-educational, all of whom followed a common 'grammar type' curriculum and involved a total of 701 science teachers. A novel approach to the distribution and collection of questionnaires was used to off set two possible causes of fallacious results that can arise as a consequence of using survey techniques involving questionnaires (Cohen et al., 2000; Bell, 1991; Anderson et al., 1975). Firstly there was a concern that with only a small number of questionnaires being returned it would be difficult to justify a claim that the sample was truly representative of the group as a whole. Secondly there was the additional concern that the responses on the questionnaire might not truly reflect either the beliefs or actual practice of the teacher because "there is a tendency for an individual to make the response which he feels is expected of him" (Kerr, 1964 p. 14). For example an analysis of the data from one section of the questionnaire indicated that a large percentage of teachers were claiming to "Make regular use of "demonstrations that verify facts and principles"...and that this kind of work was 'frequently used' " (Kerr, 1964 p. 43). Yet data from another part of the same questionnaire indicated that "The same physics teachers placed "to verify fact and principles already taught" eighth in order of importance [out of ten] of aims" (p. 44).

Further evidence that the teachers were responding to the questions without those responses reflecting their actual beliefs or practices is evident when it is considered that *all* of the teachers involved in the study completed the ranking of the ten suggested purposes of practical work. This in itself would be unproblematic if, as Tasker (1981) claims, "To the teacher and curriculum writer the features and purposes of the various investigative tasks employed in science lessons are clear" (p. 35). Yet Kerr (1964) reports that the researchers involved in his study "were repeatedly told by *teachers* and students that they had been so engrossed in what they were doing and how it was done that they had given little thought to why they did it" (p. 20. Italics added).

If some teachers had apparently given little thought to the reason why they had chosen to use a particular practical this then raises the question as to the extent to which their retrospectively applied rankings can meaningfully be said to represent what were effectively non-existent views.

Despite these problems the study did provide the first large-scale insight into teachers' views as to the nature and purpose of school practical work in England and Wales. The findings, which basically involved the teachers arranging ten suggested aims (purposes) for practical work in order of perceived importance, are summarised in table 2.1 below:

Table 2.1 Teachers' ten suggested aims (purposes) for practical work in order of perceived importance (From Kerr 1964 p. 27)

Pooled Order of Importance of Aims of Practical Work				
		Physics teachers		
		Years 1-2 KS3	Years 3-5 KS4	6th Form
1	To encourage accurate observation and careful recording	5	4	1
2	To promote simple, common-sense, scientific methods of thought	4	3	4
3	To develop manipulative skills	7	8	6
4	To give training in problem solving	9	9	8
5	To fit the requirements of practical examination regulations	10	10	10
6	To elucidate the theoretical work so as to aid comprehension	6	2	2
7	To verify facts and principle already taught	8	7	5
8	To be an integral part of the process of finding facts by investigation and arriving at principles	3	1	3
9	To arouse and maintain interest in the subject	1	5	9
10	To make physical phenomena more real through actual experience	2	6	7

In conclusion Kerr (1964) reported that whilst most science teachers placed strong emphasis on individual practical work this work had become relatively "inflexible, repetitive, outmoded and often inadequately integrated with the theory… In all science subjects, there was plenty of practical work being done but it was not well integrated with the theory and it was unlikely to achieve the unique educational value often claimed for it" (pp. 95-96).

2.2.2 The studies by Beatty 1980 and Thompson 1975

Comparing the results obtained by Beatty (1980), with those obtained by Kerr (1964), Beatty and Woolnough (1982) reported that, with respect to KS3, there had been a change in the perceived order of importance ascribed to the same aims. A direct comparison was not possible since both the study by Beatty (1980), in common with that undertaken by Thompson (1975) into physics practical work at 'A' level, had used an expanded list of twenty aims. Nevertheless a cautious comparison between all three studies can be made by comparing the order of importance of only those ten aims, proposed by Kerr (1964), that are common to all three studies. Bennett (2003) has suggested that despite a certain degree of variation between the studies in terms of teachers, subjects and pupil ages, there is a general consensus that most teachers perceived the "most important aims of practical work as being:

- to encourage accurate observation and description;
- to make scientific phenomena more real;
- to enhance understanding of scientific ideas;
- to arouse and maintain interest (particularly in younger pupils);
- to promote a scientific method of thought."

(Bennett, 2003 pp. 78-79)

Whilst alternative lists have been proposed (Trumper, (forthcoming); AAPT, 1997; Arons, 1993; Hodson, 1990; Klopfer, 1990; Woolnough and Allsop, 1985; Beatty, 1980; Anderson, 1976; Thompson, 1975; Shulman and Tamir, 1973; Novak, 1970; Kerr, 1964) they frequently share the same, or at least broadly similar, generic aims. Shulman and Tamir (1973), for example, suggest that there are five primary aims for practical work:

1. to arouse and maintain interest, attitude, satisfaction, openmindedness and curiosity in science.
2. to develop creative thinking and problem solving ability.
3. to promote aspects of scientific thinking and the scientific method (e.g.. formulating hypotheses and making assumptions).
4. to develop conceptual understanding and intellectual ability, and
5. to develop practical abilities (e.g., designing and executing investigations, observations, recording data, and analyzing and interpreting results).

Whilst not identical both the list proposed by Shulman and Tamir (1973) and that outlined by Bennett (2003) are, broadly speaking, similarly to one another as is the list proposed by Hodson (1990) who suggests that the main aims of practical work are:

1. to motivate pupils, by stimulating interest and enjoyment.
2. to develop certain 'scientific attitudes' such as open-mindedness, objectivity and willingness to suspend judgement.
3. to give insight into scientific method, and develop expertise in using it
4. to enhance the learning of scientific knowledge.
5. to teach laboratory skills.

Many of these lists were constructed on the basis of reviews of the then current literature (Trumper, (forthcoming); Arons, 1993; Shulman and Tamir, 1973; Thompson, 1975; Novak, 1970; Kerr, 1964). However, as much of the literature can be characterised as opinion-based (Garrett and Roberts, 1982; Blosser, 1981) these lists are based upon, and reflect, the rhetoric at a particular period of time rather than necessarily the reality of practical work as found in the school laboratory, as the following examples illustrate:

> [T]he following ten statements [the ten aims proposed], referring in particular to practical work, were collected from published reports on science teaching methods… (Kerr, 1964 p. 21)

> We can find in the literature... a long list representing the purposes of supporters of laboratory work...we can summarize them according to four different categories (Trumper, forthcoming)

> The most common objectives explicitly voiced [in the literature] in connection with the introductory physics laboratory (and also the ones most frequently implied by the instructions provided and the contexts chosen) are... (Arons, 1993 p. 278)

Despite the arbitrary nature of any particular list that proposed by Hodson (1990) provides a useful, although by no means unique or exhaustive, framework in which to review the rhetoric regarding changing historical perspectives as to the purpose of practical work. In this context changes and developments in the use of practical work occur when, as a consequence of debate and/or policy change, greater or lesser emphasis is placed upon one or more of the aims used to justify its use.

2.3 Key historical episodes

There have been a number of key historical episodes that have been influential in changing the emphasis placed upon one or more of the justifications for the use of practical work. Such episodes were influential in determining the general perception of the role of practical work in school science at a particular time and it is to these that I now turn.

2.3.1 Pre-Thomson Report: circa 1800 - 1918

Whilst it is of questionable value to try to define precisely the start of the debate as to the role and value of practical work it is instructive to see that by as early as the end of the eighteenth century the nature of the debate is already well defined. That the debate itself has changed little during the intervening period can be seen from the continuing relevance of a statement made by the Edgeworths (1811), just over two hundred years ago (the first edition appeared in 1798), in which they claimed:

> The great difficulty which has been found in attempts to instruct children in science has, we apprehend, arisen from the theoretic manner in which preceptors have proceeded. The knowledge that cannot be immediately applied to use, has no interest... they may learn the principles of mechanics... but if they have no means of applying their knowledge, it is quickly forgotten...Their senses should be exercised in experiments, and these experiments should be simple, distinct, and applicable to some object in which our pupils are immediately interested. (p. 723)

Whilst a small number of schools were carrying out practical work, within their programme of science education, such schools were, up until 1860, the exception rather than the rule. The Science and Art Department, stimulated into action by the growing needs of industry and the Report of the Devonshire Commission (1875) which had found little evidence of the use of observation and direct experimentation in school science, started to provide funding with the aim of increasing the extent and scope of science teaching in schools. The consequence of this action was, as Kerr (1964) reports, that "From 1867 to 1897 the number of candidates receiving some kind of science instruction for Science and Art Department awards rose from 10,230 to 160,239 though during this period the examiners complained repeatedly about the neglect of practical work and the undue attention to 'mere bookwork' " (p. 10).

Despite this increase the primary justification for the use of the limited amount of practical work, which tended to be of the form of teacher demonstration, principally involved the practical verification of previously taught conceptual material. However, in 1884 Armstrong proposed, to an International Conference on Education, the adoption of a 'heuristic', or discovery based, approach to science education in which, as he later wrote, "Heuristic methods of teaching are methods which involve our placing students as far as possible in the attitude of discovery - methods which involve their *finding out* instead of being merely told about things" (Armstrong, 1903 p. 236. Italics in original).

The conviction that pupils needed to discover facts about science for themselves lead Armstrong to place great store by the physical manipulation of apparatus and the development of what he believed would be transferable psycho-motor skills arguing that "The power of devising and fitting up apparatus, as well as devising and carrying out experiments is cultivated. Thus handiness is acquired" (Armstrong, 1903 p. 257).

With the wide and rapid acceptance of the heuristic approach within the school system the emphasis for the justification of practical work shifted towards its purpose as a means of providing an insight into scientific method and the acquisition of relevant skills.

2.3.2 Thomson (1918) to Norwood (1942)

The Thomson Report of 1918 marked a clear turning point in the direction of science education in Britain. The findings were clear and unambiguous, and heralded a change in emphasis away from method and back towards content:

> We are driven to the conclusion that in many schools more time is spent in laboratory work than the results obtained can justify.... Insistence on the view that experiments by the class must always be preferred to demonstration experiments leads to great waste of time and provides an inferior substitute. The time gained by some diminution in the number of experiments done could be well used in establishing in the pupils' minds a more real connection between their experiments and the general principles of the science or the related facts of everyday life.
> (Thomson, 1918 pp. 21-22)

Practical work was to be considered justifiable only in so far as it offered support to the learning process. There was no longer any justification for practical work *per se* since the emphasis for its justification had switched to the psychological support that it offered pupils in terms of providing reinforcement of conceptual knowledge taught using other methods. The end of this period was characterised by a desire to broaden the justification of practical work so as to place greater emphasis on its role as a basis for skill acquisition.

2.3.3 Norwood to Nuffield (1966)

After the publication of the Norwood Report (1943), in which a curtailed programme of practical work was advocated, the justification for its use shifted away from the psychological towards that of enabling pupils to acquire physical skills that would be transferable to future employment in the rapidly expanding technological industries. Towards the end of this period the crisis of faith in Western scientific ability, caused by what has come to be known as *The Sputnik Effect,* shook the political establishment sufficiently to ensure the inevitability of a thorough review of the science curricula in British schools. By the 1950's the arguments that had been raised against a heuristic approach had themselves all but been rejected despite what Connell (1971) refers to as the 'prominent' use of arguments designed to show that it was ineffective in terms of the use of teaching time. In fact the influential Report of the Science Masters' Association (1953) stated, quite unequivocally, that pressure on teaching time could better be overcome, not by a reduction in individual investigation and a more judicious use of teacher demonstration, but by the narrowing of the syllabus. Whilst lacking any research evidence to support the merit of such a claim the Report of the Science Masters' Association (1953) proposed that "As much experimental work as possible should be done individually or in groups - in fact, the whole of the science course can well be built around experiments which children perform. There is so much material to be taught that any part of the syllabus that does not lend itself to individual work might well be omitted" (p. 5).

The change in emphasis that accompanied the resurgence of the heuristic approach, coupled with pioneering work by Bruner (1961), gave rise in Britain to the development of the Nuffield discovery based learning courses. By the late 1960's the Nuffield view of 'the pupil as scientist' who needed to *do* science in order to *understand* science; a position encapsulated in the much quoted proverb that 'I hear and I forget, I see and I remember, I do and I understand', was firmly established.

2.3.4 Post Nuffield

By the late 1970's and early 1980's there was growing doubt about the claim that 'doing' leads to 'understanding' (Hodson, 1992; Driver, 1983; Tasker, 1981). In addition there was a growing realisation that the conceptual demands that were required for discovery learning to be successful were beyond the ability of the overwhelming majority of academically average pupils (Bennett, 2003; Lazarowitz and Tamir, 1994; Bates, 1978). Concern was also expressed (Kreitler and Kreitler, 1974) that in some courses, such as Nuffield Combined Science, the shift away from the transfer of conceptual knowledge had gone too far and had spawned approaches that were almost devoid of conceptual content. At the same time Shulman and Tamir (1973) suggested that this change in emphasis meant, *ipso facto,* that the laboratory *itself* had become the very essence of the science learning process. The growing doubts regarding the discovery learning approach were succinctly summarised by Driver's (1983) oft-cited counter-claim of "I do and I am even more confused" (p. 9).

During the 1980's doubts about the discovery learning approach led to the emergence of an alternative approach to practical work that had evolved out of an earlier American scheme, *Science - A Process Approach (SAPA)* (American Association for the Advancement of Science (AAAS), 1967). This approach, exemplified by the *Warwick Process Science* (Screen, 1986), was dominated by an emphasis on the processes of science, as epitomised by practising scientists, with little emphasis on scientific facts or concepts. Commenting on this lack of emphasis towards scientific facts Screen (1986) states that "the most valuable aspects of a scientific education are those that remain after the facts have been forgotten" (Quoted in Bennett, 2003 p. 89).

This shift in emphasis towards the processes of science was also reflected in the way educational courses and materials were, by the late 1980's, keen to be seen to associate themselves with the process-led approach (Millar, 1989). Indeed the dominance of the process-led approach was affirmed in a Department of Education and Science Policy Statement (DES 1985) that stressed that *the* essential characteristic of education in science was the introduction of pupils to the *methods* of science.

Yet by the late 1980's early 1990's there was mounting criticism of this approach (Hodson, 1992; Millar, 1989; Wellington, 1989; Millar and Driver, 1987). In particular it was argued (Millar, 1989; Millar and Driver, 1987) that content independent processes, such as classifying, hypothesising, lateral thinking and observing could not be taught; they are simply abilities that we all have a natural propensity to develop and that are evident even in children of a very young age. The approach also came in for criticism on the basis that "In recent years there has been a tendency, in some quarters, to give such priority to the processes of science that content has come to be regarded as relatively unimportant" (Hodson, 1992 p. 68).

2.4 Five generic aims for the use of practical work

Despite the high hopes and expectations of those who advocated a central role for practical work in the teaching of science, research has consistently found that it is no more successful in achieving *most* of these generic aims than other non-practical methods of teaching. It is to that research, and its implications for the five generic aims suggested by Hodson (1990), to which I now turn.

2.4.1 The role of practical work in enhancing the learning of scientific knowledge

Research findings into the effectiveness of practical work in enhancing the development of conceptual understanding remains ambiguous. Hewson and Hewson (1983) report a significant enhancement of pupils' conceptual understanding amongst that half of their study group, of pupils aged 13-20, who had received a primarily practical-based instruction compared to the other half of the study group that had received a traditional non-practical instruction. However, in other similar studies such findings have not been duplicated. Indeed Mulopo and Fowler (1987), in a study of 120 grade 11 pupils studying chemistry, reported no significant difference in the level of conceptual understanding amongst pupils irrespective of whether they had been taught using either practical or traditional non-practical methods. In contrast they report that the most appreciable factor in determining the extent of conceptual development was not the method of instruction but rather the pupil's level of intellectual development.

Indeed major reviews of the literature, within both the first and second editions of the *Handbook of Research on Teaching* (Shulman and Tamir, 1973; Watson, 1963), and subsequent reviews relating specifically to practical work (Lazarowitz and Tamir, 1994; Hofstein and Lunetta, 1982; Blosser, 1981; Bates, 1978) have all concluded, when outcomes are measured using pen and paper tests, that the use of practical work offers no significant advantage in the development of pupils' scientific conceptual understanding.

Although Hofstein and Lunetta (1982) observe that as with a glass that can optimistically be said to be half full and pessimistically half empty, the same is true regarding the effectiveness of practical work in so far as "Many of these studies have reported nonsignificant results, meaning that the laboratory medium was *at least* as effective in promoting student growth on the variable measured as were more conventional modes of instruction" (p. 212. Italics added). However, given the central role of the laboratory in the new curriculum, its high financial cost and the high aspirations that accompanied its introduction, these non-significant findings, corroborated by further recent studies (Watson et al., 1995; Chang and Lederman, 1994; Burron et al., 1993; Jackman and Moellenberg, 1987), are at best disappointing. Clackson and Wright (1992) summarise the situation thus:

> Although practical work is commonly considered to be invaluable in science teaching, research shows that it is not necessarily so valuable in science *learning*. The evidence points to the uncomfortable conclusion that much laboratory work has been of little benefit in helping pupils and students understand concepts. Its main justification seems to have been

> moderate success in the teaching of measuring techniques, and in improving manual dexterity; skills which it might be more appropriate for pupils to acquire through craft based activities. (p. 40)

Indeed Yager et al. (1969) argue that some academically able pupils may in fact consider laboratory work to be wasteful of their time, serving only to delay their pursuit of new theories and concepts. Connell (1971) suggests that even *if* this were the case, a point he argues requires further investigation to establish, this would more than likely only be indicative of a mismatch between the practical work and the pupils' academic ability. Similarly Van den Berg and Giddings (1992) argue that such beliefs, if held by the pupils, would be a criticism of the form of specific practical tasks rather than constituting a criticism of practical work *per se.*

However, these arguments seem, generally speaking, to further reinforce Ausubel's (1968) assertion that "In dividing the labour of scientific instruction, the laboratory typically carries the burden of conveying the method and the spirit of science whereas the textbook and teachers assume the burden of transmitting subject matter and content" (p. 346). However, it is important to note that Ausubel goes on to make a distinction in this context between different forms of laboratory work and states that "Laboratory work in this context refers to inductive or hypothetico-deductive discovery experiences and should not be confused with [teacher] demonstrations" (p. 346).

Hodson (1992) has claimed that it is necessary to introduce the pupils to the relevant scientific concepts *prior* to their undertaking any practical work if the task is to be effective as a means of enhancing the development of their conceptual understanding. More recently Millar (1998) has questioned whether the observation of specific phenomena within the context of a practical task can, unaided, lead to the development of conceptual understanding. In this context it has been proposed (Millar et al., 1999; Brodin, 1978) that the function of practical work might be better understood in terms of a link, or bridge, between previously taught scientific concepts and subsequent observations.

One explanation that has been advanced (Tamir, 1991) for the lack of research evidence to support the use of practical work as an effective means for developing pupils' conceptual knowledge is that, in contrast to teacher demonstration, its use can generate cognitive overload. Cognitive overload occurs as a consequence of simultaneous demands made of the pupils by practical work in that they need to apply intellectual and practical skills as well as prior knowledge (Johnstone and Wham, 1982).

Therefore despite the frequent claims that one of the aims of practical work is to provide an effective means of developing conceptual understanding the research findings suggest, at least when the outcomes are measured using pen and paper tests, that there is no significant advantage to its use.

2.4.2 The role of practical work in motivating pupils

Perhaps the most disappointing fact is that *despite* claims that pupils are said to prefer a laboratory centred approach (Lazarowitz and Tamir, 1994; Pickering, 1987; Ben-Zvi et al., 1976; Hofstein et al., 1976) and that its use encourages and motivates pupils to study science (Arce and Betancourt, 1997; Hannon, 1994; Lazarowitz and Tamir, 1994; Ben-Zvi et al., 1976; Kerr, 1964) there is a broadly shared view (Osborne et al., 2003; House of Commons Science and Technology Committee, 2002; Osborne and

Collins, 2001; Millar and Osborne, 1998; Osborne et al., 1998; Jenkins, 1994) that far too many "young people are, at age 16, closing off the option of entering a career in science or engineering at a time when the UK is suffering from a shortage of scientists and engineers" (House of Commons Science and Technology Committee, 2002 p. 23). In fact this is happening *despite* the devotion of a significant proportion of science teaching time to the pursuit of practical work. Indeed Bennett (2003) has argued that there is little reason to doubt that the amount of time spent on practical work will not have changed appreciably since the studies by Thompson (1975) and Beatty and Woolnough (1982) in which it was found that one third of the time allocated to science education, during 'A' level study, is devoted to some form of practical work (Thompson, 1975) with this rising to one half of science teaching time for pupils within the 11-13 age range (Beatty and Woolnough, 1982). In fact the Minister of State for School Standards, (House of Commons Select Committee on Science and Technology, 2002) stated that in terms of the proportion of practical work within science education in the United Kingdom "The evidence we have... the TIMSS assessment... which was published in December 2000, indicated that the amount of practical being taken on in schools here is actually greater than is the case elsewhere" (Question number 514).

A recent study by Windschitle and Andre (1998) into pupil motivation and the influence of epistemological beliefs on learning found that practical work was primarily effective in motivating epistemologically more mature pupils and that in contrast the epistemologically less mature pupils found traditional teaching styles more motivating. Other studies (Berry et al., 1999; Arce and Betancourt, 1997; Watson and Fairbrother, 1993; Ben-Zvi et al., 1977) report that pupils are more frequently motivated by practical work in which they are allowed to exercise some degree of control over the design and which they find both challenging and rewarding. Although Lazarowitz and Tamir, (1994) suggest that the motivational effectiveness of such tasks can be reduced if it is perceived as too difficult.

2.4.3 The role of the practical work in teaching laboratory skills

One of the difficulties in reviewing the literature that relates to the effectiveness of practical work in the teaching of skills is that the term 'skill' has been used to mean different things to different people in different studies (Bennett, 2003). Hofstein and Lunetta (1982) argue that many studies take too narrow a view of laboratory skills and consequently neglect to measure development in skill areas such as creative thinking, problem solving, general intellectual development, observing and classifying. Hodson (1990) distinguishes between 'craft skills' which are content specific - learning to read a micrometer, carrying out a titration - and content independent skills such as observation and manual dexterity which are generalisable to other contexts or disciplines whilst Gott and Duggan (1995) question the appropriateness of using the term 'skill' to describe *any* content independent processes. Dawe (2003) argues that content independent skills are, because of their generalisability, of more value to *all* pupils whilst content specific skills are of value primarily to future scientists or technicians. However, Ausubel (1968) argues, with regard to problem-solving skills, that there is no reason to believe that even if they could be taught, in the context of one subject, that they could be transferred to other contexts or disciplines. Heaney (1971) reports that whilst a heuristic approach leads to the development of problem-solving skills a more traditional 'didactic-with-demonstration' approach is actually detrimental to the development of such skills; a finding that has not been confirmed in any other study. Indeed Millar (1989) and Millar and Driver (1987) argue that content independent processes cannot be taught but are rather innate abilities that we all have a natural propensity to develop. Similarly studies into pupils' perspectives about laboratory work (Boud et al., 1980; Osborne, 1976) report that pupils themselves do not believe that their problem-solving skills improve as a consequence of undertaking practical work.

Similar ambiguity surrounds the effectiveness of practical work in the development of creative thinking. Hill (1976), using the Minnesota Test of Creative Thinking, reported an improvement in creativity after pupil involvement in practical work in chemistry. In contrast Gangoli and Gurumurthy (1995), using an 'objective-type' test devised and standardised by Gurumurthy (1988), reported no evidence of improvement in creative thinking within their study.

Hofstein (1988) has pointed out that if the term 'skill' is interpreted narrowly to mean only 'manipulative skill' then practical work has, perhaps unsurprisingly, been found to have a measurable advantage over other non-practical types of instruction within science education (Gangoli and Gurumurthy, 1995; Ben-Zvi et al., 1977; Kempa and Palmer, 1974). However, whilst not denying its relative effectiveness in this area White (1996, 1979) and Clackson and Wright (1992) have questioned both the appropriateness, and cost effectiveness, of its use as a means for developing content independent manual dexterity with White (1979) suggesting that "if skill in manipulation *per se* is the aim, not merely skill with scientific apparatus, there are cheaper and probably more efficient and effective ways of developing it. Needlework and fine woodwork are instances" (p. 762). Such criticism echoes that made about sixty years earlier in the British Association Report (1917) in which it was suggested that some purposes for undertaking laboratory work are of an intrinsically lesser value than others and that "In the laboratory the development of dexterity and skill is only a secondary consideration" (British Association Report, 1917. Quoted in Connell, 1971 p. 138).

Responding to the almost total ambiguity of research findings regarding the value of laboratory work, Hofstein and Lunetta (1982) claim that; (i) similarly ambiguous results have been found when studying *any* attempt to improve teaching and that; (ii) many past studies contained design weaknesses that render the conclusions drawn problematic.

Yet despite the studies undertaken to date the empirical results as to the value of practical work remain, other than as a means for improving manual dexterity, at best ambiguous. This ambiguity, Bates (1978) argues, means that the onus of proof therefore still remains firmly on those who believe otherwise to prove their case:

> Teachers who believe that the laboratory accomplishes something special for their students would do well to consider carefully what those outcomes might be, and then to find a way to measure them for the answer has not yet been conclusively found: What does the laboratory accomplish that could not be accomplished as well by less expensive and less time consuming alternatives? (p. 75)

2.4.4 The role of the practical work in developing scientific attitudes

The term 'scientific attitude' is both broad and weakly defined within the literature. Indeed it has been pointed out (Gardner, 1975) that the term 'attitude' has been appropriated by different researchers to describe on the one hand 'scientific attitudes' and on the other hand 'attitudes towards science'. Aiken and Aiken (1969) discussing traits such as intellectual honesty, openmindedness and curiosity referred to them as "the more cognitive scientific attitudes" (p. 295). In contrast Hofstein and Lunetta (1982) use the term attitude when discussing the development of "favourable attitudes toward science" (p. 210). There has been relatively little research (Hofstein and Lunetta, 1982) to evaluate the effectiveness of practical work as a means of developing scientific attitudes although in marked contrast it has been pointed out (Simon, 2000) that there have been in excess of two hundred studies into attitudes towards science.

Part of the explanation for this is to be found in terms of differences between the generic aims for practical work used by different researchers. Thus whilst Shulman and Tamir (1973) place both attitude and interest towards science in the same generic category Hodson (1990), whose categories are used within this study, places them into different generic categories and, as such, the term 'attitude' relates only to scientific attitudes and not to attitudes towards science.

Yet even when the term 'attitude' is used only with regard to scientific attitudes there is little evidence within the literature as to what constitutes a scientific attitude or, more importantly, how these are determined. Thus whilst Henry (1975) suggests that scientific attitudes include the need: (i) to be observant, (ii) careful, (iii) patient and (iv) persistent, Lazarowitz and Tamir (1994) suggest a much expanded list of scientific attitudes that includes "honesty, readiness to admit failure, critical assessment of the results and their limitations, curiosity, risk taking, objectivity, precision, confidence, perseverance, responsibility, collaboration, and readiness to reach consensus" (p. 98).

However, from a study of seventeen senior biology laboratories Fordham (1980) reported that the pursuit of scientifically correct results meant that honesty, far from being a scientific attitude that was developed through the use of practical work, was frequently its first casualty in so far as "If the experiment doesn't work we go to somebody else and get their results... it looks better when you get the results that you are supposed to... it's pretty obvious you won't get as good a mark as someone who got it to work" (p. 114).

Despite differences as to what might, or might not, be considered an appropriate scientific attitude Gauld and Hukins (1980) have pointed out that the majority of the scientific attitudes that appear in the literature fall into three generic categories: (i) general attitudes towards scientific ideas, (ii) attitudes towards the evaluation of scientific ideas and (iii) commitment to a particular set of beliefs about science. From a more fundamental perspective Bennett (2003) has argued that despite the difference between scientific attitudes and attitudes towards science both are inextricably linked with behaviours, dispositions and beliefs rendering a clear-cut distinction between them highly problematic.

In conclusion Gardner and Gould (1990) claim, with regard to the development of scientific attitudes, that "While students generally enjoy hands-on experience and the opportunity to work individually or in small groups, we cannot conclude that such experiences will, by themselves, bring about major changes in styles of thinking" (p. 151).

2.4.5 The role of the practical work in developing insights into and expertise of scientific method

Lazarowitz and Tamir (1994) have claimed that it is by undertaking practical work that pupils will develop an understanding of the nature of science, the way scientists work and in particular "the multiplicity of scientific methods" (p. 98). Yet such a multiplicity of methods is often overlooked given the strength of the prevailing view (Bennett, 2003) of the scientific enterprise that is firmly embedded within a hypothetico-deductive (Popper, 1989) view of science. In this context Bencze (1996) has argued that undue emphasis on a hypothetico-deductive view of science has, as a consequence, meant that science education has failed to reflect the fact that much of the research reported within the media is based on correlational studies that involve blind testing - methods that are rarely used within school laboratories. Millar (1989a) has pointed out that even if the hypothetico-deductive view of science *is* an appropriate model for the scientific enterprise it does not accurately represent the nature of practical work as it occurs within the school laboratory.

Indeed Martin (1979) has claimed that much practical work undertaken within the school laboratory has been reflective of "dubious or discarded philosophies of science" (p.331), a reference to the now widely discredited inductive view of science (Millar 2004) that underpins discovery learning. In the same context Layton (1990) has questioned the extent to which any philosophy of science has been used to systematically guide the nature of practical work in the school laboratory noting that "the philosophy of science has rarely been used in a systematic and deliberate manner as a prime source of objectives for student laboratory work" (p. 37).

Hodson (1989) has argued that the perceptions about both the nature of science and scientific method are shaped by the distorted manner in which text-books portray the relationship between experiment and theory in that "The actual chronology of experiment and theory is rewritten in text-books.This helps to sustain the myth that the path of science is certain and assigns a simple clear cut role to experiments" (p. 57).

Matthews and Winchester (1989) suggest that only if pupils are allowed to see that science is often less than certain and that the relationship between experiment and theory is not always clear cut will they develop an understanding of scientific method. Lazarowitz and Tamir (1994) suggest that such an approach will mean that "the distorted image many students have of scientists (unusual persons wearing white gowns, working in isolation, and exhibiting extraordinary behaviour) may be discarded, and students may realize that scientists are ordinary persons" (p. 109).

When these issues, along with a desire for greater financial accountability within the education establishment (Bates, 1978) and the higher cost of building and maintaining school laboratories are taken into account, the *prima facie* case for practical work no longer appears quite as self evident as it did when the National Science Teachers Association asserted that:

> The time is surely past when science teachers must plead the case for school laboratories. It is now widely recognised that science is a process and an activity as much as it is an organized body of knowledge and that, therefore, it cannot be learned in any deep and meaningful way by reading and discussion alone. (1970 p. 3)

2.5 Current perspectives on the nature and purpose of practical work

An increasing scepticism as to the effectiveness of the laboratory-centred approach to science teaching has led many researchers (Hodson, 1996; Van den Berg and Giddings, 1992; Woolnough and Allsop, 1985; Gagné and White, 1978; Ogborn, 1978) to question both the nature and purpose of practical work and how best such a purpose could be achieved.

The current debate has served to highlight the fact that there still remains, despite the long history of debate, a wide range of differing views as to the nature and purpose of practical work. Just how wide this range is can be illustrated by examining a few of the more extreme positions that mark out the boundaries within which most views can be found.

Kreitler and Kreitler (1974) propose that the purpose of practical work is to provide a means of enabling pupils to gain direct experience with scientific concepts that in turn generate episodes that serve to give those concepts meaning. They reject as wholly unrealistic the suggestion that its purpose, even in part, is to aid in either the development of problem solving skills or the generation of both curiosity and interest in science.

Woolnough and Allsop (1985) argue that the purpose of practical work needs to be separated from the development of conceptual understanding and advocate the need to "deliberately and consciously separate practical work from the constraint of teaching scientific theory. We must stop using practical as a subservient strategy for teaching scientific concepts and knowledge ...We will make no progress until we have cut this Gordian Knot" (pp. 39-40).

Hofstein and Lunetta (1982) assert that the purpose of laboratory work is all to often narrowly perceived as being directed only towards the growth of conceptual knowledge. In this manner, they argue, it neglects to recognise that it serves a purpose in the development of such areas as; creative thinking, problem solving, scientific thinking and general intellectual development and the effect it can have on pupil attitude to science.

Ogborn (1978), suggests that this diversity of opinion is a reflection of the fact that the nature and purpose of practical work can only be understood within a teaching context and it is that context that gives it purpose and that "Two of the most central questions concerning laboratory work are, quite simply, 'why?' and 'how?'. What should it be for, and how can those aims be brought about in reality? Single answers are not expected. 'What for?' depends upon 'for whom?', and 'how?' depends upon ' in what circumstances?' " (p. 3).

Yet despite these differences Millar et al. (1999) suggest that most science educators recognise the educational value of practical work and would agree that it should constitute a significant proportion of the time spent in teaching science at school. A caveat to this (White, 1996) being that whilst there might be a consensus that laboratory work has an educational value such consensus arises only if the term 'educational value' remains very loosely defined.

Chapter 3.0

Research methodology

3.1 Introduction

This study is a critical exploration of the effectiveness and affective value of practical work across twenty-five multi-site case studies. It employs a condensed fieldwork strategy that uses tape-recorded interviews and observational field notes.

3.2 Background

Despite the often favourable rhetoric that surrounds the role and value of practical work amongst educational policy makers and shapers (House of Commons Science and Technology Committee, 2002) research has consistently found that practical work is no more successful in achieving a broad range of teaching goals than alternative teaching strategies (Tobin, 1990; Hofstein and Lunetta, 1982). Indeed Hodson (1993) claims that empirical substantiation regarding the effectiveness of laboratory work, as a way of learning scientific concepts, is hard to interpret as is its impact on pupils' understanding of the nature of science (Klopfer, 1990; Millar, 1989). The only unambiguous research findings regarding practical work are that it is more effective than alternative strategies with regard to the development of manipulative skills (Gangoli and Gurumurthy, 1995; Hofstein, 1988; Ben-Zvi et al., 1977; Kempa and Palmer, 1974). However, even in this area, questions have been raised (White, 1996; Clackson and Wright, 1992) as to both the appropriateness and cost effectiveness of practical work as a means for developing manual dexterity.

Similarly whilst pupils are said to prefer practical work, over alternative methods of teaching science, (Lazarowitz and Tamir, 1994; Pickering, 1987; Ben-Zvi et al., 1976; Hofstein et al., 1976) the claim that it both encourages and motivates pupils to study science (Lazarowitz and Tamir, 1994; Lawson et al.,1989; Ben-Zvi et al., 1976; Kerr, 1964) is not reflected in the continuing decline in the number of pupils opting to study sciences at 'A' level (House of Commons Science and Technology Committee, 2002) and in particular in physics.

When the higher cost of building and maintaining school laboratories, relative to standard classrooms, and the growing requirement for greater financial accountability within the education establishment (Bates, 1978) are also taken into account the need for a study that probes beyond the rhetoric and into the reality of practical work seems all the more pressing.

Whilst previous large-scale quantitative studies, the most recent of which is now over twenty years old, have provided an insight into the views of teachers and pupils on practical work (Beatty and Woolnough, 1982; Thompson, 1975; Kerr, 1964) they did not compare these views with the reality of practical work in the school laboratory:

> The analysis of the aims section of the questionnaire gives a clear picture of the views of teachers on practical work. However this analysis may not necessarily reflect what is taking place in the laboratory and the question that must be posed is ' are they doing it?'.
> (Beatty and Woolnough, 1982 p. 109)

This study aims to provide a critical exploration of the relationship between the rhetoric of practical work, both as presented in the literature and in the views expressed by teachers and pupils, and its reality as manifested within the school science laboratory. It is only by ensuring that such rhetoric is not mistaken for reality (Crossley and Vulliamy, 1984) that educational policy makers will be able to focus upon the improvement of *actual* practice rather than what they are lead, from the rhetoric, to believe such practice involves.

To explore the relationship between the rhetoric and reality of practical work requires a strategy that, unlike a traditional survey-based approach, brings the researcher into closer contact with teachers and pupils as they undertake practical work in its principal natural school setting - the laboratory (Beatty and Woolnough, 1982). To achieve this an approach that moves away from the questionnaire based techniques, used in previous large-scale studies, was chosen. Indeed, it has been suggested (Crossley and Vulliamy, 1984) that a questionnaire-based approach is unlikely to provide an accurate insight into the reality of teaching within its natural setting since it has a tendency to reproduce existent rhetoric.

By choosing a strategy that sought to collect information on practical work within a natural laboratory setting it was hoped to be able to achieve a higher degree of *ecological validity* than would have been the case had the study used either a questionnaire or an interview-based approach. Ecological validity, a concept initially developed by Bracht and Glass (1968), is one of the factors that can enhance and/or threaten the external validity of a study. Ecological validity relates to generalisability in the sense that it considers the *conditions* (i.e., settings, treatments, researchers, dependent variables and the like) under which the findings obtained in one 'environment' might be expected to be found in another. In terms of an interview based study there is the particular difficulty, in terms of ecological validity (Cohen et al., 2000; Hammersley and Atkinson, 1983), that arises when attempting to relate inferences, formed on the basis of responses from interviews, to the reality that the interview was designed to probe. It was therefore decided that in order to maximise ecological validity the most appropriate strategy to study the reality of practical work within the natural laboratory setting would be to use a case study approach (Crossley and Vulliamy, 1984). There are a number of precedents for the use of a case study strategy to explore, in a critical manner, the relationship between the rhetoric and reality within an educational context (see for example Ball, 1981; Sharp and Green, 1976). It has also been suggested (Yin, 2003) that the use of a case study strategy is well suited to the investigation of "a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 13).

3.3 Research focus

From the literature review it became apparent that the broad issue of the effectiveness of practical work offered the potential for further interesting, and potentially beneficial, research given its prominent position within the rhetoric of practical work in school science. Whilst the use of practical work within the framework of school science has deep historical roots and few, if any, would question its continued use (Millar et al., 1999) it was apparent from a review of the literature that two broad questions had yet to be satisfactorily answered:

1. How effective is practical work in science as a teaching and learning strategy?
2. To what extent does practical work in science motivate secondary school pupils, as is frequently claimed?

It then became necessary to develop an appropriate research strategy that would be most suited to addressing these issues.

3.4 Initial strategy

The desire to penetrate beyond the rhetoric and into the reality of practical work seemed best met by a study in which the researcher would observe, over a period of at least three successive terms, a broad range of practical tasks as they were undertaken in their natural laboratory setting.

The initial idea was that each observation would follow one particular small group of pupils - usually no more than four pupils - as they undertook the entire practical task. This small group would be selected by the teacher on the basis of their being representative of the class as a whole. The small group would be audio-recorded throughout the task, the tape recorder being left on the bench. The researcher would observe and make field notes of the group from a distance of a few meters, ideally on an unused bench adjacent to that at which the small group worked, but would in no way interact with the group. Both the teacher and pupils within the small group would be interviewed after the lesson with these interviews again being audio-recorded. The choice of class, task and teacher would be determined in consultation with the head of department to ensure that the researcher had access to the full academic ability range (low, middle and high) from across those year groups selected for the study.

However, despite requests to four local schools, none of those approached was willing to provide the extended period of access required for such a study. It did not appear, from initial telephone conversations with the four heads of department at these schools, that they were opposed to providing access for research *per se* but rather to the specific idea of *extended* access. Their concern was that extended access would unavoidably disrupt a whole host of other long-term commitments and obligations entered into by the school, such as teacher training, Ofsted inspections and public examinations that made significant demands upon both teachers and pupils at different points in the academic year. These reasons were also cited by two further heads of department from schools outside of the immediate locality who also turned down a request for extended access even when this had been reduced from the initial request of three terms to a curtailed period of only one in an attempt to secure access.

3.5 Pilot study rationale

At this point, although extended access had yet to be arranged, it was decided to press ahead and undertake a small-scale pilot study. There were a number of reasons for undertaking a pilot study at this stage. One of these reasons was the need to investigate certain procedural issues relating to the practicalities of carrying out a study in the natural laboratory setting. These included: (i) an evaluation of the effectiveness of the audio-recording system within the noisy setting of a school laboratory. (ii) The extent to which the observation and audio-recording might effect the behaviour of the pupils within the small group involved. (iii) The effectiveness of a digital camera as a means to record rapidly changing classroom data such as notes placed on the blackboard by the teacher. It was also envisaged that by carrying out a pilot study at this stage it would provide an opportunity to assess whether a case study approach would have the potential to generate a sufficient amount of high quality data to enable the research questions to be fully addressed. Finally whilst the initial research questions had emerged from the literature review it was hoped that they could be refined and/or modified in light of the preliminary data from the pilot study, in order that they better reflect contemporary cases (Yin, 2003).

It was considered that a pilot study of this nature would require access to only two or three practical lessons; a request that my thesis supervisor was confident was unlikely to be refused by any head of science that he knew. It was also felt that a short pilot study might provide a useful opportunity to arrange, during face to face discussions with the head of science, subsequent access for the main study.

Given the initial rejections of requests for extended access it was felt important that the researcher be able to accept and meet any access opportunity offered. To achieve this it was decided, at least in the first instance, to approach only local and easily accessible schools and only if the need arose would those further afield be contacted. The need did not in fact arise. The first school contacted by telephone, one that had previously turned down a request for extended access, agreed enthusiastically to the request for access to one, or possibly two, practical lessons. Indeed this enthusiasm was reflected in the offer that, if convenient to the researcher, such a visit could be arranged there and then for a mutually convenient time the following week.

3.6 The pilot study

The pilot study took place in a small rural comprehensive school on the outskirts of a northern market town. The study involved the observation of three different practical lessons, two on the first visit and a third on a second visit a week later. The practical lessons, two Year 8 classes and one Year 10, were selected by the head of department on the basis that they had already been planned and the equipment booked for the two days scheduled for the observations. The choice of which small group to observe was to be left to the discretion of the class teacher who would be asked to suggest a typical example from those within the class.

3.7 Emergent issues

The findings that emerged from the pilot study had a profound effect on both the focus of the research questions and the nature of the research strategy that was subsequently adopted within the main study.

With regard to evaluating the effectiveness of audio-recording within the laboratory setting it was found that whilst the tape recorder picked up a lot of background noise the clarity was sufficiently reliable to enable a transcription to be made. However, whilst audio-recordings could be made, their effectiveness was dependent upon the ability of the researcher to minimise the 'reactivity effects' (Cohen et al., 2000; Lave and Kvale, 1995). Reactivity effects relate to:

> respondents behaving differently when subjected to scrutiny or placed in new situations, for example, the interview situation – we distort people's lives in the way we go about studying them (Cohen et al., 2000 p. 116)

Despite using the same procedure to carry out the audio-recording two very different types of behaviour were observed that appeared to reflect a different level of pupil anxiety about taking part in the study. One group of academically high ability pupils, described by their teacher as being the most able in their top-set class, appeared, from the frequent personal comments and large amount of off-task talk and general jovial banter, to have totally ignored the presence of both the researcher and the tape-recorder. The audio-recording of their interaction, as they undertook the practical task, illustrated how effective audio-recording could be despite the considerable background noise. In contrast the second group, composed of academically low ability pupils, appeared anxious from the start and repeatedly sought reassurance from both the researcher and their teacher that the tape would be confidential. These reassurances appeared to have little effect and the pupils refused to speak in anything more than whispers that, for the purpose of transcription, were wholly unintelligible.

Whilst it had been planned that the researcher would remain a passive observer it became apparent, after a silence of almost ten minutes broken only by intermittent giggling, that to obtain any useful information from this academically low ability group would require a more active role for the researcher. As this was a pilot study, the researcher explored the effect of interacting with the group using semi-structured questions as a means to focus on the task they were undertaking as well as general issues relating to practical work.

What emerged was that whilst this academically low ability group were initially reluctant to be observed, or audio-recorded, whilst undertaking the practical task this reluctance was reduced when the researcher actively interacted with the group. One possible explanation for this might have been the encouragement engendered amongst these academically low ability pupils by the intentional naiveté of the researcher's questions, a technique of encouragement that Stenhouse (1984) claims has been used to explain his own successful interview technique. As such this approach appeared to give these pupils the confidence to express their own views openly and honestly without fear of being assessed by a scientifically knowledgeable person.

The use of the digital camera to record blackboard notes during the lesson was found to be disruptive. In a manner similar to the reactivity that can accompany the use of video cameras in a classroom (Cohen et al. 2000) it was found, especially with academically low ability pupils, that its use was taken as an unauthorised excuse to break off from their study in order to make comical poses for the camera. The researcher's observations, supported by comments from the teachers involved, suggested that the novelty of its use during their first and only encounter with the researcher produced an undesirably disruptive effect on the lesson. It was at the same time found that, since the pupils were always given sufficient time to copy down notes from the board before undertaking the practical task, there was also time for the researcher to copy these down in a field note diary before the task itself commenced.

An unexpected procedural difficulty that emerged was that of trying to arrange post-practical interviews with the pupils. Whilst the head of science was willing to provide access to practical lessons within the department it was stressed to the researcher that the pupils would be expected to leave the laboratory at the end of the lesson so as not to be late for their next lesson. The only option that was available to the researcher was therefore to arrange pupil interviews to coincide either with break-times during the school day or, if more convenient, at the end of the day before the pupils left the school. However, it was found that whilst some of the pupils (the academically high ability group) were willing to return during their break, the low ability group would not. Indeed, even when their teacher requested that they return to the laboratory at the end of the school day for a brief interview they failed to turn up.

It also became apparent that the small groups that had been selected by the teachers for observation were not typical of their respective classes. Indeed the small groups observed appeared atypical both in terms of their behaviour and academic ability. During subsequent discussions with the teachers involved it was acknowledged that these small groups were atypical. The groups selected by the teachers were either the most academically able, or amongst the most able, in their respective classes and, in the case of the low ability class, had been specifically chosen because they were considered by the teacher to be the best behaved in the class. Whatever the combination of reasons it became apparent that an approach that required the teacher to select a small group for observation was unlikely to produce reliably representative groups.

Since the observation of the small group occupied a large proportion of the time when the teacher was not interacting with the class as a whole it was planned that the interview with the teacher would be deferred until immediately after the lesson. If this proved impractical, as a consequence of further teaching immediately after the observed lesson, then it would be deferred to the earliest possible opportunity thereafter on that day. It was hoped that, by reducing the time between lesson observation and teacher interview to a minimum, the teacher's views and recollections of that lesson would remain very clear. The pilot study showed that this appeared to be a successful approach in so far as the teachers appeared willing to give up their own time either during lunch or a subsequent free teaching period.

A number of unexpected ethical issues emerged from the pilot study one of which was the tension between ensuring the confidentiality of information provided by the pupils during their interviews whilst also ensuring, particularly when female pupils were involved, that interviews never occurred in an unsupervised, and hence potentially compromising, situation. The approach that was adopted in the pilot study, after discussion with the teacher, involved the teacher remaining in a side room off the laboratory with the door open so that such interviews were effectively being carried out under their supervision. However, a number of comments by the pupils, albeit light-hearted in manner, indicated that they were aware of their teacher's presence and, as a consequence, were mindful of what they said. Their caution was subsequently borne out when, during a subsequent discussion with their teacher, the teacher made a direct reference to a comment made earlier by one of the pupils during the interview that they had evidently been able to overhear.

Another issue of ethical concern that emerged from the pilot study related to the use of Ofsted information and the question of ensuring the anonymity of not only the teachers and pupils but also the schools involved in the study. This point arose when it was found that the use of any direct quotation from an on-line Ofsted report could be used, with a moderately powerful search engine, to locate the specific Ofsted report from which the quotation had been taken and, in so doing, identify the school. Once a school has been identified in this manner it would require little additional effort to identify teachers within the department from a school's own Web site. Given the over riding ethical obligation on the part of the researcher to protect the anonymity of the teachers, pupils and their institutions (Frankfort-Nachmias and Nachmias, 1992) it was decided not to proceed with the inclusion of such quotations within the main study. My thesis advisory group concurred with this decision on the basis that whilst a determined individual could probably ascertain the identity of a school or particular teacher, with or without these quotations, the offer of anonymity required the researcher to take all *reasonable* steps to prevent this from occurring.

However, it was in terms of providing a preliminary source of data that could be used to refine and focus the relatively broad initial research questions, that the pilot study was most valuable. In particular the pilot study illustrated the wide variety of practical work, both in terms of type and intention, which meant that the initial research question of whether practical work *per se* was an effective teaching and learning strategy had no single answer. Instead what emerged was the recognition of a need to consider the issue of the effectiveness of practical work in terms of particular tasks. In a similar manner Ogborn (1978) has argued for the need to recognise that there is no single purpose for practical work in general but rather that each task will have its own specific purpose:

> What should it [practical work] be for, and how can those aims be brought about in reality? Single answers are not expected. 'What for ?' depends upon 'for whom?', and 'how?' depends upon ' in what circumstances?'. (p. 3)

Another important finding that emerged from the pilot study was that of what the pupils meant when they said that they liked practical work. Whilst pupils invariably made the claim that they liked practical work it was almost always expressed in terms of its being liked better than some other method of teaching rather than in any objective sense. Indeed, there was little evidence from the pilot study findings to support the view that practical work was successful, in the manner that educational policy makers might hope, in motivating pupils to pursue science post KS4.

In terms of the viability of a case study strategy there was clear evidence, from both the transcripts and field notes, that this approach, that used observations and interviews, was able to produce useful and interesting information that bore directly on the areas of interest.

Yet despite the evident bonhomie between the researcher and the members of the department it was found that the head of department, whilst willing to offer further access to individual lessons if this was required, was unwilling to consider any form of extended access to the department.

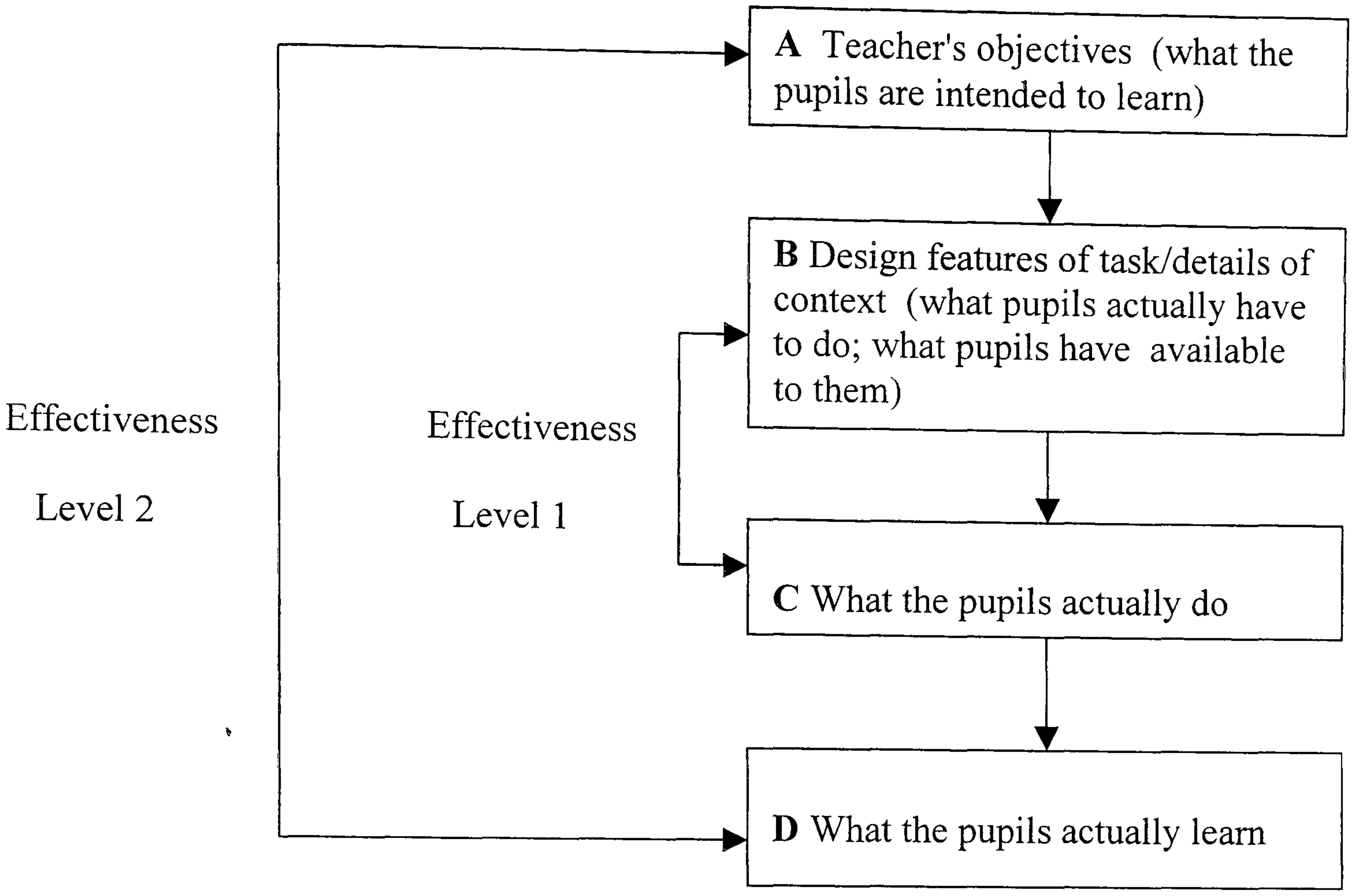
In order to be able to evaluate the effectiveness of a diverse range of practical tasks a theoretical framework was required that would enable the issue of what was meant by 'effectiveness' to be clarified.

3.8 Theoretical framework

Given the wide variety of practical work it was decided that the issue of effectiveness had to be approached not in general terms but rather in terms of how effective a specific task is *relative* to the aims and intentions of the teacher who chose it. As Millar et al. (1999) point out the need is "to ask about the effectiveness of *specific* pieces of practical work for achieving *specific* learning outcomes" (p. 34).

In order to do this a model of the processes involved in designing and evaluating a practical task developed by Millar et al. (1999 p. 37) has been used and this is shown below in figure 3.1.

Figure 3.1 A model of the process of design and evaluation of a practical task (From Millar et al., 1999, p.37)



Given that the aim of this model is to consider the effectiveness of a specific task *relative* to the aims and intentions of the teacher the starting point (Box A) is an evaluation of the teacher's learning objectives in terms of what it is they want the pupils to learn. Once the teacher has decided what it is that they want the pupils to learn the next step (Box B) is for them to design a specific practical task that they believe has the potential to enable the pupils to achieve the desired learning objectives.

However, because the pupils might not do exactly as was intended by the teacher when they designed the task the next step in the model in figure 3.1 (Box C) therefore considers the question of what it is that the pupils actually do as they undertake the task. There are various reasons as to why and to what extent what the pupils actually do might differ from what was intended by the teacher. For example, the pupils might not understand the instructions or, even when they do and adhere to them meticulously, faulty apparatus could prevent them from doing what was intended by the teacher. Alternatively even if the task is carried out as intended by the teacher and all of the apparatus functions as intended the pupils still might not engage mentally with the task using the ideas that the teacher had intended them to use. The last step in the model (Box D) is therefore concerned with the question of what it is that the pupils actually learn as a consequence of undertaking the task.

The use of this theoretical model allows the question of the effectiveness of a specific practical task to be considered at two separate levels.

The first level of effectiveness therefore relates to the issue of what pupils *do* relative to what the teacher intended them to do. This level of effectiveness, henceforward referred to as 'level 1 effectiveness', is about the relationship between boxes B and C in the above model. The second level of effectiveness considers what the pupils *learn* relative to what the teacher intended them to learn. This second level of effectiveness, henceforward referred to as 'level 2 effectiveness', is about the relationship between boxes A and D in the model. This model can therefore be used to clarify what is meant by the 'effectiveness' of a specific practical in terms of:

1. Does the task enable the pupils to do the things the teacher actually wanted them to do when they chose to use that specific practical task?
2. Does the task promote pupil learning?

By combining this model of effectiveness with a model of knowledge (Tiberghien, 2000) in which there are two distinct domains: the domain of observable objects and events (o) and the domain of ideas (i) it is then possible to consider each of the two levels of effectiveness in terms of these two distinct domains. The effectiveness of any practical task can now be analysed and discussed in terms of two principal levels with each level being further divided into two domains. In terms of task effectiveness these levels are defined in the following way:

- A task is effective at level 1:o if the pupils *do* with the objects and/or materials the things that the teacher intended them to do and, as a consequence, they see the intended outcome.

- A task is effective at level 1:i if the pupils *think* about the task using the ideas that the teacher intended them to use.

In contrast at level 2:o and 2:i the issue of effectiveness relates to whether or not the task enables the pupils to *learn* the things intended by the teacher. Level 2 effectiveness is therefore considered in terms of the two following distinct domains:

- At level 2:o a task is effective if the pupils *learn* and can recollect details about the objects/materials/events that they have observed and/or handled.

- At level 2:i a task is effective if the pupils *learn* and can recollect the scientific ideas that provide an explanation about the objects/materials/events that they have observed and/or handled.

These two levels of effectiveness, each of which can be considered with respect to the two distinct domains of knowledge, can be represented (Figure 3.2) using a 2x2 effectiveness matrix:

Figure 3.2 A 2x2 effectiveness matrix

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	Set up the equipment and operate it in such a manner as to see what the teacher intended.	Think about the task using the ideas intended by the teacher.
at level 2 (what pupils learn)	To set up and operate similar equipment. Discover patterns within their observations/ data.	To understand their observations /data by being able to link them, using the ideas intended by the teacher, with the correct scientific theory.

Effectiveness at level 2:i is therefore a necessary prerequisite if, as has been suggested (Millar et al.,1999; Solomon, 1988; Woolnough and Allsop, 1985; Brodin, 1978; Shamos, 1960) a function of practical work is to provide a link between the domain of observable objects and/or events and the domain of ideas. However, since it appears unlikely that a task could be effective at level 2:i were it not also effective at both level 1:o and 1:i task effectiveness across level 1 appears a necessary requirement for the successful linkage of the two distinct domains of knowledge.

To illustrate the use of the 2x2 effectiveness matrix consider its application to a practical task in which, for example, the pupils were investigating current in a parallel circuit (Figure 3.3).

Figure 3.3 The 2x2 effectiveness matrix for a practical task involving an investigation of current in a parallel circuit

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	Set up a working parallel circuit and be able to operate and read with sufficient accuracy an ammeter in order to obtain the readings intended by the teacher.	Think about the electric current as a flow of electrons passing around the circuit that divides and recombines as it passes into and out of the branches in a parallel circuit.
at level 2 (what pupils learn)	To set up a parallel circuit. Discover that the ammeter readings in both branches of a parallel circuit sum to the ammeter reading before and after the branch.	That the data obtained from the ammeter readings, if thought of as measuring the size of an electric current passing around the circuit, can be understood in terms of the scientific idea that electric charge is conserved in a parallel circuit.

Given the limited opportunity for subsequent access it will be difficult to assess, in terms of effectiveness across both domains of level 2, what pupils are able to recollect about a particular practical task. It must also be recognised, even when return access is granted, that it will be very difficult to ascertain the specific contribution made by the practical task, since it is frequently only part of a larger teaching sequence, to the pupils' recollection of specific material.

Despite these difficulties it is hoped, since some tasks are repeated in different academic years, to probe the extent to which pupils who have carried out the same task on previous occasions are able to recollect details of both what they learnt and how to undertake the task.

A possible challenge to the theoretical model used in this study (Figure 3.1), in which a distinction is made between two distinct domains of knowledge: the domain of observable objects and events (o) and the domain of ideas (i), is that all observation is theory-laden. It has been argued (Hanson, 1958) that even basic observation statements that report sensory experience, and to which empiricists seek to anchor their claims of knowledge about the world, are themselves dependent upon the theoretical framework within which the observer consciously, or unconsciously, chooses to operate:

> There is a sense, then, in which seeing is a 'theory-laden' undertaking. Observation of x is shaped by prior knowledge of x. Another influence on observation rests in the language or notation used to express what we know, and without which there would be little we could recognise as knowledge. (Hanson, 1958 p. 146)

Indeed it has been reported (Gott and Welford, 1987) that prior knowledge of the theoretical shape of magnetic field lines surrounding a bar magnet enables pupils to see the magnetic field lines formed by iron filings that pupils who lack this prior knowledge are unable to see. Similar results (Hainsworth, 1956) have also shown that what pupils see when they examine cells under a microscope depends markedly upon whether they have seen diagrams of such cells before being asked to examine them for themselves.

That observation statements and ideas might be thought of as occupying the two extremes of a 'theory-ladenness' continuum (Shapere, 1982; Maxwell, 1962) suggests that any attempt to divide the continuum into two distinct categories - observable objects and/or events and ideas is necessarily arbitrary (Driver et al., 1996). However, whilst such a distinction might be arbitrary Driver et al. (1996) make the point that "while an observation statement may be theory-laden, it is not necessarily laden with the theory which it is being used to test" (p. 33). Therefore provided that a theory-laden observation statement is not being used to test the theory with which it is laden it can be thought of as providing a 'pseudo-pure' observational statement. Indeed Feyerabend (1988) claims "observation statement[s] are not just theory-*laden* ... but *fully theoretical* and the distinction between observational statements... and theoretical statements is a pragmatic distinction" (p. 229. Italics in original).

A pragmatic distinction between observables and unobservables i.e. objects and/or events and ideas will be used within this study that utilises what Feyerabend refers to as 'quickly decidable sentences' (quoted in Maxwell, 1962 p. 13). In the sense that such sentences will be used here a quickly decidable sentence is defined as:

> [A] singular, nonanalytic sentence such that a reliable, reasonably sophisticated language user can very quickly decide whether to assert or deny it when he is reporting on an occurrent situation.
> (Maxwell, 1962 p. 13).

Whilst recognising the undeniably diffuse nature of any line that attempts to distinguish between observation and theory such a distinction, between these two clearly recognisable domains, remains a very useful method of analysing different aspects of the effectiveness of practical tasks.

3.9 Task characterisation

A feature of the model of the processes involved in designing and evaluating a practical task (Figure 3.1) is that it distinguishes two distinct dimensions. The first of these dimensions "is the intended learning outcome, or learning objective, of the task... The second dimension is the task design itself" (Millar et al., 1999 p. 39).

To be able to draw conclusions between features of the task design, for example its degree of openness/closure, and the effectiveness of that task at either level 1 or 2 it is essential to have a clear perspective as to the type of each practical task observed. In order to characterise each particular task a typology of practical work, developed for use at primary and secondary school level by Millar et al. (1999) has been used.

This typology, itself a modification of an earlier typology of laboratory work at upper secondary and undergraduate level (Millar et al., 1998), has been used successfully in a recent study that sought to investigate the characteristics of practical work in science classrooms in Namibia (Kapenda et al., 2002). However, since the pilot study only involved practical tasks undertaken in KS3 and 4 examples in the original coding categories that related specifically to post KS4 level practical work have either been removed or replaced. (Examples of a task profile form and the coding categories appear in appendices A.1, A.2, A.3, A.4, A.5 and A6).

3.10 The modified research questions

The two initial research questions that had emerged from a review of the literature had been relatively broad in terms of their focus:

1. How effective is practical work in science as a teaching and learning strategy?
2. To what extent does practical work in science motivate secondary school pupils, as is frequently claimed?

The pilot study had shown that whilst a *specific* task could be effective, in so far as it enabled the pupils to set up the apparatus and *do* what the teacher intended, it could nevertheless be ineffective in terms of enabling the pupil to learn what the teacher had intended. It had also shown that whilst pupils frequently claimed to like practical work this appeared to have little influence given that many of the pupils questioned had little, if any, intention of pursuing the study of science post KS4.

It was therefore decided that the research questions could be refined in order to take account of both the preliminary findings that had emerged from the pilot study and the theoretical framework that had been developed. The refinement process resulted in the formulation of the following more specific research questions:

1. To what extent are specific practical tasks effective in enabling pupils to *do* what the teacher intended?

2. To what extent are specific practical tasks effective in enabling pupils to *learn* what the teacher intended?

3. Does practical work have an affective value and, if so, in what sense?

In addition to helping in the refinement of the research questions the pilot study also helped to refine, and further develop, the nature of the research strategy that would be used within the main study to answer these questions.

3.11 The modified research strategy

Given that it had emerged from the pilot study that each practical lesson could be considered as a self-contained entity, or case study, in its own right there no longer appeared any methodological advantage in undertaking all of the observations in a single extended in-depth study in one particular school. From a theoretical perspective there was the recognition that whilst the hallmark of an in-depth case study is its high ecological validity, its Achilles' heel is its relatively low population validity. Population validity, like ecological validity, can enhance or threaten the external validity of a study and refers to the extent to which it is possible to generalise from the research findings, obtained from a relatively small sample population, to members of a much larger population (Cohen et al., 2000; Cohen and Manion, 1982; Bracht and Glass, 1968). It has been suggested (Shaughnessy and Zechmeister, 1985; Crossley and Vulliamy, 1984; Entwistle, 1973; Bolgar, 1965) that the use of a single case study is always open to criticism on the grounds that its population might not be a representative sample of the larger population to which subsequent generalisations may wish to be made. Spindler (1982, p.8) argues in its defence that, provided the settings of a particular case study do not differ 'markedly' from those within the larger population (i.e. it has a high degree of ecological validity), it is likely that any findings will be generalisible, to a substantial extent, to the larger population. However, Bell et al. (1984) claim that the extent to which subsequent generalisations can be made depends to a large degree on intuitive judgements about the ecological validity of the study and that "results are not easily generalizable, except by an intuitive judgement that 'this case' is similar to 'that case' " (p. 76). Spindler (1982) seeing both ecological, *and* population, validity as being in tension with each other cautions against any attempt to increase population validity, at the expense of ecological validity. Such action, he asserts, would be undesirable in terms of the detrimental effect that it could have on the *quality* of information that it would provide, claiming that "it is better to have in-depth, accurate knowledge of one setting than superficial and possibly skewed or misleading information about isolated relationships in many settings" (p. 8).

However, Crossley and Vulliamy (1984) note that such an argument assumes that a concern for ecological validity will always take precedence over that of population validity - an assumption that might not be feasible and/or desirable in all educational research involving the use of case studies. It has also been pointed out (Yin, 2003; Walker, 1980) that in many situations the in-depth case study is simply not a realistic option:

> 'Anthropological' style research which is usually held up as the distinguishing mark of case study research is rarely feasible in democratic mode evaluation or research, there is simply not the time for such methods as they are normally practised and they are rarely accessible to practitioners. (Walker, p. 43)

It was therefore decided, given the willingness of the pilot school and seven other schools subsequently contacted to offer limited access, to use a multi-site case study approach that employed a 'condensed fieldwork' strategy (Walker, 1980 p. 43). The advantage of this approach being that it presented an opportunity not only to achieve a high degree of ecological validity but also, by increasing the size of the sample population, to raise the population validity of the study. By raising the population validity, whilst seeking to maintain the high level of ecological validity traditionally associated with single, in-depth, case studies (Crossley and Vulliamy, 1984), this approach was seen as a means of enhancing the external validity of the study i.e. the extent to which any finding could be generalised to larger populations and different environments.

Because interviews are able to generate considerable relevant information within short periods of time they are ideally suited to condensed fieldwork studies (Vulliamy and Webb, 1996; Stenhouse, 1984; Walker, 1980). Indeed, Stenhouse (1984) strongly suggests that by their very nature "case studies are predominantly interview-based. You are not getting enough time to do true participant observation, and therefore you are trying to collect, in interview, observation from participants" (p. 226).

However, since case studies typically use two or more methods of data collection for triangulation purposes (Yin, 2003; Hakim, 1997; Patton, 1987; Cohen and Manion, 1982) this study used, in addition to audio-recorded interviews with teachers and discussions with pupils, researcher observations and field notes. The use of teacher interviews and semi-structured questions with the pupils also offered the advantage that it provided the researcher with the opportunity to draw upon, and use, observational data directly (Fang, 1996) so as to focus questions on to specific areas of interest. In addition brief discussions with laboratory technicians and other teaching members of the department provided background data on both the school in general, and the science department in particular.

3.12 School selection

In order to achieve a high degree of ecological validity it was necessary to ensure that the sample of schools, whilst representative, were not what Spindler (1982, p.8) termed 'markedly dissimilar'. Whilst the question as to when schools cease to be 'dissimilar' and become 'markedly dissimilar' is one of degree, it was felt, at least in terms of how schools are often perceived and reported in the media, that a useful distinction could be made in terms of school type. In terms of ecological validity it is arguably questionable as to the extent to which research findings obtained in one particular type of school setting e.g. an independent, selective, single-sex Catholic boarding school, could be usefully generalised to a larger sample composed only of comprehensive schools and therefore the type of school provides a useful, although arbitrary, means of determining the degree of dissimilarity.

With the overwhelming majority of pupils in England being educated within a comprehensive school setting it is possible, by restricting the study to only comprehensive schools, to claim, at least in terms of school *type,* that none of those within the study are 'markedly dissimilar'. Despite restricting the study to one specific school type - the comprehensive - different examples of this type of school, in terms of their size, location and status would be included within the sample to ensure that it was representative of the larger population of comprehensive schools from which the sample was drawn.

Whilst the use of only one type of school - the comprehensive - would mean, in terms of the ecological validity of the study, that it would be difficult to support any generalisation of the findings to other *non*-comprehensive school types it does ensure that generalisations can be made to that type of school in which the majority of our pupils are educated.

The selection of schools was opportunistic in so far as initial requests for access were made, in all but one case, to schools in which my thesis supervisor knew the head of science. Given the relatively large number of such contacts it was possible to ensure a sample that was broadly representative of comprehensive schools across three educational authorities in terms of size, status and environmental setting. Such a selection process was principally concerned with ensuring what Bell (1984) refers to as "naturalistic coverage" (p. 75) rather than with meeting the statistical sampling requirements associated with traditional quantitative research.

To maximise the likelihood that access would be granted it was decided that initial contact would be made directly with the heads of department by my thesis supervisor. The letter gave a brief outline of what was required and suggested that after a few days the researcher would contact them by telephone to discuss the matter further. All eight schools contacted in this way agreed, during a follow-up telephone call, to provide access to two practical lessons during a day-long visit to the department.

It was both hoped and expected that after the initial observation of two practical lessons it would be possible, having met with and talked to members of the department, to arrange a subsequent visit, at a mutually convenient time, to undertake one (and at one school two) further observation. The study, planned to involve twenty-five multi-site studies, would therefore be comparable in size to those multi-site studies undertaken by Firestone and Herriott (1984) and Stenhouse (1984) that involved twenty-five and twenty-six multi-site case studies respectively. It was felt that by using a similar sized sample it would be sufficiently large as to ensure that the issue of population validity would not constitute a threat to the external validity of the study and, it was hoped, would actually enhance it.

3.13 Pupil age range

In terms of the age range to be included within the study three options were initially considered. The first of these was to restrict the study to practical work at 'A' level. This option was abandoned relatively quickly given the reluctance of teachers to allow open access to their 'A' level classes, due to the increased examination load faced by these pupils. Two further options remained. The first of these was to restrict the study solely to KS3 and 4 Year groups for whom science was a compulsory subject. The advantage of this was that the teachers had no objection to granting access, other than when this clashed with specific events such as internal or public examinations and, because of the relatively large number of classes, there was always a considerable amount of practical work being carried out. The second option was to study practical work throughout the secondary school age range but to use a sample that whilst predominantly composed of KS3 and 4 lessons would included a limited number of 'A' level practical lessons to which access might be negotiated.

Whilst it was recognised that practical work features prominently across the entire secondary school age range it was considered, from the perspective of ecological validity, that the compulsory/non-compulsory divide that separates pre and post GCSE study might be expected to produce very different results at least in terms of the effectiveness of practical work in the affective domain. Similarly it was felt that the heavy predominance of subject specialist teaching at 'A' level, in contrast to the situation at KS3 and 4 in which many practical lessons are taught by non-subject specialists (Millar, 1987), offered another reason not to combine pre and post GCSE practical work. It was therefore decided, on the basis of these considerations, to restrict the study to practical work at KS 3 and 4.

3.14 Data analysis

There were two main sources of data within this study: (i) audio-recordings of teacher interviews and discussions with pupils and (ii) field notes made by the researcher during the course of the observed practical lesson.

The first stage of analysis involves the preparation of the raw data, a process that involves the transcription of audio-tapes made during the lesson and in the subsequent teacher interview. The transcript then has appended to it various points of information from the field notes that, whilst relevant, were non-audible e.g. pupil gestures, teacher movements, use of physical props to support a verbal point and the like.

At this point the issue of how best to present the data within the thesis needed to be resolved. One possible approach (Rudduck, 1984; Stenhouse, 1984; Stenhouse, 1978) would have involved the construction of a series of 'case records' in which each case record would be "a cautiously edited selection of the full data available, the selection depending on the fieldworker's judgement as to what was likely to be of interest and value as evidence" (Rudduck, 1984 p. 202). Stenhouse (1984; 1978) suggests that such case records be presented in their entirety within a study since the primary function of a field study "should be seen as concerned with the creation of sources and not, in the first instance at least, with the creation of reports or portrayals" (1978 p. 25). Adopting this approach would have resulted in the creation of an appendix to the thesis in which the complete case records of twenty-five studies would have been presented. However, both Rudduck (1984) and Reid (1978) suggest that caution is needed with regard to any potential decision to include copious amounts of recorded data. Reid (1978) goes further and claims that:

> Apart from supporting the book and paper industry, it is a curious habit... it also begs the question as to why the author should have bothered to present an interpretation at all if it is not superior to another, or if the whole job can be done by the reader... In any case, research has never been only about the collection of data and it is always about interpretation, presentation and communication. (p. 29)

Whilst it was considered desirable to include some aspects of the data, both for illustrative purposes and to enhance face validity, it was decided not to use case records in the manner suggested by Stenhouse (1984, 1978). The approach that was adopted within this study has been to construct a 'case study report' for each practical lesson observed. A case study report differs from a case record in that whilst it too provides an edited selection of the full data available, its primary purpose is not to provide a public record but to assist the researcher in the analysis of what would otherwise be an unmanageable amount of data. This does not preclude the inclusion of a case study report within the thesis. Indeed it is planned to use three such reports but that these will be provided as exemplars of a particular type of practical task rather than as a source of primary data with little or no interpretation.

Each case study report uses a common format that is designed to separate out, from the chronological record of the events within a particular lesson, views that relate to practical work in general. To achieve this aim each case study report provides, in chronological order, an account of the actual practical lesson in terms of the following three elementary sections:

- Task presentation i.e. how the task is presented by the teacher to the pupils.
- Task actualisation i.e. what the pupils actually do, think and talk about when they undertake the task.
- Task summarisation i.e. how the teacher summarises the task.

Each case study report also includes two sections that deal with issues that relate to teacher and pupil perspectives on practical work both in general and as they relate to the specific task observed. These two sections are:

- Teacher's views on practical work.
- Pupils' views on practical work.

The last of these two sections, that investigates pupils' views on practical work both in general and with regard to the specific task being undertaken, will be used to probe the extent to which practical work in science can be considered to motivate secondary school pupils.

Case studies undertaken at the same school are grouped together even if the studies in a particular school occurred on different dates. The case study reports from a particular school are preceded by an introduction that provides generic information about the pupils and the teacher.

The final section of each case study report, in addition to providing a profile form of the practical task, analyses and discusses the effectiveness of the task in terms of the theoretical model (Figure 3.1) and the 2x2 matrix representation of practical work.

3.15 Validation technique

One of the problems of a case study approach is the potential for researcher bias to manifest itself, however unintentionally, in the selection of data for inclusion within the study. Whilst Stenhouse (1981) saw the inclusion of all primary data sources, in the form of case records, as a possible solution to this problem, another solution involves triangulation (Yin, 2003; Hakim, 1997; Patton, 1987; Cohen and Manion, 1982).This study triangulates on the basis of data (Patton 1987) in so far as the data used in the study is collected from multiple sources so as to corroborate the same fact or perception using different primary source material.

3.16 Summary

This study aims to provide a critical exploration of the relationship between the rhetoric and reality of practical work. In particular it aims to address the following three questions:

1. To what extent are specific practical tasks effective in enabling pupils to *do* what the teacher intended?

2. To what extent are specific practical tasks effective in enabling pupils to *learn* what the teacher intended?

3. Does practical work have an affective value and, if so, in what sense?

To answer these questions it has been decided to use twenty-five multi-site case studies employing a condensed fieldwork strategy that uses tape-recorded interviews and observational field notes as its primary source of data collection. How this data is presented is the issue that will now be addressed in chapter 4.

Chapter 4

Case study reports

4.1 Introduction

This chapter has three aims. The first is to present, in a clear and concise manner, details about each school, teacher and lesson observed so as enable any particular case study to be located within the broader framework of the study as a whole.

Secondly, whilst the primary purpose of writing the case study reports was as a first step in the analysis of a large amount of data, rather than to provide a public record, it may be useful to include a number of such reports in this thesis in order to illustrate both their level of detail and data. Therefore, although their inclusion within this chapter is primarily illustrative, indeed sections 4.4 – 4.6 may be skipped without adversely affecting the analysis being presented, they do provide a link, albeit a second hand one, between the reality of practical work in the school science laboratory and the analysis presented in chapters 5 - 7.

Thirdly this chapter aims to outline the structure of the following three chapters and provide an explanation as to why such a structure was chosen for reporting this study.

4.2 Details of schools, teachers and lessons observed in the study

Given that the schools, teachers and pupils who took part in this study did so with a promise of anonymity, it has been necessary to change all names. Doing so has presented an opportunity to create a system in which it is relatively easy to identify in which school a particular teacher taught. The system involved randomly assigning the name of one of eight rivers in the North-East of England to each of the schools that took part in the study: Derwent, Foss, Kyle, Nidd, Ouse, Rye, Swale and Ure. Table 4.1 identifies the type, size, age range and Education Authority of each school and assigns to each the pseudonym that will be used throughout the study.

Table 4.1 School Type

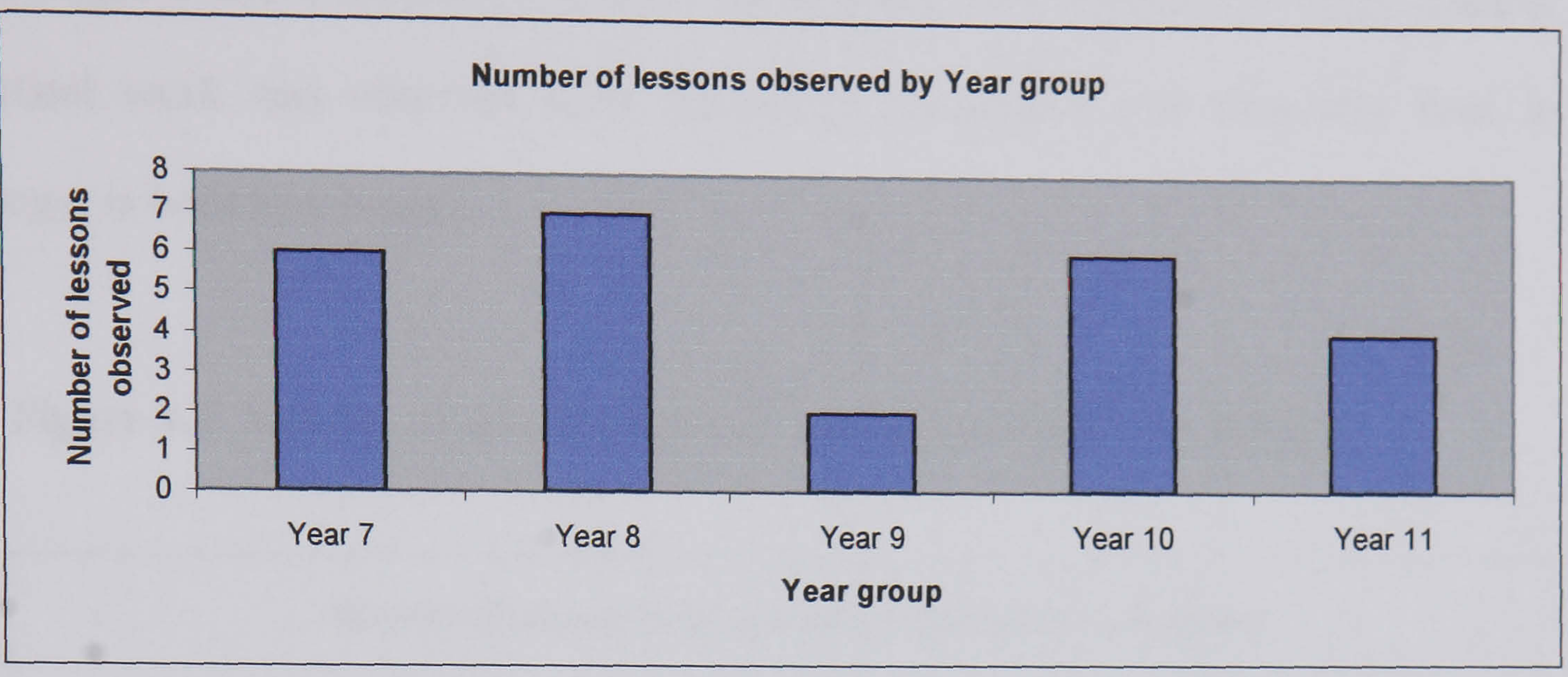
School	Type	Size	Age Range	Education Authority
Derwent	Urban comprehensive	500	11-16	A
Foss	Urban comprehensive	1480	11-18	A
Kyle	Urban comprehensive	1550	11-18	B
Nidd	Rural comprehensive	890	11-18	B
Ouse	Rural comprehensive	630	11-18	B
Rye	Rural comprehensive	720	11-18	C
Swale	Rural comprehensive	670	11-16	B
Ure	Rural comprehensive	1280	11-18	C

Teachers from a particular school were then randomly assigned the name of a town or village, again from the North-East of England, whose name started with the same letter as that of their school. So, for example, it can be seen at a glance that Mrs Ramsgill taught at Rye School whilst Mr Ulleskelf taught at Ure School. Although the names of both teachers and schools have been changed, it was felt important, whenever this was compatible with the preservation of anonymity, to provide as much factual information about the teachers and schools as possible, so gender, subject specialism, title and length of teaching experience have not been changed. Due to the relatively large number of pupils involved in the study (n > 250) it was impractical to assign to each pupil a different alias. In order to ensure clarity, when quotes from different case study reports are presented, pupils are identified using a system that links them to their teacher and hence to a school. Each pupil is referred to using the first and last letter of their teacher's name, followed by a number in order to distinguish them from other pupils involved in that lesson. For example a quotation preceded by DX10 is from a pupil taught by Mr Drax at Derwent School. If pupils responded to questions asked by the teacher, for example Mr Oldstead, during the lesson and could not be identified they are simply referred to as ODa, ODb, ODc, etc.

This study set out to investigate practical work within Key Stage 3 and 4 Year groups for whom science was a compulsory subject. Given the five Year groups, three in Key Stage 3 and two in Key Stage 4, there was a desire to ensure that this 3:2 ratio of Year groups was reflected in terms of the number of practical lessons observed in each of the two Key Stages. The ideal distribution of twenty-five lesson observations would therefore have comprised fifteen from Key Stage 3 and ten from Key Stage 4. Within Key Stages 3 and 4 it would therefore have been hoped to observe five practical lessons for each Year group. In reality the distribution of lessons, across both Key Stages and Year groups, was determined primarily on the basis of what practical work happened to be available on the day that the observation took place and the willingness of a particular teacher to be observed. In a few instances, when the researcher was presented with a number of possible observations, lessons were selected so as to ensure that the overall distribution of practical work converged, rather than diverged, towards the desired distribution in terms of Key Stage 3 and 4. Figure 4.1 illustrates that, despite the somewhat lower than desired number of Year 9 observations, the overall distribution ratio between the two Key Stages of 15:10 was in fact the value desired.

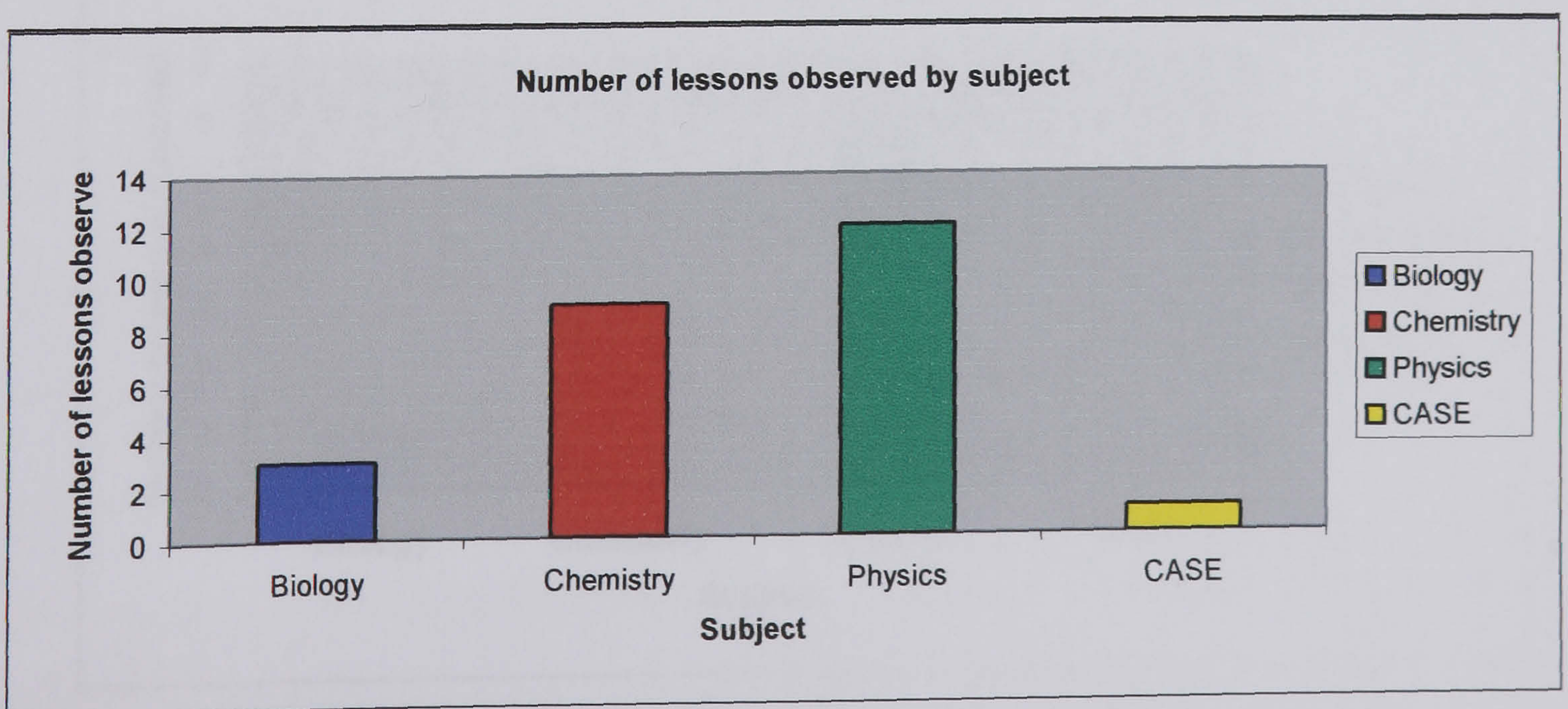
Original in colour

Figure 4.1 Number of lessons observed by Year group



Although there was a desire to achieve an equitable balance of observations across the three sciences the actual distribution, as shown in figure 4.2, reflected a more limited use of practical work in biology, compared to physics and chemistry, in these eight schools. Whilst the CASE lesson could, in terms of the material used, have been categorised as a physics lesson it was felt that because the school had adopted the use of CASE to develop general cognitive ability, rather than being science specific, it was useful to make this distinction when classifying the lessons observed by subject.

Figure 4.2 Number of lessons observed by subject



Original in colour

Figures 4.3 and 4.4 show the distribution of lesson observations by subject in both Key Stages 3 and 4 separately in order to illustrate that, within these eight schools, practical work was observed more frequently in physics and chemistry than in biology, in both Key Stages.

Figure 4.3 Number of lessons observed across Key Stage 3 by subject

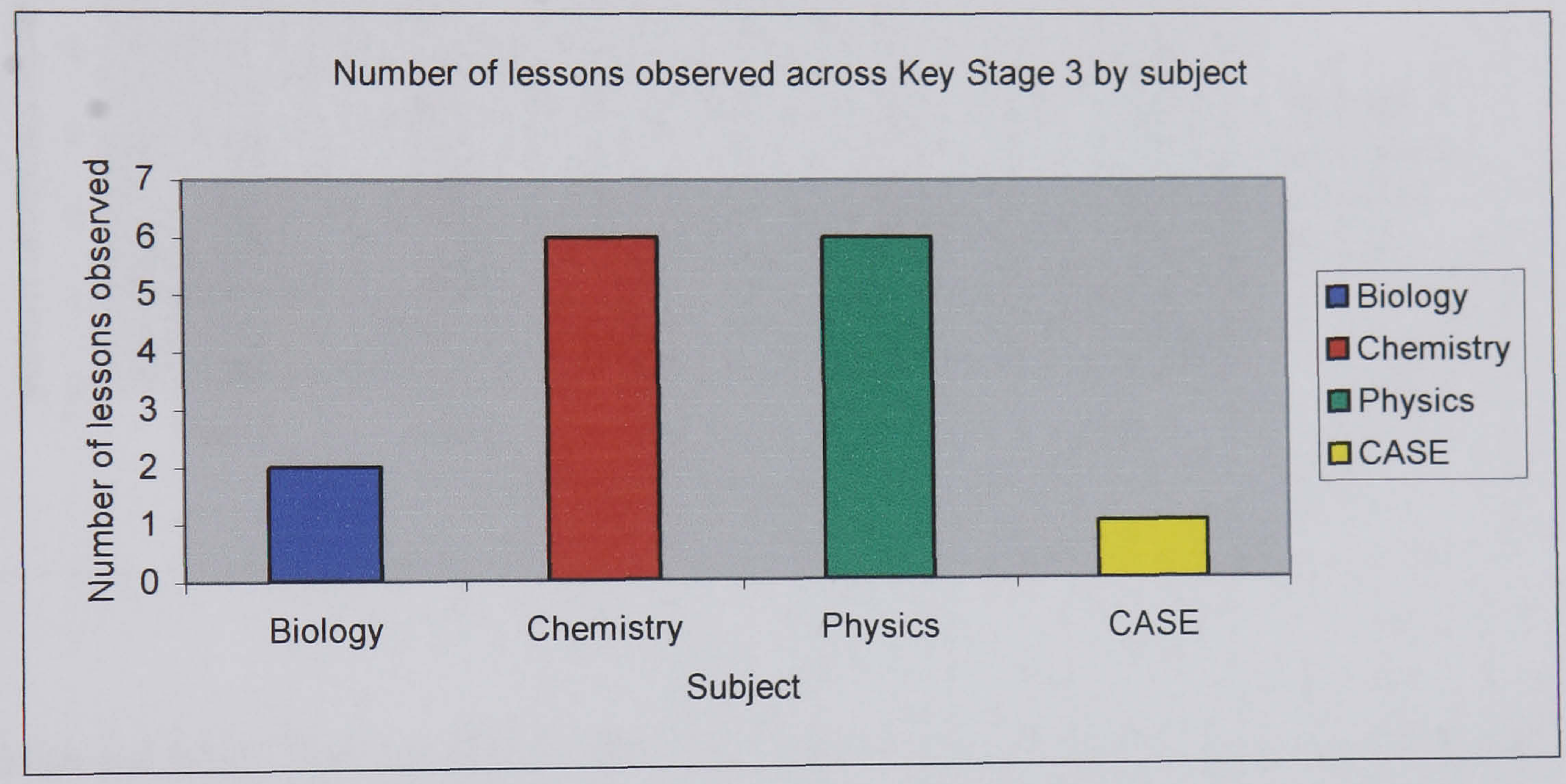
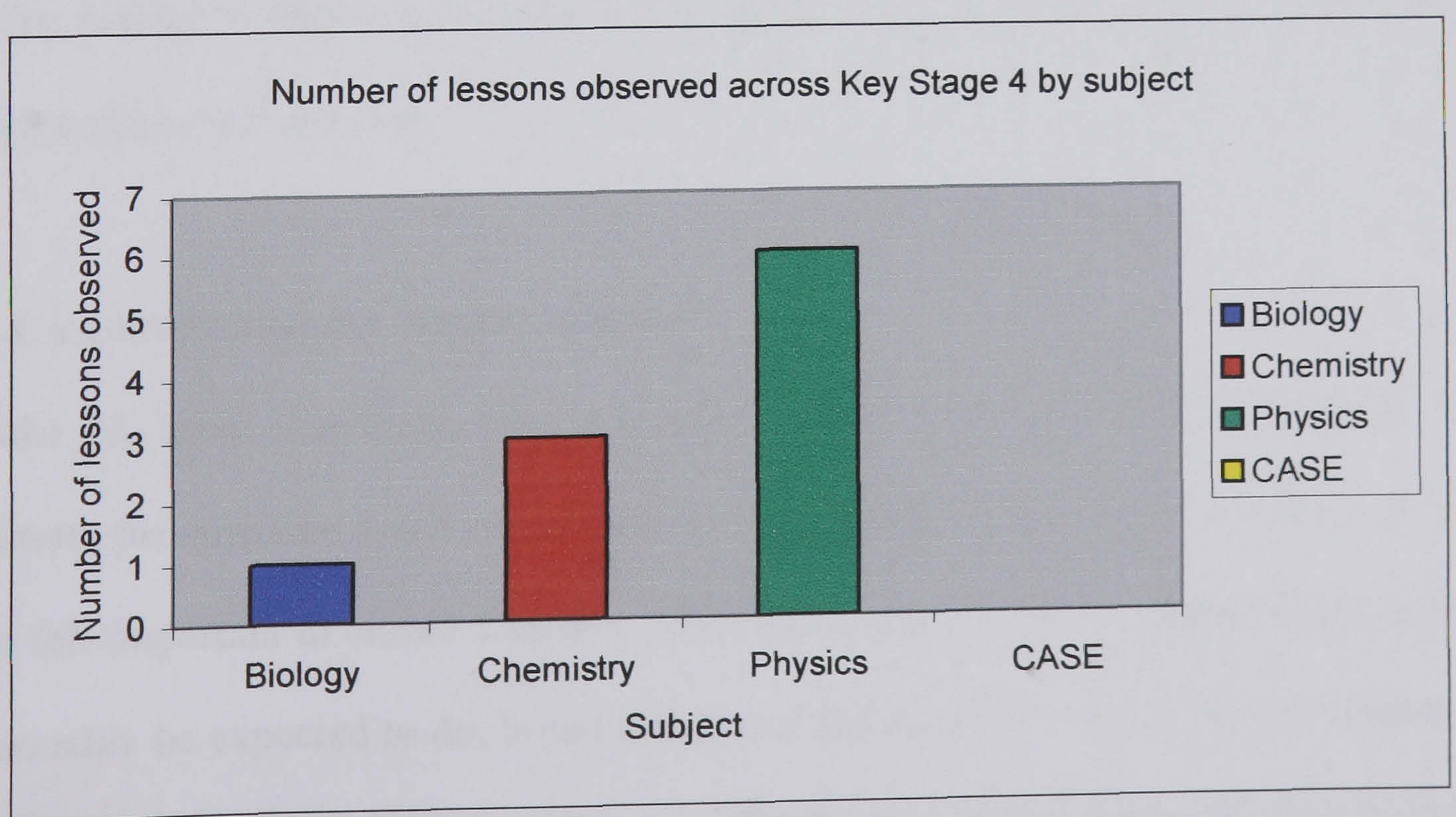


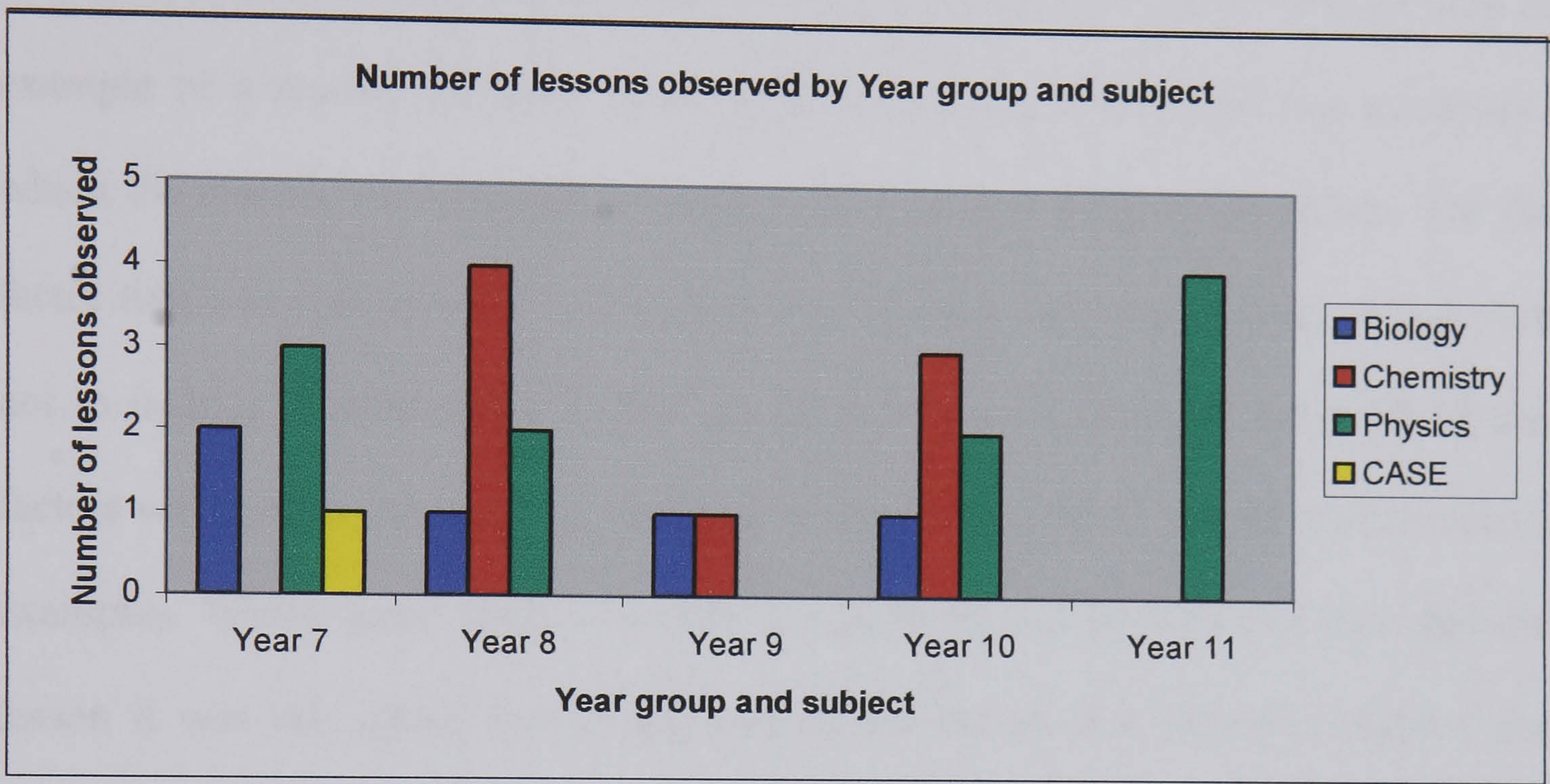
Figure 4.4 Number of lessons observed across Key Stage 4 by subject



Original in colour

Figure 4.5 combines the data on the number of lesson observations by Year group with the data on lesson observation by subject to provide an over view of the sample as a whole.

Figure 4.5 Number of lessons observed by Year group and subject



Additional tables that provide further information about the practical lessons observed including details on the number of pupils, gender, departmental perception of class ability, teacher's subject specialism and length of teaching experience are to be found in appendices A.7 and A.8.

4.3 Case study reports: An introduction

Whilst the three case study reports in this chapter have been selected primarily to illustrate the structure and level of detail within the case study reports in general it was also felt important to ensure that they reflected, as well as such a small sample could reasonably be expected to do, broad features of the study as a whole. In this respect it was decided, given that the overall lesson distribution ratio between the Key Stage 3 and 4 was 15:10, to present two case studies from Key Stage 3 and one from Key Stage 4. In addition, given the 14:11 distribution of male to female teachers, it was felt that whilst the sample could not be equally balanced, in terms of gender representation, it should include examples of teaching by both male and female teachers. It was also considered appropriate, given the 9:16 ratio of teachers teaching within their subject specialism, to those teaching outside of it, to include only one example of a teacher teaching within their subject specialism and two examples in which the teacher was required to teach outside of their subject specialism. The final factor that was instrumental in the choice of the three case study reports was a desire not to include teachers from within the same school. It emerged, when all of these factors were taken into account, that case studies 5, 10 and 12 would provide suitable examples. Whilst these studies include examples of two physics and one chemistry lesson it was felt, given that twenty-one of the twenty-five lessons observed were either physics or chemistry, that this was a justifiable choice. The three case study reports chosen were:

(i) Case study report 5. A Year 8 class undertaking a chemistry practical task. The teacher, Mr Saltmarsh, is a biology graduate with over twenty-five years teaching experience.

(ii) Case study report 10. A Year 10 class undertaking a physics practical task. The teacher, Mrs Ramsgill, is a chemistry graduate with over twenty-five years teaching experience.

(iii) Case study report 12. A Year 7 class undertaking a physics practical task. The teacher, Mrs Kettlesing, is a physics graduate with over fifteen years teaching experience.

4.4 Case study No. 5

This case study, undertaken at Swale School on the 7th of November 2002, involved the observation of a Year 8 Chemistry lesson. The lesson, entitled 'Splitting the colours in dyes', was set within the broader teaching topic of atoms, elements, compounds and mixtures.

4.4.1 The teacher

Mr Saltmarsh is a biology graduate with twenty-seven years teaching experience, twenty-two of which have been spent at Swale. The head of department described him as a very experienced teacher liked and respected by both colleagues and pupils alike, particularly the academically lower ability ones whom he prefers to teach. Whilst Mr Saltmarsh has taught all aspects of Science up to Key Stage 4 he tended to concentrate primarily on the teaching of biology and was the only member of department to have taught agricultural science, as an option to replace biology, for academically lower ability pupils.

4.4.2 The pupils

The Year 8, set 3 of 6, (low to middle ability pupils) has twenty-eight pupils comprising twelve boys and sixteen girls. Mr Saltmarsh stated that whilst officially a middle ability group it was in fact composed predominantly of academically low ability pupils. No pupils within the class had either behavioural problems or were registered as having special educational needs. Whilst pupils were sometimes permitted to form their own small groups, on the basis of peer friendships, this was not always the case and, in this lesson, Mr Saltmarsh formed the groups. Since groups, these varied in size from two to three pupils, were formed solely on the basis of who sat next to whom, and friends tended to sit next to each other, most of the groups were composed of friends who, when questioned, claimed they would have chosen to work together anyway.

4.4.3 The practical task as intended by the teacher

Mr Saltmarsh gave three main aims for this task:

(i) Pupils would be able to *observe* that food dyes, that appeared to be only one colour, were in fact made up of a mixture of different colours.

(ii) To *learn* the method of using chromatography since they would need to be able to use it in order to undertake the practical task in their next lesson.

(iii) For the pupils to *learn* that dyes are made from a mixture of substances.

The task involved placing a small drop of food dye on a strip of chromatography paper. The paper was then to be suspended in a beaker of water (solvent) in such a way as to ensure that the food dye on the paper remained about half a centimetre above the level of the water in the beaker. As the water moved up the paper it dissolved the dye and carried the constituent colours at different rates up the paper. Once the water reached the top of the paper, or earlier if there was insufficient time, the chromatography paper was to be removed from the water. The final level that the water reached on the paper would be marked, using a pencil, before the paper was dried to fix the colours in their respective positions on the strip of paper.

The lesson was the second of three on the topic of chromatographic separation. The first lesson had involved the pupils watching a video on the separation of inks using a chromatographic technique almost identical to that which they would now use. The final lesson would involve a further practical task, produced on a commercial work sheet, in which the pupils would assume the role of detectives and, using chromatography, solve a 'crime' by identifying the ink that had been used to write a forged cheque.

4.4.4 The lesson

Figure 4.6 shows the basic structure of this lesson

Figure 4.6 A flow diagram of the basic lesson structure

10.00 – Lesson starts.

↓

10.00 - 10.03 Pupils enter class and settle down. Mr Saltmarsh takes a register.

↓

10.03 - 10.13 Mr Saltmarsh sets up equipment on the front bench and explains, as he demonstrates, the procedure to be used.

↓

10.13 - 10.31 Pupils collect, then set up, equipment and carry out task.

↓

10.31 - 10.35 Pupils pack away equipment and Mr Saltmarsh explains how the write-up is to be structured.

↓

10.35 - 10.47 Pupils wrote-up task.

↓

10.47 - 10.51 Mr Saltmarsh stops the pupils writing and gets them to place chromatography paper on the heater.

↓

10.51 - 10.59 Mr Saltmarsh moves around the laboratory and comments upon, and marks, the pupils' write-up.

↓

10.59 - 11.00 Pupils sit quietly waiting for the bell.

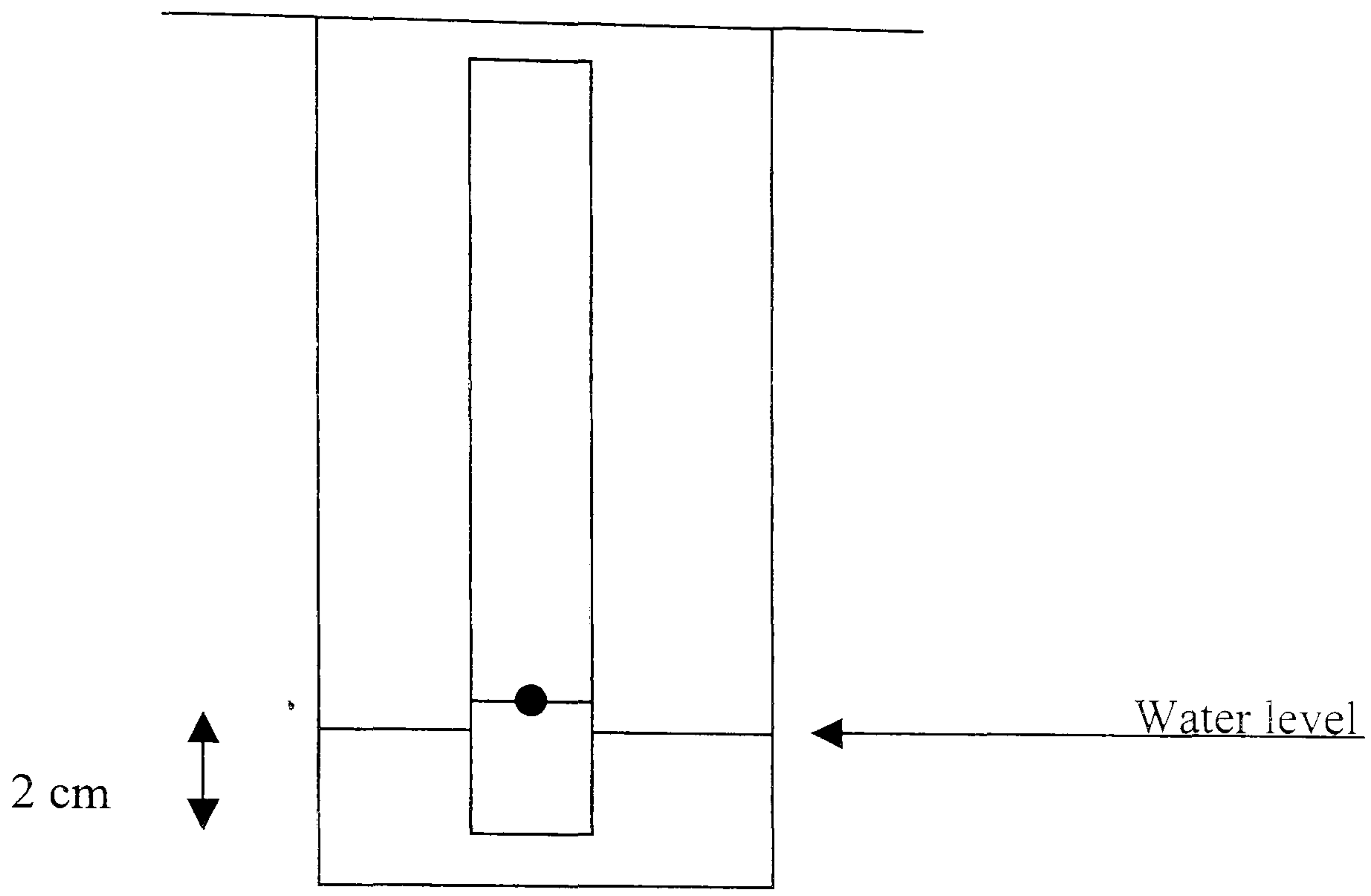
↓

11.00 - Lesson ends.

4.4.5 Task presentation

The pupils entered the laboratory punctually and moved quietly to their places. The white-board, at the front of the laboratory, had the diagram (Figure 4.7) on it:

Figure 4.7 Mr Saltmarsh's diagram of the chromatography apparatus



Mr Saltmarsh took a register before placing the current task into context during which their attention was drawn to the need to work quickly:

> Mr Saltmarsh: Remember that last lesson we had the video about chromatography and we talked about the splitting up of things using chromatography. Today we said we've got this experiment that we've got to set up fairly quickly.

He then paused, moved to the back of the laboratory, and then made a point, as he returned to the front, of scanning the floor for school bags that had not been put safely under the benches:

> Mr Saltmarsh: Just make sure all your bags that are on the floor are underneath the bench out of the way so when you're sort of moving about and walking and things we don't want people tripping up like last lesson.

The pupils laughed at this apparent recollection of someone falling over but quickly moved their bags under the benches. Moving to the bench at the front, on which he had set out the apparatus needed for the task, he clapped his hands to get attention:

> Mr Saltmarsh: A quick reiteration of what I want you to do, ok.

As he spoke all background noise in the class ceased. A highly structured exposition coupled with a demonstration then followed that took the pupils through the procedure that they would use. The exposition and demonstration reminded the researcher of a children's television programme in which the presenter demonstrates the task whilst, at the same time, using simple language to explain what is being done:

> Mr Saltmarsh: You'll need to do it a little bit more carefully than I'm doing it, fold on that line ok [folding chromatography paper on pencil line] and Sellotape it to the lid like that. [Sellotaping his paper to the lid] We're going to put the inks on the pencil line and then slide it in.

The similarity to the style of presentation used on a children's television programme appeared not to have been lost on Mr Saltmarsh who, at one point, added:

> Mr Saltmarsh: I'm not a Blue Peter presenter so I haven't done one of these previously.

He then went through the entire procedure concentrating on specific details:

> Mr Saltmarsh: You need to make sure you've got just a bit more [length of chromatography paper] than the depth of the actual beaker. If you put too much [dye] on you get a great big blob so be careful and just put the tiniest drop on. I want a line two centimetres up from the bottom like that. You should have rulers and pencils you shouldn't need to ask for those. It needs to be about a centimetre above there. Check again by standing it at eye level.

The only variable that was left for the pupils to determine for themselves was which two dyes, from the five provided, they would use. Whilst the task presentation concentrated almost exclusively on specific details of how the task was to be carried out, there was one exception. This occurred when Mr Saltmarsh, having marked the chromatography paper with a pencil, asked the pupils why they would need to use a pencil rather than a pen:

> Mr Saltmarsh: You'll mark the paper so that you can do it accurately.
> Why do we use a pencil?
> SHa: Because the ink will run if you use a pen.
> Mr Saltmarsh: Yeah, the ink will separate if we use pen colour lines.

One possible explanation for the strong showing of hands might have been that this particular point was mentioned in the video on chromatography that the pupils had watched in the previous lesson. Having gone through the procedure, up to the point where his own dye marked paper was immersed into water and the dyes were beginning to separate, the pupils were asked whether there were any questions. None were forthcoming. Approximately fifteen minutes after the start of the lesson Mr Saltmarsh quickly grouped the pupils into pairs and threes on the basis of who was already sitting next to whom and told them to get started.

4.4.6 Task actualisation

The pupils collected the equipment, which had been placed for them on the front bench, and set about the task. Despite the very detailed nature of the instructions that the pupils had received, they appeared to find it difficult to get the task set up. The primary reason for this appeared to be the undue significance that the pupils ascribed to duplicating the precise numerical measurements given by Mr Saltmarsh rather than seeing them as a guide. One pair of pupils, when challenged by Mr Saltmarsh as to why they had thrown their strip of chromatography paper in the bin, were overheard to say that they had done so because they had put their pencil line slightly higher than the two centimetres that he had suggested.

During this stage of the lesson Mr Saltmarsh circulated amongst the groups assisting those groups that were finding it difficult to get the apparatus set up. The main difficulty seemed to be adjusting the length of chromatography paper in an attempt to duplicate the length of paper used by Mr Saltmarsh that took an inordinate amount of time. In part this might have been due to their attempt to adhere rigidly to the instructions given to them in the task presentation.

The fact that many pupils appeared unduly concerned about inconsequential details might however also have been due to the fact that they had no broad overview of the task. There was no evidence, from their actions, that they understood that the principal factors for achieving a successful result were only that the bottom of the strip, whatever its length, was immersed in water and that the drops of dye were placed about one centimetre above the water level.

The ability of pupils to follow procedural instructions, yet still lack a broad overview of the task, was exemplified by two pupils. Whilst this pair had followed the instructions to the letter, and had actually spent quite a while getting the strip of chromatography paper to the same length as that used by Mr Saltmarsh, they remained unclear about what was going to occur:

> Researcher: Have you understood how to do it because you seem to have it working well?
> SH9: We thought we were doing it wrong.
> Researcher: Did you, why was that?

SH10: Because of the water level, 'cause it soaked through.
Researcher: Weren't you expecting the water to go up the paper?
SH10: No.
SH9: No we thought only the dye would.
Researcher: So what you thought would happen was that the colours would go up but the water itself wouldn't go up the paper?
SH10: That's right.
Researcher: So that's something you didn't expect?
SH10: That's right.

Whilst Mr Saltmarsh had suggested that the pupils might like to practice placing small drops of dye on the little off-cuts of chromatography paper, not many pupils did this. One pupil who appeared, to the researcher, to be doing just that was, from the off-cuts left on her desk at the end of the lesson, seen to have only been doodling. Throughout the period in which the pupils worked on the task Mr Saltmarsh maintained a very disciplined atmosphere in which even those pupils who seemed relatively uninterested in the task completed it successfully.

After about twenty minutes many of the pupils had started the chromatographic separation process and the whole class was called to attention:

> Mr Saltmarsh: Look at your experiment that you've done and you can see, hopefully, [unclear] and you can see the colours have moved up the paper with the water as the water moves up the paper. You'll need to keep an eye on it because when it [the water] reaches the top you want to take it out of the water and let it dry because that dry piece of paper is going to be your results for this experiment. Ok that is what you'll see. Now when we take it out we've got to put a pencil line to show where the water finished going up. Ok you won't know about why that is today but we'll talk about that in tomorrow's lesson. So you need to keep an eye on that all the time. As soon as it reaches the top or let's say quarter to eleven or ten to eleven it's time to pack up and put a line on in pencil and say that's where the water finished going, ok. You need to remember that whilst your experiment works.

Mr Saltmarsh then moved to the lap-top, open on the front bench, and switched on the data projector. Figure 4.8, which contained information on the practical task, appeared on the screen at the front of the laboratory:

Figure 4.8 Information on the practical task

Splitting the colours in dyes	
Diagram	Diagram of beaker with water and paper in
Method	How you set up the experiment
Results	(Paper dried)
Conclusion	(What do the results mean)

Mr Saltmarsh then proceeded to run through the material on the screen:

> Mr Saltmarsh: The heading, this heading [pointing to title on screen], tries to explain to the reader what you've done or what you're doing. You don't want to use complicated words that we don't understand.

At this point there was a commotion at the back of the class when two pupils knocked over their beaker spilling the water. Mr Saltmarsh nodded his head towards a cloth by a sink and continued:

> Mr Saltmarsh: If we spill it then it spoils the whole thing. The diagram that I want you to draw needs to be about half a page and it's what is in front of you, ok [pointing to diagram that had been on white-board throughout the lesson], but I don't want you to spend hours drawing a picture. It's a diagram that I want you to draw. Then your method, how you set-up. What's the first thing you did, number one. The second

> thing you did, number two. Remember when you're writing your method you can always refer to your diagram. The results will want to be these papers [pointing to chromatography strips in beakers]. You're going to dry them, at ten to eleven, dry them, stick them on the heater over there [pointing to heater at side of the laboratory] and in tomorrow's lesson you'll get them back and you can stick them in your book.

The pupils then worked in silence on their write-up of the task with the silence only being broken when pupils raised their hands and asked how to spell specific words. After about ten minutes Mr Saltmarsh interrupted the class to remind them that it was time to remove their chromatography paper from the beaker, pour the water down the sink, and bring the paper over to the heater. Mr Saltmarsh, who had strung up a drying line over the radiator before the lesson, took the wet papers from the pupils and attached them to the line with pegs.

4.4.7 The teacher's task summary

Mr Saltmarsh provided two distinct summaries, one just before the pupils removed the chromatography paper from the beakers that dealt with the results they had obtained, and the other, at the end of the lesson, summarising the write-up.

The first summary drew together the pupils' findings and enabled Mr Saltmarsh to provide a basic conclusion that the pupils could see had been drawn from the results that they had obtained. This summary also provided an opportunity to ensure that one of his three stated learning objectives; that the pupils observe that dyes are made of a mixture of different colours, was made explicit:

> Mr Saltmarsh: What do your results mean? But already you can say something can't you about these lines and colours. What can you say about those colours even now before we've finished the experiment?
> SHb: Two colours are coming out from the ink [only one pupil raised a hand to respond]

> Mr Saltmarsh: Good. There's a mixture of colour in there isn't there yeah? Maybe two, maybe three, maybe half a dozen but there is clearly, in some of these dyes, a mixture of colours to make that single colour.

The second summary, which took place just before the end of the lesson, and after Mr Saltmarsh, who marked the work in the lesson as the pupils were doing it, had finished marking all of the write-ups, related to the actual write-up itself and what would be done in the next lesson. Although Mr Saltmarsh had stipulated how he wanted the write-up to be done, some pupils had deviated from this slightly. This second summary provided an opportunity for Mr Saltmarsh to show, and praise, good examples of work that had been done as he had requested and, at the same time, draw attention to work that was not as he had wanted:

> Mr Saltmarsh: There's some excellent diagrams here [the pupils had copied his diagram from the white-board so they all looked alike - the only difference being the neatness of presentation]. There's some really good clear diagrams with labels horizontal and neat. I mean just look at that [holding up a pupils book to show a neat clear diagram]. You don't even need a method with some of these diagrams. You can see what to do from the diagram. And then [moving to another pupil's desk and looking down at their work] some people have done the method without numbers and have got a long screed, ok. Try to make it so that once a person has read a sentence they know what you did. So that somebody could come along, look at your work, and actually do the same experiment without any help, ok.

A brief introduction was then provided into the practical task that would carry out in the next lesson explaining that this would also involve the use of chromatographic separation of inks. The pupils' books were then collected in, after which they sat quietly at their desks for about a minute until the bell went.

4.4.8 The teacher's views on practical work

Whilst recognising the educational significance of practical work Mr Saltmarsh considered that too much emphasis was currently being placed on maximising the quantity of practical work rather than on its quality, something that he felt ought to be reversed:

> Mr Saltmarsh: Yes it's got a significant educational value but what I think is that we should do less of it but what we do we should do really well.

Yet despite this claim, and the fact that the class had already seen the separation of inks using chromatography on a video in the previous lesson, Mr Saltmarsh had allocated both this and the next lesson to allowing the pupils to undertake almost identical tasks involving chromatography. This apparent contradiction, between his own frequent use of practical work and his stated belief that it should be used much more sparingly, was further emphasised when, in discussing the use of practical work in general, Mr Saltmarsh appeared to cast doubt on the educational value of this particular practical task:

> Mr Saltmarsh: You spend really a whole lesson doing practical work and they'll not get very much out of it. [Raises eyebrows and nods head towards the line of chromatography strips drying above the radiator.]

As a justification for what could arguably be said to be an unnecessarily large amount of practical work for what is, within the syllabus, a relatively small sub-topic, Mr Saltmarsh referred to the enjoyment that he believed pupils felt when doing practical work:

> Mr Saltmarsh: I think we go back to a carrot thing [carrot and stick argument] that we have this feeling in our mind that we want to do as much practical with them as possible because they enjoy it.

In addition to providing an enjoyable experience he felt that practical work provided an opportunity in which to develop manipulative skills. However, even in this respect, he expressed a certain degree of scepticism as to how effective practical work might be:

> Mr Saltmarsh: You've got to say there is another aspect in that there are manipulative skills that the children do require. But the ones that are able to do it [the task] seem to have these anyway beforehand. So is it in the practical that they're learning those manipulative skills? I don't know.
> Researcher: When you say manipulative skills do you mean fine motor skills, for example how to hold a delicate piece of equipment, or do you mean the specific ability to read off numbers?
> Mr Saltmarsh: All of that. I mean all of that and following instructions as to how to do it.
> Researcher: So lots of that is really not subject specific?
> Mr Saltmarsh: No it isn't [subject specific].
> Researcher: Could it be done just as well in domestic science?
> Mr Saltmarsh: Yeah, yeah [nodding head vigorously to indicate strong agreement].

When asked what he considered to be the principal value of practical work *per se,* he replied:

> Mr Saltmarsh: I think if things have gone well, in a specific practical, it does help the children to understand and remember what they've done, rather than just writing it down.

Yet despite making this claim he appeared to harbour doubts as to the potential value of practical work in certain situations:

> Mr Saltmarsh: I sometimes wonder what the kids actually do get out of it. I think we may be better in some lessons actually having a video. We do the work on a video [the teacher records a video] and show it to them and have a series of results for them to look at and for them to get the information from that, rather than some of the practicals that we do.

4.4.9 The pupils' views on practical work

Whilst all of the pupils appeared to have positive views about practical work these views were invariably statements of relative preference in which they specifically compared practical work to other non-practical aspects of science work, in particular writing, rather than claiming to like practical work *per se*:

> Researcher: Do you like doing practicals?
> SH3: It's the best part of science.
> Researcher: Why's that?
> SH3: I prefer to do something me and I really don't like writing and all that.
>
> Researcher: Do you think this experiment is fun?
> SH6: Yeah.
> SH5: Yeah it's better than work.
> Researcher: It's better than work?
> SH5: Yeah.
> Researcher: So this really isn't work? [pointing to beaker with chromatography paper in]
> SH5: No, it's like better than writing.
> Researcher: But what about when you have to write up the results?
> SH5: But you don't have to write pages and pages.
>
> Researcher: Do you like practical work?
> SH9: Yeah it's better than writing.

When questioned about the specific value of practical work a few pupils claimed that it provided a means of helping them to learn and recollect information:

> Researcher: So when you do science do you prefer doing practical or written work?
> SH7: Practical.
> SH8: Yeah practical.
> Researcher: Why?
> SH8: Because like you get to do more and not just writing.
> Researcher: But do you think it helps you understand though?
> SH7: Yeah.
> Researcher: Really?
> SH7: Yeah because if you just write it down you don't exactly…
> SH8: [Interrupting] Learn anything unless you do it yourself.

Researcher: But what's good about practical work [other than it being better than writing]?
SH9: You actually remember it.

Yet when the pupils' views were probed further, in order to ascertain the nature of these recollections, it was found that they were limited to fragmentary procedural details that were essentially descriptive in nature and that there was no evidence that they were able to recollect any scientific ideas:

Researcher: Do you remember any practical that you did before this?
SH5: Yeah we got like different chemical in the tubes like blue liquids and then put like a red in with them and see what they turned out like.
SH6: Yeah you mix a and b, like copper sulphate and something else, and you mix it like together.
Researcher: And that was to help you learn what?
SH6: I don't know really. [Both pupils are laughing loudly.]

Researcher: What practicals do you remember doing?
SH7: Distilling stuff.
SH8: Yeah.
Researcher: What did you distil, crude oil?
SH7: Yeah a blue liquid.
SH8: Yeah it was a blue liquid.
SH7: Just a blue liquid, we don't know what it was, just a blue liquid and we got water out of it.
Researcher: You got water out of it, how did that work?
SH7: Well we got a bottle.
SH8: We put a liquid in it, put a thermometer in it, put it on a tripod, put a Bunsen burner under it and it went through all the tubes in place and it went into a test tube in a beaker.
SH7: Hot water went into a beaker.
SH8: Yeah.
SH7: And if the temperature goes over too far, over a hundred, you had to take it out and then hold on a bit and then have another go.

Despite having undertaken a considerable amount of practical work since starting at the school, the vast majority of it being small group work, these pupils' recollections were limited to these two examples, both of which took place in the two weeks preceding this observation. Whilst it was impractical to post-test the pupils to ascertain what they still remember about these two particular tasks at a future date, it seems reasonable to assume, given that they could recollect no earlier practical tasks, that these too will soon be completely forgotten. The only example of a task that the pupils did appear able to recollect differed from the two previous examples, not in that the pupil remembered what the task was designed to show, but rather in the fact that the task was unusual in that an accident occurred and it was this accident that the pupils recollected:

> SH9: We were heating this oil and when it got to about two hundred degrees we stopped and someone knocked it off the table and it went all over the table and we weren't allowed to go anywhere near the table and we had to move.

Here the factor that appears to mark out this event, was not who carried out the task but rather that it was, for whatever reason, unusual.

The claims made by the pupils that practical tasks helped them remember appears, from the recollections they provided, to relate primarily to the procedural components of the task. Thus whilst pupils SH7 and SH8 were able to provide an almost bullet point recollection of the method used to distil a blue liquid there was no evidence of any recollection of scientific explanation as to *why* substances can be separated by distillation.

4.4.10 Summary

Mr Saltmarsh had three main objectives for this task:

(i) Pupils would be able to *observe* that food dyes, that appeared to be only one colour, were in fact made up of a mixture of different colours.

(ii) To *learn* the method of using chromatography, since they would need to be able to use it in order to undertake the practical task in their next lesson.

(iii) For the pupils to *learn* that dyes are made from a mixture of substances.

Using the theoretical model of effectiveness, discussed in chapter 3, it is possible to construct a 2x2 effectiveness matrix for this task that is shown in figure 4.9:

Figure 4.9 Task effectiveness: Investigating the chromatographic separation of colours in dyes

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	Pupils construct a separation column to match the provided instructions. Pupils observe how a drop of dye placed on the filter paper spreads out as liquid seeps up the paper, so that several spots or streaks can be seen.	Pupils talk in terms of different substances; moving up the paper at different speeds; several spots implying several substances; dyes as mixtures of substances.
at level 2 (what pupils learn)	Pupils can state how to set up and use a chromatographic separation column. Pupils state that separated colours are different dyes that made up their initial dye; this can be used to separate a mixture of dyes into its components; that the pattern from an unknown dye can be compared with that of a known one to help identify the unknown one.	Pupils state that: different substances move up a chromatography column at different speeds; this can be used to see if something contains more than one substance; this can be used to separate the components substances in a mixture; that the chromatogram of an unknown sample can be compared with those of a known samples to see if they contain the same component substances.

From the above 2x2 matrix it can be seen that of the three aims the first two relate to outcomes within the domain of observables (domain o) whilst the third relates to outcomes within the domain of ideas (domain i).

In terms of what pupils do in the domain of observables, level 1:o, the intended outcome of which required the pupils to; construct a separation column to match the provided instructions and to observe how a drop of dye, placed on the filter paper, spreads out as liquid seeps up the paper, so that several spots or streaks can be seen, the task was very effective. All of the pupils, in what was a relatively low academic ability class, managed to do and observe what Mr Saltmarsh had intended. To a large extent this was due to three main factors:

(i) The task was simple, highly structured, and required the use of only basic non-scientific skills.

(ii) The procedure was fully demonstrated by the teacher before the pupils attempted the task themselves.

(iii) The pupils had, during the previous lesson, watched and discussed a similar procedure that they had watched on a video.

Whilst the task was effective at level 2:o, in so far as the pupils were able to set up and talk about what they were doing, there was no evidence of the pupils learning, as one of the intended learning outcomes at level 2:o requires, that the separated colours were different dyes and that these different dyes made up their initial dye. Indeed, rather than talking about the separated colours on the filter paper as dyes, the pupils persisted throughout the lesson to talk about these colours as if they were separate to, and distinct from, the dyes in which they were somehow contained:

Researcher: Do you know why you're doing this?
SH3: Yeah, well half and half.
Researcher: Half and half? Why do you think you're doing it?
SH3: To see what colours are in the ink.
SH4: To see what colours run, what colours spread.

Researcher: Do you know why you're doing this? [Points to separation column.]
SH7: To get lots of colours, pretty colours. [Points to separation pattern on the chromatogram].
SH8: To see [points to chromatogram] the colours that come from the pen.

Researcher: What's this showing then? [Points to chromatogram on which a dot of black dye had separated into blue and pink dyes a dot of red dye into yellow and blue dyes.]
SH9: It's showing that black contains colours, lighter colours and the red has turned into blue and yellow, which makes red.
Researcher: So all those colours together [pointing to blue and pink] will make?
SH9: Blue and pink make black.

However, even if the pupils had stated (and they had not) that the separated colours were different dyes, it would not be possible, with any degree of certainty, to ascertain the contribution that the practical task made to this intended learning outcome given that the pupils were able to state *before* they undertook the task, although *after* watching a video of a similar task, that a particular dye was made up of a mixture of different colours.

What might reasonably be expected, given that three double lessons will have been devoted to the method of chromatographic separation, is that the pupils ought to have learnt, and indeed appeared to have to a limited extent, how to set up and use a chromatographic separation column.

Whilst there was no evidence that the pupils learnt that the pattern from an unknown dye can be compared with that of a known one to help identify the unknown one Mr

Saltmarsh did allude to this possible use when outlining what would be undertaken in the following lesson (also planned as a practical lesson):

> Mr Saltmarsh: Tomorrow's lesson… we'll do a piece of detective work about a garage that has been forging some cheques and you want to find out who the person is who's been forging the cheques. You'll use chromatography to do that job because you have to identify which in has written the forged cheques.

The practical task was not effective in the domain of ideas either at level 1:i or level 2:i. Whilst Mr Saltmarsh's had stated that an intended learning outcomes was for the pupils to learn that dyes were made from a mixture of substances (level 1:i) he made no reference to this idea during the lesson and instead drew the pupils attention to the fact that their observations showed that one colour could be made of a mixture of colours:

> Mr Saltmarsh: What can you say about these colours [points to chromatogram] even now before we've finished the experiment?
> SH10: That two colours are coming out of the ink.
> Mr Saltmarsh: Good. There's a mixture of colours in there isn't there? Yeah? Maybe two, maybe three, maybe half a dozen, but there is clearly, in some of these dyes, a mixture of colours to make that single colour.

Given that the pupils had already watched a video on chromatographic separation there appeared, to the researcher, to be three primary reasons for requiring the pupils to undertake this practical task for themselves:

(i) To gain first-hand experience in setting up, and using, a chromatographic separation column in order for them to be able to use this procedure as part of the practical task planned for the next lesson.

(ii) To produce, and observe, the phenomenon of chromatographic separation.

(iii) To provide an enjoyable, short-term, activity that would engage the pupils for the duration of the lesson.

That these were the primary reasons for carrying out the task is supported by the fact that, throughout the lesson, the emphasis was always directed towards the achievement of learning outcomes within the domain of observables as opposed to those within the domain of ideas.

4.5 Case study No. 10

This case study was undertaken at Rye School on the 16th of January 2003. The observation was of a Year 10 physics lesson entitled 'Voltage' that was within the broader topic of electricity.

4.5.1 The teacher

The teacher Mrs Ramsgill is a chemistry graduate with twenty-nine years teaching experience, nineteen of which have been spent at Rye. Whilst colleagues in the department spoke highly of her, some of the pupils in the observed lesson commented that she was unable to maintain class discipline and that her frequent use of pre-printed work sheets made her lessons extremely boring. In addition to 'A' level chemistry Mrs Ramsgill taught all aspects of science up to, and including, Key Stage 4, although she said that she found physics the most difficult of the three sciences to teach.

4.5.2 The pupils

The Year 10, set 3 of 4 (low ability group), had twenty-two pupils comprising fourteen boys and eight girls. Mrs Ramsgill expressed the view that this was an academically weak group all of whom would be entered for the foundation tier, double award, GCSE paper. There were no pupils within the class registered as having special educational needs. One pupil had behavioural problems that frequently gave rise to disruptive behaviour during lesson time. The pupils sat with and formed their own small groups on the basis of peer friendships with the composition of such groups changing only infrequently.

4.5.3 The practical task as intended by the teacher

Mrs Ramsgill stated that she had three aims for this lesson:

> Mrs Ramsgill: I hope it'd reinforce, first of all, the idea that the voltage is sort of the push. Secondly, I want them to get the idea that the voltage is going across the parallel circuit so that when they measure the volts in the parallel circuit they get the supply voltage across the bulb and that the voltage across the series circuit should add up to the total voltage across the two bulbs.

She stressed that she had only limited experience with this particular practical task, having used it only once before with academically higher ability group, and was, therefore uncertain as to whether it would help the pupils achieve her three stated aims:

> Mrs Ramsgill: I'm going to follow this practical to see if that helps them to get to that basic idea of what's happening with the voltage

The task required the pupils to follow the instructions on a work sheet to construct two circuits. One contained two identical bulbs connected in series to a low voltage power supply; the other contained two identical bulbs connected in parallel to the same low voltage power supply. There were three practical tasks associated with each circuit. For the series circuit the pupils were firstly required to measure the potential difference across each of the two bulbs separately before measuring the potential difference across them both together. For the parallel circuit the pupils were first required to measure the potential difference across the low voltage power supply before measuring the potential difference across each bulb separately. The pupils were then required to answer five questions on the work sheet shown in figure 4.10 below:

Figure 4.10 Work sheet questions

QUESTIONS

Q1 What do you notice about the brightness of the lamps in each of the circuits?

Q2 What do you notice about the p.d. in each circuits?

Q3 Is the p.d. shared in a series circuit?

Q4 Does the same apply for a parallel circuit?

Q5 Select the correct formula to represent your findings about p.d., and write it under the appropriate circuit [diagram].

$$V_{total} = V_1 + V_2$$

$$V_{total} = V_1 = V_2$$

4.5.4 The lesson

Figure 4.11 shows the basic structure of this lesson

Figure 4.11 A flow diagram of the basic lesson structure

13.20 - Lesson starts.

↓

13.20 - 13.28 Pupils enter class noisily over a period of about five minutes and continue to talk noisily as Mrs Ramsgill takes a register.

↓

13.28 - 13.33 Mrs Ramsgill re-caps previous lesson and reminds the pupils of the equipment used to measure current and potential difference. Demonstrates how to set up the circuit, and hands out Heinemann work sheet.

↓

13.33 - 13.38 Mrs Ramsgill read through work sheet but little could be heard because a few pupils continue to interrupt.

↓

13.38 - 14.10 Pupils collect apparatus and carry out practical tasks.

↓

14.10 - 14.17 Pupils pack away apparatus. Mrs Ramsgill calls pupils around desk at front of laboratory and gives a brief summary of the task, introduces the word 'resistance', and tells pupils to complete the work sheet for homework.

↓

14.17 - 14.20 Pupils move back to their places, pack away their book and shout across the room to each other as they wait for the bell.

↓

14.20 - Lesson ends.

4.5.5 Task presentation

The pupils came into the laboratory late and, despite the fact that Mrs Ramsgill repeatedly asked them to quieten down, continued to talk amongst themselves whilst she took a register. The pupils were then called to gather around the front bench, a request that one pupil refused to accede to. The ensuing disruption that this caused required five minutes to resolve with other members of the class using this as an excuse to become disruptive. Once the class had finally all assembled around the front bench Mrs Ramsgill recapped the work from the previous lesson. Throughout this exposition there was a continuous, and clearly audible, level of off-task background chatter amongst the pupils and repeated requests for quiet appeared to have little effect. It was observed that such requests were frequently responded to with a range of immature animal-like noises. The recap over, Mrs Ramsgill handed out the work sheets and described to the pupils, with the aid of a demonstration, how they would construct the series circuit. The exposition and demonstration appeared designed to provide the pupils with the information required to construct the circuits on the work sheet. During this exposition Mrs Ramsgill suggested that they construct the circuit before they inserted the voltmeter.

One pupil, who had looked at the work sheet and had evidently noticed the presence of a switch symbol in the circuit diagram and the absence of a switch in the circuit Mrs Ramsgill had demonstrated, interrupted:

> RLa: Miss Ramsgill, what will we use as a switch?

Whilst a relevant question, Mrs Ramsgill did not reply but instead moved straight on and began to read through the questions on the work sheet. This done, she informed the class that they would work in groups of three to four since she felt it beneficial that each pupil take a participatory, as opposed to observatory, role:

> Mrs Ramsgill: Right you need to be working in groups of threes or fours. You don't want to be working in bigger groups because you wont be doing the actual experiment some will just be watching.

Finally, and just before the pupils started the practical work, the class were instructed not to adjust the power supply setting, although no reason was given for this request.

4.5.6 Task actualisation

The pupils collected the equipment and set about constructing the circuit. The background noise was so loud that the researcher was, at times, unable either to make himself heard or hear the pupils' responses even when standing next to them. Despite the high level of noise generated by the pupils, many of whom appeared to have little interest in the task itself, Mrs Ramsgill was unable to get the pupils to work quietly. Some pupils who appeared keen to work suggested to the researcher that the level of noise and general disruption had an adverse effect on the lesson and, in particular, prevented them from hearing the teacher's exposition and seeing the demonstration:

> Researcher: But what was it [the demonstration in the previous lesson] meant to explain?
> RL7: I don't know, I couldn't hear or see it. So we just came back and then we had more work sheets to do.
> RL8: This [practical task] is actually quite good because you're here.
> RL7: Yeah because you're here talking to us.
> RL8: Yeah everyone's being quieter than normal.
> Researcher: Really?
> RL7: Yeah.
> RL8: So just imagine what it's like normally.

Whilst a few of the pupils claimed that the construction of the circuits was a relatively easy task it appeared, to the researcher, that almost all of the groups observed found the construction of these simple circuits, from the circuit diagrams on the worksheet, relatively difficult:

> Researcher: So you're happy going from the diagram to this [pointing to the equipment on the bench]?
> RL2: Yes.
> RL1: Pretty easy doing circuits. [Then, turning on the circuit, the

voltmeter went off the wrong end of the scale.]
Researcher: What happened there?
RL1: I don't know, wrong way around I think.
Researcher: What bits the wrong way around?
RL2: Wait there was a volt reading.
RL3: Yeah but that went that way. [Pointing off the scale]
Researcher: So you've swapped the bulb connections around?
RL1: And we'll see if it goes the other way.
Researcher: Does it matter which way it goes through the bulb?
RL1: Yes.
Researcher: Oh it still goes that way [pupils had switched on the modified circuit but the voltmeter reading still went off the wrong end of the scale]. Any ideas what it can be?
RL1: Might be the power thingy [pointing to low voltage power supply].

Researcher: Do you find it easy going from the circuit diagram to the circuit itself?
RL5: It's a bit tricky but it's just getting used to it [pupils then spent over five minutes trying, unsuccessfully, to get the circuit to work].
RL6: It's got no reading [pupils had switched on the circuit but the voltmeter had repeatedly gone of the wrong end of the scale and the pupils were unable to correct this].

Unfortunately, despite the procedural problems encountered by the pupils in setting up the two basic circuits, Mrs Ramsgill was unable to help for most of the lesson; since she was continually required to resolve, and manage, behavioural problems that arose within a small group of four pupils.

What appeared to happen, in the remaining groups, was that the pupils were able, by the repeated use of random trial and error techniques, to eventually get the circuits to function as intended. When, for example, the voltmeter went off the wrong end of the scale, the pupils simply began randomly to swap connections around each time testing the circuit to see if the modification had the desired effect, rather than thinking about the reason for its not working. If their circuit change did not have the desired result another connection was altered and, in two cases, the pupils actually returned the circuit to the incorrect state that it had been in immediately prior to their previous test, without apparently realising this:

Researcher: Is this trial and error?
RL2: Yeah.
Researcher: So what's that reading [pointing to voltmeter]?
RL2: Five.
RL1: But how come the light bulbs aren't on? [The pupils are measuring the potential difference across the low voltage supply but had not managed to include the bulbs in the series circuit]

Once the pupils had managed to get the circuits to work they were able to start measuring the potential difference across different points in the two circuits. The procedural instruction to measure the potential difference across different parts of the circuit also generated frequent problems. Pupils seemed to find it both difficult and time consuming to recognise what points in their circuit the voltmeter needed to be connected to in order to correspond to its position in the circuit diagram. There was also little evidence that the pupils actually understood what it was they were measuring. Most of the pupils appeared to consider the task little more than an activity in which they were required to collect a set of numbers from a voltmeter that meant little, if anything, to them:

Researcher: What results have you found?
RL6: Them ones [pointing to a list of numbers scrawled across a page of an exercise book].
Researcher: So what have you found out from those two point two, two point two, four point four. This was for the first ones in series so what's it told you?
RL7: I don't know.
Researcher: You've set it up, and it appears as if it's working, but does it help you to understand anything?
RL7: Not really.
RL8: No.
RL9: Because we don't know what we're doing.
Researcher: So you're just following the instructions?
RL8: That's all we do in this lesson. Mrs Ramsgill doesn't really teach a lot she just gives us something to do and we have to do it.
Researcher: So you just get a work sheet and you follow it through?
RL8: Yes.
RL7: Yeah.
RL9: And it's boring because we don't understand it.

What became apparent, during the discussion with these four pupils, was that whilst they had successfully constructed their circuits and taken (correct) voltage readings in both cases, they had no understanding of the basic concepts involved in this topic including those of voltage, current and potential difference:

> Researcher: Do you understand the difference between voltage, current and electricity?
> RL7: A mish-mash together.
> RL8: Yeah.
> RL7: All together.
> Researcher: I mean if I asked you what is potential difference?
> RL8: I don't know.
> RL7: Erm [shakes head to indicate that they also do not know].
> RL9: [Raises shoulders and shakes head indicating that they have no idea.]

The pupils continued to collect values for the potential difference between different points in the circuit, although it often seemed that the practical task was actually confusing rather than helping them to learn about potential difference in series and parallel circuits:

> Researcher: So what readings have you got?
> RL8: Four point eight.
> RL7: I think you should try that one again because if you look they're all four point eight [in the parallel circuit] and [in the series circuit] they're two point four and that one's actually four point eight [across both bulbs] so shouldn't that come to two point four as well?
> RL8: Ah.
> RL7: Are you sure?
> RL8: Let's try it then.
> Researcher: So what you're saying is that in the series circuit you've got two point four for each bulb, you got four point eight over both of them, but because of what you found in the parallel circuit [that all their readings had been numerically the same] you now think that four point eight was wrong and it should be two point four?
> RL8: Yeah.
> RL7: Yeah.

Towards the end of the lesson, when most of the pupils appeared to have collected all of the data and a number of pupils had deposited their exercise books on her desk, Mrs Ramsgill called the class to attention:

> Mrs Ramsgill: At this point I do not expect books handed in, but I do expect you to be putting away your apparatus and to have written down your results.

It took Mrs Ramsgill five minutes to get the class relatively quiet and back in their places after having replaced the equipment in the trays at the side of the laboratory. Once this was completed she moved on to the summary.

4.5.7 The teacher's task summary

The summary focused on trying to use some of the specific numerical values obtained by the pupils to help them to infer general rules about the potential difference in both parallel and series circuits. However, the few responses offered by the pupils were limited to statements about either their own specific numerical results or to vague and descriptive accounts of their observations:

> Mrs Ramsgill: Look at those results. What did you notice about the voltage readings on all your parallel circuits?
> RL13: That if you added one and two together they equalled three.
> Mrs Ramsgill: On parallel circuits?
> RL13: Oh, parallel circuits?
> RL14: Ours equalled four point nine.
>
> Mrs Ramsgill: Can anybody think of …
> RL15: [Interrupts] Because the pd's went into both bulbs.
> Mrs Ramsgill: What did you get on your results?
> RL13: The pd was shared.

Given the pupils' limited understanding of electricity, and the fact that they had not been formally introduced to the concept of resistance, it was arguably unrealistic to have expected the pupils to be able to explain why the potential difference was shared equally between the two bulbs in series. That this was overly optimistic became evident when, despite prompts from Mrs Ramsgill, none of the pupils were able to answer the question that she then asked:

> Mrs Ramsgill: Why do you think both bulbs had the same reading? What were the bulbs doing to the current that we were talking about before? [It was unclear to what this referred.] What was it doing? [The pupils did not respond.] Word beginning with r… [Pauses but none of the pupils respond.]Resistance.

With the above question Mrs Ramsgill also acknowledged that the pupils should have obtained, and indeed all those observed did obtain, the same voltage reading across each of the two bulbs. However a certain degree of confusion was then introduced when she used the term 'different voltages' instead of different *readings* of the voltage across both bulbs; both of which the pupils observed to have the same numerical value:

> Mrs Ramsgill: What did the different voltages that you got tell you about the resistances of the two bulbs?

Rather than understanding that the question was designed to elicit the response that different readings of an identical voltage across both bulbs meant that the bulbs had the same resistance one pupil, arguably because her use of the word 'different', inferred that the bulbs must have been different, even though the voltages across them both had been the same:

> RLb: That maybe they're different.

Rather than trying to rectify the confusion Mrs Ramsgill provided an explanation as to why voltage readings that were actually numerically different, could be obtained across identically rated bulbs, even though *no* such difference had been observed in this class, in terms of changes in a particular bulb's resistance with time:

> Mrs Ramsgill: Sometimes old bulbs [that appear the same] can have different resistances.

The pupils were then asked how many of them had copied all six of the circuit diagrams and answered all five of the questions from the work sheet. Only three pupils said they had, and the rest of the class were told that homework was to complete all of these tasks.

4.5.8 The teacher's views on practical work

Mrs Ramsgill gave three main reasons for using practical work both in general and in this specific case. Firstly using a range of teaching methods to teach the same material gave those pupils for whom one particular method of teaching was ineffective a second opportunity to grasp the material:

> Mrs Ramsgill: What they have done so far is they have seen a practical with some demonstration and we've worked on some work sheets where they were doing this from the demonstration [using the results from the teacher demonstration]. Some of them have got it, some of them haven't. I'm going to follow this practical to see if it helps them all to get that basic idea of what's happening with the voltage.

Secondly, as a chemist teaching outside of her subject specialism, Mrs Ramsgill adhered closely to the departmental scheme of work. If the scheme included the use of a particular practical task, at a particular point in the teaching sequence, this was incorporated it into her lesson planning just as it appeared in the scheme:

> Researcher: Why did you choose to do this as a practical?
> Mrs Ramsgill: It was part of the new scheme of work we are now using.
> Researcher: So it wasn't really your choice?

Mrs Ramsgill: No, no it wasn't.
Researcher: Is that the same for the work sheets?
Mrs Ramsgill: Yes, they are part of the same scheme.

The third reason that she suggested for using practical work was that it gave low ability pupils something to do and, in so doing, made the task of teaching them easier:

Mrs Ramsgill: It gives them something to do, especially the ones who get bored with too much writing... [pausing and laughing]. It can make my life easier.

Asked whether such practical was an effective method of teaching she suggested that the effectiveness of a practical task depended not so much on the task itself, but upon the mood of the pupils, the day of the week, and indeed the time of the day:

Researcher: Do you think that this practical task is an effective way of teaching this then?
Mrs Ramsgill: If they're feeling like doing practical it's effective, if they're feeling like not doing practical, because it's an afternoon, it's not effective.

After the lesson as the pupils left the laboratory, making loud animal-like noises as they did so, she approached the researcher shaking her head in a manner that suggested utter disbelief at the pupils' poor behaviour:

Mrs Ramsgill: It's hard to get anything done when they don't feel like doing practical work.
Researcher: Would non-practical work be easier?
Mrs Ramsgill: No [screws up her eyes and shakes her head], that'd be even worse.

Although the pace of the lesson was unhurried, and the pupils completed the task within the lesson and obtained the desired empirical data for both circuits, she still felt that there was insufficient time:

Mrs Ramsgill: There just isn't time in an hour to do a proper practical. You just can't do it.

Yet, when asked, she did acknowledge that the pupils had obtained good results and that she considered the practical task to have been a success:

Researcher: Do you think it was a successful lesson?
Mrs Ramsgill: I'm pleased. Yes they all seemed to get good results.

Whilst she considered that the task had been a success, this did not reflect the achievement of her stated aims for the lesson, but rather the pupils' ability to carry out the procedure successfully and collect the required empirical data.

4.5.9 The pupils' views on practical work

Whilst the pupils, in general, expressed positive views about practical work a few pupils claimed that this particular practical was boring. Responses to questions regarding views on practical work fell into two broad categories:

(i) Statements of relative preference.

(ii) Opinions/beliefs about the educational value of practical work.

When pupils were asked whether they liked doing practical work their responses indicated that their liking for practical work was, in reality, only a statement of relative preference that indicated that whilst they liked practical work *more* than other non-practical work in science they did not necessarily like practical work *per se*:

Researcher: Do you like practical work?
RL3: It's better than just writing.

Researcher: Do you like practical work?
RL7: I think it fits in better than just writing all the time because you're actually doing something.
RL8: Yeah it's better than writing.

One pupil claimed that the act of actually having to construct the electric circuit made them think more than they might otherwise have done and, in so doing, kept them engaged during the lesson. In this respect, however, their thinking appeared to be directed towards achieving the procedural objective rather than understanding what was being observed:

> RL3: I think it's good if you actually do the experiment because it makes you think a bit more. If the teacher's saying it you might just switch off.
> Researcher: So the fact that you actually had to make the circuit...
> RL3: Yeah, it made you think more.

There was little evidence that the pupils found it easier to recollect a practical task that they have done for themselves, rather than if they had merely read about it or had it demonstrated to them. Indeed, the actual recollections offered by the pupils suggest that their ability to recollect a particular practical task depended to a much larger extent upon whether it included a memorable event, frequently an observed phenomenon, than with whether or not the pupils had actually undertaken the task themselves:

> Researcher: What other practicals do you remember?
> RL4: That one with the brick [a teacher demonstration of the Thermite reaction] that we did outside that was quite good.
> RL5: Yeah he put loads of different stuff in it, set light to it and it just, whoosh. That was pretty exciting.
> Researcher: What other practicals do you remember doing?
> RL9: The one with the iron over the flame and it sparkles.
> Researcher: And what did that show you?
> RL9: That it sparkled.

Despite having claimed that practical work helped them to remember, their recollections were fragmentary and related primarily to the procedure and the nature of the phenomenon observed rather than concepts. Further, despite their frequently stated preference for practical work over non-practical work, the amount of practical work *per se* did not appear to influence their decision as to whether to pursue science post Key Stage 4:

Researcher: Are you planning on doing science after Key Stage 4?
RL7: Yeah.
Researcher: Which one, do you know?
RL7: Biology.
Researcher: Which of the sciences do you do less practical work in?
RL7: Biology.
RL8: We don't normally do much in biology.
Researcher: So you'd both like to do biology after, but there is less practical in it?
RL7: Yeah.
RL8: Hmm [nodding in agreement].
Researcher: So it's not practical that really makes you like a subject. What is it that makes you like a subject?
RL7: I don't know I just find it easier than the others [physics and chemistry].
RL8: [Nodding in agreement.]

4.5.10 Summary

Mrs Ramsgill had three stated aims:

(i) To reinforce the idea that the voltage is sort of the push.

(ii) To get the idea that 'the voltage is going across (*sic*) the parallel circuit' so that when they measure the volts in the parallel circuit they get the supply voltage across the bulb or the set.

(iii) That the voltage across the series circuit should add up to the total voltage across the two bulbs.

With regard to the first aim there was no evidence of this reinforcement occurring. Indeed, neither the exposition that she provided at the start of the lesson, nor the work sheet itself, contained any material designed to help meet this aim.

Using the theoretical model of effectiveness discussed in chapter 3, it is possible to construct a 2x2 effectiveness matrix for this task that is shown in figure 4.12 below:

Figure 4.12 Task effectiveness: Investigating the voltage in two bulb series and parallel circuits

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	Pupils set up circuits with two bulbs: (a) in series (b) in parallel, to match given diagrams. Pupils connect a voltmeter correctly at the points intended. Pupils read voltmeter correctly.	Pupils talk about: voltage as a measure of the 'push' of the battery; voltage in terms of a 'difference' between two points in a circuit. Pupils use terms 'series' and 'parallel' correctly in discussing circuits.
at level 2 (what pupils learn)	Pupils state that: the voltage reading across each component in parallel is the same and equal to the reading on a voltmeter across the battery; the sum of the voltage readings across components in series is equal to the voltage reading across the battery; if the components in series are identical, the voltage across each is the same.	Pupils state that: the voltage (or pd) across each component in parallel is the same and equal to the battery voltage; the sum of the voltages across components in series is equal to the battery voltage; if the components in series are identical, the voltage across each is the same.

The task was effective at level 1:o in that it enabled the pupils to construct successfully both a series and parallel circuit containing two bulbs in which they used a voltmeter to take reading across different points in the circuits. The most likely explanation for this effectiveness was that the pupils had a relatively large amount of time to carry out an essentially simple closed task that involved a highly structured procedure, the details of which were contained on the worksheet provided.

Furthermore specific parts of the procedure had also be demonstrated to them by Mrs Ramsgill in order to try to ensure that they knew what they were meant to do.

In terms of effectiveness at level 1:i the task appeared relatively ineffective. Whilst the pupils were able to read the voltmeters there was no evidence that they thought about the voltmeter readings as measuring the potential difference between two points in a circuit. Indeed, whilst the pupils did use scientific terminology such as volts, voltage, pd, current and electricity these terms were used interchangeably and, for most pupils, the word 'volts' appeared to mean no more than a numerical reading that was obtained from a voltmeter.

In terms of effectiveness at level 2:o the task appeared relatively unsuccessful. Whilst most pupils could describe their results as a set of specific numerical values they were frequently unable to state the nature of any relationship between these individual values. The most frequent reason for this was simply that the pupils did not know what relationship they were looking for and so unless the voltage readings were exactly identical with each other, and the supply voltage reading, (parallel circuits), or added up to exactly the value of the supply voltage reading (series circuits), the approximate relationship between these reading was simply not sufficiently obvious to enable the pupils to recognise the underlying relationship.

Similarly the task was ineffective at level 2:i in that there was no evidence from the statements made by the pupils that they had learnt that in a parallel circuit the voltage (or pd) across each component in parallel is the same and equal to the battery voltage or that the sum of the voltages across components in series is equal to the battery voltage and, if the components in series are identical, the voltage across each is the same. One possible reason for this ineffectiveness was that, rather than discovering the scientific ideas about potential difference in series and parallel circuits, as Mrs Ramsgill had intended, the pupils' principal concern, throughout most of the lesson, appeared to have been simply to discover how to get their circuits to work.

In terms of affective outcomes there was little evidence from pupil - pupil conversation that the task was successful in generating any interest about potential difference, electricity or even science in general. Indeed, the task did not even appear to provide a short-term enjoyable activity and certainly was ineffective in maintaining pupil engagement for the duration of the lesson. The researcher's overall impression was, as the following example illustrates, that most of the pupils had little understanding of, or interest in, the task seeing it merely as something preferable to writing:

> Researcher: Is it a good idea that you're spending all this time actually just getting the circuit set up?
> RL8: I don't know, but if we're actually setting up the circuit it saves us writing.

What the task did provide, although this was not a stated aim of Mrs Ramsgill, was an opportunity for the pupils to practice constructing simple electric circuits from circuit diagrams, a skill they appeared to be very much lacking in. Whilst acknowledging that the task was an integral part of a published scheme of work currently used by the science department at Rye, the overall impression was that the task was, in almost all respects, wholly ineffective as a means of attaining the aims stated by Mrs Ramsgill.

4.6 Case study 12

This case study was undertaken at Kyle School on the 22nd of January 2003. The observation was of a Year 7 Science lesson entitled 'Electromagnetism' that was within the broader topic of magnetism.

4.6.1 The teacher

Mrs Kettlesing, the teacher in charge of physics, is a physics graduate with fifteen years experience, three year of which has been at Kyle. Colleagues in the department described her as a good teacher who was well liked by both staff and pupils. In particular a number of non-physicists in the science department commented upon her willingness to assist them when they were required to teach an area of physics that they were unsure about. Mrs Kettlesing teaches physics from KS4 up to and including 'A' level as well as general science at KS3 although at this level she tends to teach the physics component of the course.

4.6.2 The pupils

Year 7, set 1 of 11, (a mixed ability group) had twenty-two pupils comprising twelve boys and ten girls. Mrs Kettlesing expressed the view that whilst this group contained pupils of very different academic ability she found that at this age they all liked doing practical work. She had also noticed that the pupils tended to work with pupils of similar academic ability and that these groupings tended to remain fixed at least for a year and often longer. There were no pupils within the class registered as having either special educational needs or behavioural problems although approximately a quarter of the pupils in that class had been identified as being kinaesthetic learners.

4.6.3 The practical task as intended by the teacher

In terms of the aim stated to the researcher Mrs Kettlesing claimed that all she wanted was for the pupils to investigate how they could use electricity to turn a wire coil into an electromagnet:

> Mrs Kettlesing: For them to understand that you could use electricity to turn it [the wire coil] into a magnet.

However, the task as presented to the pupils, and the investigations that they carried out, suggested that this aim was extended during the course of the lesson. The extended aims required the pupils to investigate:

(i) The effect that the number of turns on the coil.

(ii) The presence or absence of an iron nail core.

(iii) The direction of current flow had on the strength and/or direction of the magnetic field set up by the electromagnet.

At the end of the task she acknowledged that her initial aim had been extended much more than was required by the syllabus:

> Mrs Kettlesing: I probably went further than I should have done with a Year 7 because at this stage all they should know is that you can make electromagnets out of electricity [the aim that she had initially stated to the researcher]. All of the additional tests [that she had added to the original aim] would be in Year 9.

The task required the pupils to construct, from a provided length of insulted wire, two coils having different numbers of turns. The direction of the magnetic field was to be found using a plotting compass. The effect of altering the number of coils and inserting an iron core was to be tested by seeing how many paperclips could be suspended, in a chain, from either the end of the nail or the end of the coil.

4.6.4 The lesson

Figure 4.13 shows the basic structure of this lesson

Figure 4.13 A flow diagram of the basic lesson structure

11.35 - Lesson starts.

↓

11.35 - 11.42 Pupils enter class and settle down. Mrs Kettlesing takes register.

↓

11.42 - 11.47 Mrs Kettlesing re-caps material on permanent magnets that includes a brief history, magnetic fields, the use of plotting compasses, and the magnetisation and demagnetisation of permanent magnets.

↓

09.26 - 09.37 Mrs Kettlesing presents the practical task and demonstrates the procedure to be followed. Pupils are told to collect equipment.

↓

11.53 - 12.22 Pupils undertake practical task.

↓

12.22 - 12.27 Pupils pack away.

↓

12.27 - 12.35 Mrs Kettlesing presents a summary of the findings and pupils use this information to complete sentences on electromagnetism.

↓

12.35 - Lesson ends.

4.6.5 Task presentation

The pupils entered the class and as they did so some called out to ask whether they were doing practical in the lesson. They settled down quickly and Mrs Kettlesing took a register before she re-capped basic material on magnetism that included a brief history of its early use in navigation, the making of new permanent magnets by rubbing with another magnet and their demagnetisation by heating and/or dropping. In addition to this she reminded the pupils of how they had in a previous lesson used plotting compasses to plot out the shape of a magnetic field around different shaped permanent magnets. Finally Mrs Kettlesing provided an explanation of the macroscopic magnetism, observed in permanent magnets, in terms of the alignment of microscopic magnetic domains and how this helped to understand the magnetisation and demagnetisation of permanent magnets. Once this was completed the aim of the current practical lesson was introduced.

> Mrs Kettlesing: There is another way to make a magnet that you probably haven't done before and that's using electricity. You can make something a magnet using electricity. This is what I want you to try and do today.
> KGa: Cool.

Mrs Kettlesing then proceeded, in a highly structured manner, to present the procedure that they were to follow in order to construct an electromagnet. As she explained the procedure verbally she also demonstrated each stage of the procedure at the front of the laboratory. Since the pupils had never used the patent wire stripper she demonstrated its use so that all of the class could see how to strip the insulation from the ends of the wire. Mrs Kettlesing then demonstrated how to form the wire coil by wrapping the wire around a pencil although she made no mention as to how many turns they were to make:

> Mrs Kettlesing: What you need to do is get a pencil or a pen and wind the wire around your pencil as many times as you can. [Mrs Kettlesing starts to wind her wire around a pencil to demonstrate this but does not complete the task.] Yours will be bigger than that because you'll have wound on all your wire.

Mrs Kettlesing holds up the partially formed coil:

> Mrs Kettlesing: I'm telling you that will become a magnet if you connect it to a power supply.

The pupils were then shown how it was possible, using crocodile clips, to connect the ends of the coil wire to a six-volt battery although the actual connection, and final completion of the circuit, was not actually demonstrated

> Mrs Kettlesing: Now, if you put some electricity through there, through the coil of wire [moves the crocodile clip towards the battery terminal] as the electricity goes around the coil of wire it will turn the coil of wire into a magnet. How are you going to tell if it's a magnet or not?
> KGb: Put a compass near it.

The task as presented to the pupils was, to this point, the same as that presented to the researcher. However, in response to the pupil's suggestion to use a plotting compass to ascertain whether the coil had become magnetic, Mrs Kettlesing introduced an additional element to the task that went beyond her initially stated aim of getting the pupils simply to observe that it was possible to construct an electromagnet:

> Mrs Kettlesing: What you could do is find out which end is the north and which end is the south couldn't you. What do you think would happen? Well you could try it, swapping the electricity around so it's going the other way around the wire see what happens [holds up plotting compass] to the thing.

Having introduced that additional element to the task she then proceeded immediately to introduce yet another:

> Mrs Kettlesing: What you can do is try something else. Try it with a little coil of wire and try doing it with a big coil of wire and see if that makes any difference.

A pupil raises a hand to ask a question:

> KGb: Will the coil stay a magnet when you turn the electricity off?
> Mrs Kettlesing: No, as soon as you switch off it'll stop being a magnet. It only works whilst the electricity is on.
> KGc: Why do you need to wrap the wire around a pencil?
> Mrs Kettlesing: Because that's the easiest way to make it into a coil of

wire. I mean we could just put it on the table like this [holds up a straight piece of wire.
KGd: Why does it have to be a coil?
Mrs Kettlesing: It doesn't have to be a coil. You can try putting the electricity through a straight wire.

Mrs Kettlesing summarised the task, as she had explained it so far, and then introduced yet a further additional element to the task:

Mrs Kettlesing: And then the third thing I want you to do is to try, this time, to put the nail, one of these nails that I'm putting out [removes a box of nails from a cupboard and places it on front bench] inside the coil of wire, or start coiling it again if you want to, [demonstrates how to wind wire around the nail], and see what happens this time to the magnetism when you're winding it around something that's magnetic ok.

The pupils started to stand up in their places and were clearly excited and keen to start the practical component of the lesson and the level of background noise had increased noticeably. Mrs Kettlesing motioned the pupils to be seated and then re-capped the task in its entirety and what they were required to do. During this re-cap it was emphasised that she would be asking them questions on their findings at the end of the task and, as such, they needed to think about what they were doing:

Mrs Kettlesing: I want to see if you can tell me when you've finished what these things do. What makes a difference, how does an electromagnet become stronger and how does it work. Does it work if you turn the electricity off? Does it work if you turn the electricity in the other direction? Does it matter if you wind it clockwise or anticlockwise? Does it matter of you've got lots of coils or not many? Does it matter if you've got a nail in the middle or not? All of these things I'm going to ask you about after you've done the experiment. So you're going to have to think about all the things that you're going to find out about. Questions?

One pupil raised a hand to ask a question and as they did so other pupils, clearly impatient to get on with the task, made groaning noises and two boys were seen to gesture with their hands for the pupil to lower their hand. The pupil asked whether they could write down in their exercise books what they found out as they went along. Speaking to the whole class she informed them that other than very brief notes, that they could jot in the back of their exercise books if they did not think they could remember something, she did not want them to write anything down. Notes on the task would be made in the next lesson.

On being told to begin the pupils spread themselves around the laboratory in pairs of their own choosing and collected their apparatus from trays on the bench at the front of the laboratory.

4.6.6 Task actualisation

Whilst most of the pupils appeared to have little difficulty in actually forming the coils a few, who had used pens that were not of a uniform thickness, found that they were unable to slide their tightly wound coil off the pen. One pupil, who was working alone, was uncertain as to how far to wind the wire:

> Researcher: Hello, what's going on here? [KG5 was standing holding wire and pen but doing nothing.]
> KG5: I haven't started yet. I just have to roll up the wire. Do you have to roll it all the way to the end?

It became apparent, soon after the task had started, that the pupils were unable to master the use of the patent wire stripper and, as a consequence, a queue of pupils was now standing around waiting to strip the ends of their wire. The class was then called to attention:

> Mrs Kettlesing: Since these can be a bit tricky [holds up the patent wire stripper] to use, when you're ready, bring your coil to me and I'll strip the ends for you. If we've time at the end you can practice using them.

There appeared to be little doubt even before they carried out the task, amongst the pupils questioned, that the coil would become a magnet when electricity flowed through it. This conviction had nothing to do with the task itself, but was a direct consequence of the claim made by Mrs Kettlesing during the task presentation. As one pupil, when questioned on this, points out:

> Researcher: So you think this [points to coil] is going to be a magnet?
> KG1: Yes, well miss says.

The fact that the pupils already expected the coil to act as a magnet when electricity passed through it meant that when this was not observed - frequently as a result of a faulty plotting compass - they immediately suspected faulty equipment rather than doubting that the coil had become magnetic. From the researcher's perspective had the pupils not been expecting to see the plotting compass change direction it would have been highly unlikely that many of the pupils would have discovered that the coil had become magnetic simply because the vast majority of the plotting compasses that were used were faulty:

> KG9: Ours isn't working.
> KG10: No, we can't get it to work.
> KG9: It's either our battery, or our compass, aren't working on it.
> Researcher: What should it do?
> KG9: That [points to plotting compass] should change around.
> KG10: It's just not moving and we've tried three or four compasses.
> Researcher: Try using his compass, [points to another pupil], because I saw his work just before. [KG10 goes to borrow and returns with compass.]
> KG9: Ah, that's working.

Indeed during the subsequent interview Mrs Kettlesing indicated that faulty plotting compasses were a recurrent problem with this practical task:

> Mrs Kettlesing: ...but then you've got the problem with the plotting compasses that die on you...

Yet despite this potential problem, and her apparent knowledge of it, the pupils were not forewarned. Instead they deduced for themselves that their plotting compass, and/or battery, was faulty on the basis of their expectation that the coil would be generating a magnetic field coupled with the positive results obtained by others in the laboratory. In addition to this, as she moved from group to group, her advice to try using a different plotting compass if nothing was observed become common knowledge. At one point Mrs Kettlesing, who had borrowed a plotting compass from a group that had obtained a positive result to lend to another group whose plotting compass she suspected was faulty, again got no deflection. After examining the coil further she rewound the coil for the pupils, tested it, and got a positive result with the plotting compass. Clapping her hands to get the class's attention she informed them:

> Mrs Kettlesing: Squash your coils tight together on the pencil.

Having re-capped the use of plotting compasses to plot the shape of the magnetic field around permanent magnets, all of the pupils questioned, expected the plotting compass to change direction and/or spin around when it was bought near to the coil when connected to the battery:

> Researcher: What did you hope it would do? [To KG4 whose plotting compass was faulty.]
> KG4: I thought it would spin around.
> KG3: To spin around and then stop at one point.
> Researcher: What did you expect it [points to a plotting compass that hadn't moved] to do?
> KG6: Just move a bit.
> Researcher: What do you expect will happen?
> KG8: To kind of change direction when it, [points to plotting compass], goes near the wire.

The pupils worked through the different elements of the task and as they did so Mrs Kettlesing moved from pair to pair offering advice or, when required, assistance. As there had not been enough batteries two pairs of pupils had been provided with power packs. This was the first time the class had seen or used power packs and throughout the remainder of the lesson different pupils came over to see (and touch) the new pieces of equipment. Two of the pupils, who had used the power pack to test their small coil, had then been observed shorting their circuit because they had found that when they touched their wires together they could make sparks. The researcher approached them after they had disconnected a coil with lots more turns and had, in its place, connected up a single straight wire:

> Researcher: What have you found?
> KG11: I've got my compass stuck down the sink plug-hole.
> Researcher: You won't be able to get that out.
> KG12 We got it out just before.
> Researcher: But shouldn't you be doing this practical?
> KG11: Yeah we have been but ...
> KG12: But we're waiting for it to get...
> KG11: We're trying to get it [points at the straight wire connected to the power pack] hot now.
> KG12: So we're trying to do it without a coil.
> KG11: We're doing it in a straight line.
> Researcher: Does it work?
> KG11: No.
> KG12: We're waiting for it to warm up.
> Researcher: Should it warm up?
> KG11: Well it's not working.
> KG12: It's getting hot. [This was a statement of belief as he had not felt the wire.]
> Researcher: Does it have to be warm to work? [Feeling the wire, which was cold, and noticing that the power pack fuse had, unbeknown to the pupils, blown - probably as a result of their earlier shorting of the circuit.]
> KG12: No.

Their lack of familiarity with the power pack also meant that whilst they were surprised that the larger coil had not caused the plotting compass to move they had no idea that this was a consequence of the fact that no current was flowing through their circuit. Indeed despite their initial hypothesis that the magnetic field strength would be greater for a larger coil than a smaller one, an expectation that appeared to be based on the proportional reasoning that 'more of x means bigger and/or stronger y' their results caused them to reject this hypothesis:

> KG11: I thought the bigger one would work more.
> Researcher: Why?
> KG11: Because.
> KG12: It's more…
> KG11: Because you'd think it'd have more magnets, more magnetic, because it's bigger.
> Researcher: So what have you learnt from this practical?
> KG12: Little coils make better magnets out of electricity.

In a similar a manner an unnoticed bad electrical connection, that was rectified when the terminals were reversed, meant that two pupils, who initially failed to observe any magnetic field observed one after the reversal inferred that a magnetic field required the electric current to flow in a particular direction:

> Researcher: So what have you learnt?
> KG13: That it works well when this end is connected to the negative, but not when it's connected to the positive.
> KG14: Yeah.

As Mrs Kettlesing moved to, and spoke with, one of the first pairs to investigate the effect on the strength of the magnetic field of using the nail core she realised that she had not mentioned to the pupils how they were to investigate the magnetic field strength. Moving to her own bench she withdrew a small box from a drawer and called the class to attention:

> Mrs Kettlesing: Here, [holds up small box], are some paperclips if you want to see how many the nail will hold when you've got it inside.

However, some pupils misunderstood how they were to use the paperclips. One pair of pupils, who had managed to magnetically suspended only three paperclips from the end of the magnetised coil, found that by physically hooking the paperclip around the head of the nail, rather than simply suspending them magnetically, they could attach many more. Their understanding of why the nail strengthened the magnetic field had two distinct parts. Firstly there was a simple physical explanation in that the physical hook-like properties provided by the nail were better suited to hooking up nails:

> Researcher: What would happen if you had a little hook on the end of the wire [points to end turn of the coil] to hook them [points to paperclips] on, would that be just as good?
> KG13: Well, if you did that, it would be cheating.
> Researcher: Ok, so is the nail only better because it helps you hang the paperclips on it?
> KG13: Yeah.
> KG14: It makes it more stronger.
> Researcher: What do you mean by more stronger?
> KG14: See [picks up the coil, turns it on, and suspends a paperclip from the end turn. The coil was then shaken and the paperclip fell off. Having placed the nail inside the process was repeated but this time the paperclip was hooked over the head of the nail and did not fall off when shaken.]

Some pupils attempted to explain their observations and/or predictions in a pseudo scientific manner by using scientific terms such as electricity and magnetism without apparently understanding the precise scientific meaning of the words:

> KG6: There'll be more electric like spinning around.
>
> KG13: And it's got less magnetism stored inside.
>
> KG15: That when you put the wire *(sic)* [holds up nail] into this [points at coil] it makes more electricity going around the thing so it's more magnetic.

With about ten minutes left to the end of the lesson the pupils were asked to pack away the equipment. Once this had been done the pupils settled down quickly and Mrs Kettlesing summarised the lesson.

The pupils were then asked to complete the sentences that summarised their findings and which contained gaps for them to fill in the missing words that she had placed on the whiteboard

4.6.7 The teacher's task summary

The summary had two parts. The first was a question and answer session in which Mrs Kettlesing asked the pupils questions about the results that they had obtained and by prompting them towards the answer she was looking for sometimes succeeded in getting the pupils to state the answer for themselves. If the right answer was given the pupils were then asked to condense this into the form of a single sentence that linked an observation with a particular variable:

> Mrs Kettlesing: Can you give me a sentence, all of you need think about this one, to tell me what connects how strong the magnet is and how many times you wound the wire round?
> KGe: The further the wire…[Mrs Kettlesing shakes her head in the negative.]
> Mrs Kettlesing: The more times you wound the wire
>
> KGe: The more times you wound the wire, the more it'll stop… [Mrs Kettlesing shakes her head to indicate the answer is still incorrect] …the stronger it'll be.

When no hands were raised in response to a question addressed to the whole class individual pupils were asked by name but if this too proved unsuccessful she then provided the correct answer herself:

> Mrs Kettlesing: [Addressing KG12 who had used a power pack.] Give me a sentence relating the strength of the magnet to the electric current.
> KG12: The stronger…
> Mrs Kettlesing: No, start with 'the electric current'.
> KG12: [Shakes their head in the negative and does not respond.]
> Mrs Kettlesing: The bigger the electric current the stronger the magnet wasn't it, as you'd expect.

Mrs Kettlesing broke the summary up by mentioning the use of electromagnets in scrap yards and the advantage that they offered before summarising all of the findings:

> Mrs Kettlesing: Right. Ok we know you can make an electromagnet out of a coil of wire. If you put lots of turns of wire and you put a steal bit in the middle you'll make it stronger. If you put even more current through that'll make it stronger as well. Why do we use them? Because we can switch them on and off and they're more powerful than ordinary magnets.

The pupils, some of whom had started to pack away their books, were then called to attention:

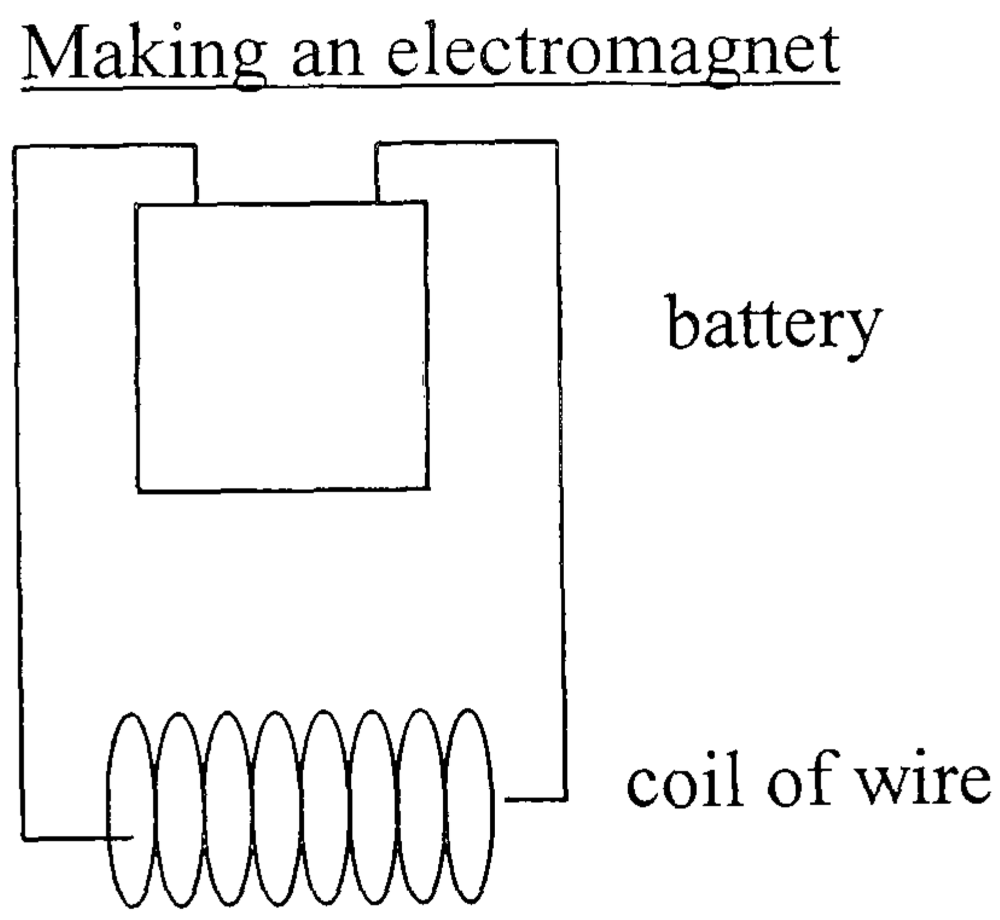
> Mrs Kettlesing: Ok folks I'm going to write this up and I'm going to leave some gaps for you to fill in and then we'll go through it in a minute or two.

The following diagram and sentences (Figure 4.14) were then put on the whiteboard:

Figure 4.14 Mrs Kettlesing's circuit diagram and questions

We can make the electromagnet stronger by:

1. using _________ turns of wire
2. putting a _________ nail inside the coil
3. putting a higher _______ through the wire



The end of lesson bell sounded before Mrs Kettlesing had time to go through the three sentences.

4.6.8 The teacher's views on practical work

Mrs Kettlesing, who was taught to use the discovery method of teaching science, believed that there were three primary reasons for using practical work in the teaching of science. Firstly the school placed a great emphasis on helping kinaesthetic learners reach their full potential and, as such, all departments were expected, where possible, to adopt an approach that enabled pupils to do things for themselves. This accorded with her own belief that pupils learnt more by doing things for themselves, rather than being told or watching a teacher demonstration.

> Mrs Kettlesing: I think they learn so much more by actually doing it than by just being told or even watching me do it.

In particular she felt that in terms of what they learnt practical work was particularly effective in enabling academically higher ability pupils to get the facts sorted out in their own minds by testing things for themselves:

> Mrs Kettlesing: I think the higher ability discover more and they get the fact straight in their mind because they've tested things out for themselves.

Secondly she believed that in discovering something for themselves, during the course of a practical task, the pupils would be more likely to remember:

> Mrs Kettlesing: We did a little bit of that [discovery learning] today because they remember something better if they think 'oh wow I didn't expect that'

Similarly she believed that academically low ability pupils would be able to recollect a particular task if they had undertaken it themselves:

> Mrs Kettlesing: I think the low ability [pupils] are more likely to remember it because they've done it themselves.

The fact that she believed that pupils remembered so much better when they did something for themselves presented her with the problem of how to ensure, if they got the wrong result for themselves, that they remembered the correct answer that she gave them during the summary to put into their books:

> Mrs Kettlesing: But if they've done it wrong and think one thing even if they've got it right in their books they probably won't remember it. But what else can you do?

In this respect she was surprised when informed that only one pupil within a Year 9 class (case study 11), whose class had all done the same practical on making an electromagnet with her when they were in Year 7, remembered even doing it:

> Researcher: Do you always do this practical with Year 7?
> Mrs Kettlesing: Yes
> Researcher: Only one pupil out of a whole current Year 9 class remembered doing this practical in Year 7 with you.
> Mrs Kettlesing: That surprises me that they don't remember it because I would have thought it would have been one of the practicals that they'd remember.

Thirdly practical work provided an opportunity for the pupils to do something different since she felt that it was overly demanding, irrespective of how interesting a lesson was, to expect the pupils to sit at their places for a whole lesson:

> Mrs Kettlesing: There's also the sense that it's a different activity. That you're just changing what you do with the class. Sat on a stool for an hour in a classroom, regardless of how interesting whatever you're doing at the front is, is hard work physically for the kids to just sit there and not do anything different.

She found the third reason for doing practical so compelling that she endeavoured, particularly with the younger pupils, to include at least some practical work in every lesson:

> Mrs Kettlesing: It's very rare, [that a lesson has no practical work], I hate lessons where I don't have any practical to do at all because I find they find it very hard to concentrate, certainly with this [Year 7] age group. Once they get to Year 10 then I don't think it's so important.

It was, in this respect, important when undertaking practical work with academically low ability pupils to ensure a relatively high degree of procedural structure. The purpose for this being to make it more likely that the task would be effective in getting these pupils to do with the objects and materials what was intended and, in so doing, generate and observe the desired results:

> Mrs Kettlesing: I think for low ability groups you need to have a certain amount of structure otherwise they won't find anything out. I need to tell them what they're going to find out or like 'put this here' or 'put that there ' or 'do this' and that way you can get them to see something.

Whilst she thought that practical work could motivate or excite the pupils she tended to consider such effects more in terms of short-term engagement for the duration of a particular lesson. Indeed she attributed a lot of the excitement displayed by Year 7 pupils towards practical work simply to the novelty of working in the laboratory for the first time and that this excitement would diminish as the novelty wore off:

> Mrs Kettlesing: They [Year 7] obviously enjoy it and, of course, with Year 7 they probably haven't done as much science as Year 9, so everything in the lab is all new.

One pupil, responding to a question about practical work, appeared to endorse this view when they claimed to like practical work because it was their first opportunity to use new materials and apparatus:

> Researcher: Do you like practical work?
> KG5: Yeah because we get to use proper wire for the first time and we get to use six vee [six volt] battery thing which is very powerful.

Although for events such as Open Evenings the department chose to use atypical practical tasks and present them as if they were typical of school science practical work she felt that the image of science, as being always exciting, that this projected was false. Further not only was such an image false but it could not be sustained and sooner rather than later the pupils realise that this image of science, as an exciting subject, did not reflect the reality of the vast majority of their science lessons at school:

> Mrs Kettlesing: On Open Evenings we always do whiz, bang, pops. The only physics one we have out is the Van de Graaff.
> Researcher: What do you think then of this image of science as being all whiz, bang, pops?
> Mrs Kettlesing: Maybe we're giving a false picture. I think we are probably. They aren't that many whiz, bang, pops and most of science is really about how does the world works and testing things out, why is this happening rather than whiz, bang, pops but that's what the kids like, particularly young boys.
> Researcher: Are you then using practical to try to encourage them into science?
> Mrs Kettlesing: We're trying to make it more exciting. I suppose we're all trying to do the same thing because it isn't exciting all of the time at secondary school is it

When discussing practical work with Mrs Kettlesing, who described herself as a kinaesthetic learner, it became evident that her beliefs as to the value and purpose of practical work were informed primarily by her own personal experiences of practical work as a pupil rather than from evidence gleaned from her own pupils. In fact most of the views that she expressed regarding the value of practical work, both as means of helping pupils to remember things and as a break from theory, were presented in terms of her own personal recollections of learning science. Indeed she was both unaware, and clearly surprised, to learn that Year 9 pupils had not remembered, as she herself had believed they would, the electromagnetism task undertaken in Year 7:

Mrs Kettlesing: When I look back at my own time at school all I really remember of science is the practical work.

Mrs Kettlesing: I found, as a kinaesthetic learner myself, that practical work helped me to remember things that I wouldn't have been able to remember otherwise.

Mrs Kettlesing: I used to hate sitting there for a whole lesson. It was really hard for a kinaesthetic learner like myself.

4.6.9 The pupils' views on practical work

All of the views expressed by the pupils about this task were positive. What emerged was that these responses could be divided into two generic categories:

(i) Statements of relative preference.

(ii) Personal beliefs and/or opinions about the educational value of practical work.

Statements of relative preference, in which the pupils compared practical work to another means of teaching, were the normal form of first level response when asked whether they liked doing practical work:

Researcher: Do you like practical?
KG9: Yeah.
KG10: Yeah.
Researcher: Why?
KG9: It's better than just writing stuff
KG10: Yeah.

None of the pupils expressed the view that practical work made it easier to recollect things although one pupil implied that they thought they would remember something observed during a practical task when they were older:

Researcher: Is it important that it [the task] works?
KG7: Yeah in case when you're older, if you're a technician, you'll know.

In terms of their personal beliefs and/or opinions about its educational value their responses suggested that they saw the primary function of practical work as being to allow them to discover, or find things out, by *seeing* an event or phenomenon for themselves:

> Researcher: Do you like practical?
> KG6: Yes.
> Researcher: Because you get to find stuff out.
>
> KG9: It's more interesting to see what happens...
> KG10: [Interrupting] Yeah what happens.
> KG9: ...rather than being told all of it.

Although there was an evident keenness to do practical work, as evidenced by the pupils asking whether they were doing practical as soon as they got through the laboratory door, there was no evidence, from their comments, that this preference was strongly influenced by their desire to avoid non-practical science. Indeed two pupils did suggest, in response to a direct question on this point, that although science would not be *as fun* without practical, it would still be fun:

> Researcher: If someone said we're going to stop all the practical in your lessons now, you're not going to do much practical, what would you say?
> KG11: It wouldn't be as good.
> KG12: No, it would be less fun.
> KG11: Yeah, less fun.

Although some of the pupils did not succeed in obtaining the desired results, primarily as a consequence of either faulty equipment or, in the case of the pupils who used power packs, a lack of familiarity with their operation they appeared, from the fact that they remained engaged and were generally jovial, to enjoy the lesson.

4.6.10 Summary

Despite the limited aim presented to the researcher before the start of the lesson Mrs Kettlesing's aim, as presented to the pupils, had been for the pupils to investigate how the number of turns on the coil, the direction of the electric current and the presence or absence of an iron nail core effected the magnetic strength of an electromagnet.

Using the theoretical model of effectiveness discussed in chapter 3, it is possible to construct a 2x2 effectiveness matrix for this task that is shown in figure 4.15 below:

Figure 4.15 Task effectiveness: Investigating of electromagnets

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	Pupils construct electromagnets with different numbers of turns, one with an iron core, the others without. Pupils connect each correctly to an electrical power supply (PS) and see that paperclips can be suspended from the end of the electromagnet when the PS is on but not when it is off.	Pupils talk about: the number of paperclips attached as a measure of the 'strength' of the electromagnet. Pupils talk about the phenomenon in terms of the relationship between number of turns, and presence / absence of an iron core, and strength of electromagnet.
at level 2 (what pupils learn)	Pupils state that: the number of paperclips that can be suspended from the end of the electromagnet increases (a) with the number of turns of wire and (b) the presence of an iron core; that the direction in which a compass needle points, if placed at the end of the electromagnet, can be reversed if the PS terminals are reversed.	Pupils state that: the strength of an electromagnet increases (a) with the number of turns of wire and (b) the presence of an iron core; that the magnetic polarity of the coil can be reversed by reversing the direction in which the electric current flows through the coil.

At level 1:o the task was moderately effective in that most of the pupils set up a working electromagnet and successfully changed the number of turns, the direction of current flow and the nature of the coil's core (air or iron). However, due to problems with faulty plotting compasses, poor electrical connections and a lack of familiarity with the power packs not all of the pupils observed all of the effects intended by the teacher. However, in terms of the stated aims the task did not appear to be effective in familiarising the pupils with laboratory equipment. In this respect it is highly probable that having not been alerted to the need to monitor, and when appropriate, reset the fuse the sort of problem that occurred during this task will, in all likelihood, reoccur. Indeed just such a problem was observed to happen with the Year 9 pupils who repeated the same task for a second time. Similarly not to have managed to practice using the patent wire striper meant that the pupils would again be unable to strip wires for themselves.

At level 1:i the task was effective in that the highly structured nature of the task meant that the pupils were told to think about the changes in the direction of the plotting compass and the number of paperclips that could be suspended as a means of measuring the direction and strength respectively of the magnetic field.

At level 2:o the task was relatively effective. Most of the pupils successfully set up a circuit containing an electromagnet that enabled them to discover how the magnetic field strength and direction varied (i) as the number of turns on the coil increased (ii) with or without an iron core (iii) with different sized current and (iv) as the direction of the electric current flowing through the coil was reversed. However, due to the faulty nature of some of the equipment and a lack of familiarity with other pieces not all the pupils managed to discover all of what the teacher intended them to discover.

Despite not having previously studied electromagnets most of the pupils questioned predicted, *before* the start of the task, that the strongest magnetic field would be generated when the coil had a larger number of turns, had an iron core in place or had a larger current flowing through the core. However, these predictions did not appear to be based on any scientific understanding but were instead based upon a basic presumption that more of x would mean a bigger and/or stronger y. Similarly although the pupils found that the nail enabled them to pick up more paperclips some pupils attributed this to the fact that the head of the nail provided a more appropriate physical form for hooking paperclips onto than the smooth end of the coil.

Since the aim of the task had only been to enable the pupils to discover a qualitative understanding of how various factors affected both the strength and direction of a magnetic field formed by an electromagnet coil there was neither the intention, or opportunity, for the task to be effective at level 2:i.

It was not possible, due to access constraints, to revisit the school at later dates to ascertain the level 2 effectiveness of the task in terms of what the pupils could recollect in both the medium and long term. However, since most of the current Year 9 had no recollection of an identical task that they undertook with Mrs Kettlesing two years earlier, it might reasonably be inferred that the task is a relatively ineffective method of learning about, and subsequently being able to recollect, details relating to electromagnetism. One possible explanation for its relative ineffectiveness in this respect might be that the task is relatively non-descript and, as such, is unlikely to generate any memorable episodes.

Although there was no evidence to suggest that the task motivated the pupils towards the study and appreciation of science *per se* the task did appear to provide a short-term enjoyable activity that engaged the pupils for the duration of that particular lesson.

4.7 The structure of chapters 5, 6 and 7

Effectiveness at level 1 relates to what pupils *do,* and *learn* about in terms of observable objects and events, relative to what the teacher intended them to. Once the teacher has decided what it is that they want the pupils to learn, their next step, in terms of the theoretical model being used, is to design or choose a practical task that they believe will be effective in enabling the pupils to achieve the desired learning objectives. Yet even when the teacher believes that a particular task has the potential to be an effective method of achieving certain learning objectives, the pupils do not always succeed in either doing or seeing what the teacher intended. There are various reasons why a task might be ineffective but what has emerged from the study is that teachers appear to use a range of strategies, whether implicitly or explicitly, to improve (or to ensure) effectiveness at level 1. The aim of chapter 5 is to present an analysis of the case study reports that indicates that teachers use a number of strategies to influence the likelihood that a particular practical task will be effective at level 1. From the practical task profile form developed by Millar *et al.* (1999) it is possible to identify three generic factors that can be used by the teachers:

- The degree of openness/closeness of the task
- The nature of pupil involvement
- The information given to pupils on the task

Whilst these generic factors do not embrace all of the actions that can be taken by the teacher, they do provide a useful framework from which to analyse the different approaches used by teachers to maximise the likelihood of a task being effective at level 1.

The chapter will also present an analysis as to why some practical tasks were observed to be ineffective and suggest that all observed cases of ineffectiveness at level 1 could be accounted for on the basis of two factors:

(i) Lack of pupil and/or teacher familiarity with equipment.

(ii) A task that whilst highly structured was not fully closed.

It will also be suggested, although this was not observed in the study, that ineffectiveness at level 1 can also occur if the phenomena themselves are genuinely hard to produce.

The chapter will end with a summary that, broadly speaking, argues that the use of closed, highly structured, practical tasks are frequently effective in terms of getting pupils to do and see what the teacher intends. However, leading into chapter 6, it will suggest that whilst closed, highly structured, activities do not *necessarily* preclude intellectual engagement (CASE being just such an example), they do render the need for such engagement superfluous in that tasks were frequently effective at this level whilst ineffective at level 2:i.

Chapter 6 will then analyse the effectiveness of practical work at level 2 and in particular at level 2:i. It will argue that the emphasis placed by teachers on effectively getting pupils to do and see, i.e. achievement of level 1 effectiveness through the use of highly structured tasks, is in tension with the achievement of effectiveness at level 2. It will argue that frequently pupils are more concerned with manipulating equipment in order to get the 'right answers' than in thinking about what they are doing and why, or with manipulating ideas. It will also present an analysis to suggest that, despite the many claims to the contrary, practical work assists very little, if at all, with the recollection of scientific concepts. It will claim that pupils' recollections appear to focus on a small number of tasks (be they practical tasks undertaken by the pupils *or* teacher demonstrations) that are 'memorable episodes' in the sense that they leave an impressive visual, aural or olfactory impression or have another 'distinguishing' feature. Whilst pupils were found to be able to recollect qualitative aspects of their sensory perceptions relating to a few memorable tasks of this kind i.e. they could describe what they did and saw – the very things that the task had achieved effectively at level 1 - they had very little recollection as to the concepts that would have been learnt if the task had been effective at level 2.

Chapter 7 will examine whether practical work can be said to have affective outcomes and, if so, in what sense. It will distinguish between motivation and interest, and between personal interest and situational interest. It will argue that what emerges from the data is that practical work does not motivate but rather it generates situational interest. It will also suggest, in contrast to frequent claims, that practical work – post Year 7 – is not liked *per se* but is merely preferred to other methods of teaching on the grounds that it entails less writing, provides an opportunity to chat with friends and requires little by way of meaningful cognitive engagement to successfully produce the phenomenon. It will suggest that this view of practical work, as 'the least bad option', helps to explain why, despite its frequent use and the claims that pupils find it fun and enjoyable, many pupils still elect not to pursue the study of one, or more, science subjects post compulsion.

Chapter 5

What pupils do with objects, materials and ideas

5.1 Introduction

This chapter is about the effectiveness of practical work in getting pupils to do what the teacher intended with the objects and materials provided, and to think about these using the ideas the teacher intended them to use. The emphasis throughout this chapter is therefore focused on 'doing' with objects, materials and ideas, as distinct from 'learning' about them, something that will be examined in depth in chapter 6.

The organisation of chapters 5 and 6 separates the discussion into doing and learning – a distinction that reflects that between level 1 and level 2 in the theoretical 2 x 2 matrix representation of practical work discussed in chapter 3. An alternative might have been to discuss first doing and learning with objects and materials, and then doing and learning with ideas, i.e. to separate the discussion using the other dimension of the 2 x 2 matrix. The reason for the choice adopted is that the former better reflected the distinction between doing and learning that emerged both in the views expressed by pupils and in the different emphasis placed on these by the teachers.

The first, and longest, part of the chapter will focus on whether the pupils did with the objects and materials what the teacher intended whilst the second, and shorter, part considers whether the pupils thought about them using the ideas intended by the teacher. The disparity in the length of these two parts reflects a similar disparity that became apparent in the observations, between the times devoted to observing and manipulating objects and materials and that devoted to thinking about the phenomena observed. The effectiveness of practical work at level 1 refers to the match between what pupils do in both the domain of observables, and the domain of ideas, and what the teacher intended them to do (Millar et al., 1999). Therefore once the teacher has decided what it is that they want the pupils to do, their next step is to present the task to the pupils in a manner that they believe will be effective in getting the pupils to do with the objects, materials and ideas what they intended.

5.2 What is required if pupils are to do what the teacher intended with objects and materials?

There are various reasons why pupils might not do what the teacher intended them to do with objects and materials. However, in the researcher's own teaching experience, these reasons – fire alarms, medical emergences and other such non-anticipated events excluded – can be grouped together under four headings. These headings categorise, broadly speaking, the basic requirements that if not met, or are only partially met, can prevent and/or hinder some, or all, of the pupils from doing what the teacher intended with the objects and materials provided. These four basic requirements are that:

(i) The pupils understand what they were required to do with the objects and materials provided.

(ii) The pupils are sufficiently proficient in the use of all of the required equipment to do what the teacher intended.

(iii) The equipment is in working order.

(iv) The phenomena are reasonably easy to generate.

Whilst the overwhelming majority of teachers in this study succeeded in ensuring that the four requirements were met, there were a few notable exceptions. In those cases, as a consequence of one or more of the requirements either not having being met or not having been met fully, some of the pupils were prevented and/or hindered from doing some of what their teachers had intended them to do with the objects and materials.

5.2.1 Understanding what is required to be done

In order for the pupils to do what the teacher intends it is essential that these intentions are communicated effectively to the pupils. Teachers observed presented procedural information to pupils using a variety of alternative methods (Table 5.1).

Table 5.1 Presentation of procedural information: Methods used and time taken

Task	Teacher	Method[s] used for the presentation of procedural information	Time taken to present procedural information (minutes)
1	Mr Dacre	Worksheet	4
2	Mr Drax	Oral / whiteboard	9
3	Mr Drax	Oral / whiteboard	11
4	Mrs Duggleby	Oral / whiteboard	8
5	Mr Fangfoss	Demo / oral	11
6	Ms Ferrensby	OHP / oral / whiteboard / worksheet	10
7	Mr Keld	Demo / oral / whiteboard	17
8	Miss Kilburn	Oral / whiteboard / worksheet	13
9	Dr Kepwick	Demo / OHP / oral / whiteboard	14
10	Mrs Kettlesing	Demo / oral	6
11	Mr Normanby	Demo / oral / whiteboard / worksheet	2
12	Mr Normanby	Oral / smartboard / whiteboard	33
13	Miss Nunwick	Oral / textbook	3
14	Mr Oldstead	Demo / oral / whiteboard	15
15	Mr Overton	Demo / oral / worksheet	10
16	Mr Rainton	Oral / textbook / whiteboard	14
17	Mrs Ramsgill	Oral / worksheet	5
18	Mrs Risplith	Oral / whiteboard	13
19	Mr Saltmarsh	Demo / OHP / oral	14
20	Mr Sewerby	OHP / oral / whiteboard / worksheet	21
21	Miss Sharow	Oral / whiteboard	11
22	Dr Starbeck	Demo / oral / smartboard / whiteboard	30
23	Mrs Uckerby	Oral / whiteboard / worksheet	10
24	Mrs Ugthorpe	Oral / whiteboard	13
25	Mr Ulleskelf	Oral / whiteboard	9

It can be seen (Table 5.1) that in all cases, other than Mr Dacre, the teachers used oral instructions in conjunction with at least one other presentational method in order to get the pupils to understand the procedure that they were to follow. By ranking the case studies in ascending order of time devoted to task presentation it is possible to construct three approximately equally sized groups that, relative to the sample as a whole, can be characterised as containing tasks that devote relatively short, medium or long amounts of time to presenting procedural information (Table 5.2).

Table 5. 2 Tasks ordered in ascending amount of time devoted to task presentation

Time spent on task presentation (minutes)	Duration: 'Short', 'Medium', 'Long'	Number of presentational methods used	Task
2	Short	Three	11
3	Short	Two	13
4	Short	Two	1
5	Short	Two	17
6	Short	Two	10
8	Short	Two	4
9	Short	Two	2
9	Short	Two	25
10	Medium	Four	6
10	Medium	Three	15
10	Medium	Three	23
11	Medium	Two	3
11	Medium	Two	5
11	Medium	Two	21
13	Medium	Three	8
13	Medium	Two	18
13	Medium	Two	24
14	Long	Four	9
14	Long	Three	16
14	Long	Three	19
15	Long	Three	14
17	Long	Three	7
21	Long	Four	20
30	Long	Four	22
33	Long	Three	12

Of the eight case studies in which the duration of task presentation is characterised as 'short', all but one task used one or two methods to present the information to the pupils. In contrast, of the eight case studies in which time devoted to task presentation is characterised as 'long', all of the tasks used three or more different methods to present the information.

In addition, even in some tasks characterised as 'medium' the time devoted to task presentation included time spent on repeating the same procedural information albeit using different methods of presentation. For example the time devoted to task presentation by Mr Overton, a biology graduate, whose lesson with a Year 8 class was a physics activity designed to investigate the magnetic permeability of different materials was composed of three elements. Firstly Mr Overton, having provided the pupils with a double-sided A4 commercially produced guiding worksheet that was part of a scheme of work (Smith, 2002) that he followed, initially gave the pupils two minutes to read through the material. Then, once the pupils had read the sheet, and even though none of the pupils was reported to have any problem with reading, Mr Overton called the class to attention and spent the next three minutes reading the entire worksheet out aloud to the class. Finally, having read the worksheet, he called the pupils around his bench where he spent another five minutes showing the pupils various pieces of equipment, including the materials to be tested, how to set the equipment up, as well as demonstrating how to carry out the actual testing procedure. Whilst the last two methods of presentation, that occupied eight minutes of the lesson, might have reinforced the information already presented in the worksheet neither contained any new information.

One teacher pointed out that whilst she had confidence in the ability of higher academic ability pupils, such as those she was observed teaching, to follow oral and/or written procedural instructions, she felt the need to supplement these two methods of presentation with a teacher demonstrations when teaching academically lower ability pupils:

> Ms Sharow: Lower sets, I'll also do a demonstration, you know, 'this is how you set it up', 'plug this in here', 'plug that in there'. [Said very slowly to give an impression that she was explaining something to pupils who could only deal with limited and very basic information.]

In contrast Mr Dacre, who was concerned with the challenge of having to fit what he considered to be a relatively large practical task into a fifty-five minute lesson, chose to use only one presentational method in order to minimise the time spent on presentation and, as a consequence, maximise the time available for carrying out the task:

> Mr Dacre: I was concerned that the practical wouldn't be finished. I thought fifty-five [minutes] it was not an easy task for them to do in that length of time… In fact it works out at about forty-five minutes because there has to be a bit of an introduction, you know where things are and what's going on… so we're talking about forty to forty-five minutes for six small practicals, it's not easy.

Having provided the pupils with two, single-sided A4 commercially produced guiding worksheets, that was part of a scheme of work that he followed, Mr Dacre gave the pupils four minutes to read through the instructions. Then with the admonishment to "Follow the instructions and you'll get the results that you need" he directed them to collect the apparatus.

It can be seen (Table 5.1) that within his fifty-five minute lesson Mr Dacre devoted only four minutes, seven percent of the total lesson time, to task presentation and forty-six minutes, or eighty-four percent of the lesson time, to task actualisation. Yet despite devoting a larger percentage of the total lesson time to task actualisation than any other teacher within the study, none of his pupils managed to undertake all of the six tasks in the available time and a large proportion of the pupils did not manage to do with some of the objects and materials what he had intended.

What emerged from the observation of this task was that, although the worksheets contained all of the procedural information needed to generate the desired phenomena, the pupils appeared unable (or unwilling) to assimilate what was a relatively large amount of written procedural information within the short period of time prior to undertaking the task itself. Indeed when questioned on what they were actually doing, it became apparent that many pupils had not read the procedural instructions:

Researcher: What's this one?
DE17: Copper sulphate and ammonia, well we didn't have the ammonia so we just used copper sulphate and it bubbled.
DE18: 'cause sir's only brought the ammonia in now. [This was untrue; the ammonia had been on the front bench since the start of the lesson.]
Researcher: Hang on, but number two [points to worksheet] doesn't say to heat it.
DE17: What?
DE18: Oh well.
Researcher: Had you not read that?
DE17: No.
DE18: We just thought you had to heat them all.

DE19: [Calling out loudly] Can I have a paper towel? [The liquid in the boiling tube had, on being vigorously heated, shot out over the desk.]
Mr Dacre: Right come here you. Why did you heat that up? Which experiment is it, copper sulphate and ammonia? Right read out the sheet and tell me where it tells you to heat it.
DE20: [The partner of DE19 looks at the worksheet.] It doesn't.
Mr Dacre: Excuse me I'm asking him [points to DE19]. It says what?
DE19: [Looking at worksheet.] It doesn't say heat it.

In findings similar to those reported by Berry et al. (1999), it transpired that the pupils, although initially reluctant to admit to not having read the instructions, did subsequently acknowledge that they had only skimmed through the worksheet, picking out those pieces of information, such as items of equipment or the names of materials, that were needed to enable them to start *doing* something:

Researcher: So, have you read the instructions?
DE2: Yar.
Researcher: So you're filling all the test tubes up with sugar? [The instructions are to fill only one test tube with sugar.]
DE2: Yar.
DE3: [Reading the instruction sheet.] That's not right.
DE2: Oh.
Researcher: So have you read them [pointing to the instruction sheet], or haven't you?
DE3: No.
DE2: I have read them [laughs], but not very well.

Researcher: So is it important that you read the instructions?
DE18: Like we didn't [laughs and points to the equipment], we just checked what we needed to get.

The fact that the pupils just wanted to get on with 'doing' supports the claim made by Berry et al. (1999) that pupils often ignore instructions because they perceive a practical task solely as a 'hands on' physical activity and, as such, focus their attention only on what is necessary to enable them to engage with the 'doing' element of the task.

Indeed two teachers, whose tasks had been less effective in getting the pupils to do with the objects and materials what they had intended, attributed this lack of effectiveness to the pupils' failure to follow the procedural information rather than to any deficiency in the procedural information that they themselves had provided:

Mr Dacre: I think one needs to plug away at the fact that sometimes we [the pupils] need to follow instructions so that we get the right answer.

Researcher: Was that [task] successful?
Mrs Ugthorpe : No, because lots of them didn't, they can't follow instructions.

Whilst it is reasonable to assume that some pupils might be unwilling to engage with the instructions they are provided with, there are cases, particularly in practical work (Johnstone and Wham, 1982; Johnstone, 1980; Johnstone and Kellett, 1980), where rather than being unwilling the pupils are unable to do with the objects and materials what the teacher intended due to what Tamir (1991) refers to as "cognitive overload" (p. 16). Cognitive overload can occur with pupils if too great a demand is placed upon their working memory as a consequence of presenting them with too much information too quickly (Johnstone and Wham, 1982). If the pupils' working memory does become overloaded then not only is there a greater likelihood that they will be unable to fully understand what they are required to do but, as Delamont et al. (1988) have argued, it will be more difficult for them to adhere to the procedure so as to generate successfully the desired phenomenon. In presenting the procedural information on a 'need to know' basis, i.e. only when it was required to undertake a particular aspect of a task, meant that some of the teachers were particularly successful in getting their pupils to do what they had intended them to do with the objects and materials.

In terms of getting all of the pupils to do as the teacher intended with the objects and materials, two of the more effective tasks were those that used multiple presentational methods to present procedural information *and* in which the task was divided into separate, self-contained, sub-units so as to reduce the amount of information presented to the pupils. In this way the pupils were presented, using a combination of different methods, with only that procedural information required for the particular sub-unit that was to be undertaken at that point in the lesson. In this respect once a particular sub-unit had been completed the procedural information associated with it could be 'discarded' freeing up working memory for the next sub-unit that they were to undertake.

For example Mr Rainton, a chemistry graduate, teaching a Year 10 low academic ability class the topic of electrolysis, used material from a textbook as well as material he had designed himself. The task was composed of three separate sub-units, the first two of which, the electrolysis of hydrogen chloride (hydrochloric acid) and the electrolysis of copper sulphate solution, were taken from the textbook whilst the third, the electroplating of a five pence piece with copper, was his own design. The information for each sub-unit was presented using up to three presentational methods and only after each task had been undertaken and summarised did Mr Rainton move on to present the procedural information for the next sub-unit. Therefore whilst the *total* amount of procedural information remained unchanged, the effect of splitting it into smaller discrete packages was to reduce the demand being made on the pupils' working memory and, as a consequence, reduce the risk of cognitive overload with respect to each particular sub-unit.

In contrast a similar, although not identical, task used by Mr Ulleskelf, a chemistry graduate, with a Year 10 class in which all of the procedural information was presented in nine minutes at the start of the lesson using only two methods of presentation was less effective in terms of getting the pupils to do with the objects and materials what Mr Ulleskelf had intended.

Whilst there was widespread use, by almost all of the teachers, of a combination of different presentational methods (Table 5.1) in an endeavour to ensure that the majority of pupils would understand what it was that they were required to do this was only partially effective. More effective were those tasks that, whilst using multiple methods of presentation, presented this information in smaller 'bite size' amounts, that reduced the demand on working memory and, in so doing, appeared to enable the pupils to focus their attention on one specific part of the task at a time.

5.2.2 Proficiency with the use of the equipment

Given that the pupils have understood what it is that their teacher wants them to do, the next requirement, if they are to successfully generate the desired phenomena and/or data, is that they, and their teacher, be sufficiently proficient in the use of any of the relevant equipment and that its correct operation is unproblematic. Before proceeding with this sub-section it is important to recognise that pupil proficiency with equipment is likely to vary, even within the same class. When considering the effect of pupil proficiency with the equipment, the focus has therefore not been to count how many particular pupils lacked proficiency with a particular piece of equipment but on whether the researcher, moving around the laboratory throughout the task, observed that the ability of more than one or two pupils to do as intended with the objects and materials was being adversely affected by their lack of proficiency (Table 5.3).

Table 5.3 Tasks in which pupils exhibited a lack of proficiency with equipment

Teacher	Task	Equipment that pupils lacked proficiency in the use of
Mrs Duggleby	Electric circuits - current conservation	Ammeter – how to read scale
Ms Ferrensby	Electric circuits - current conservation	Ammeter – how to read scale
Dr Kepwick	Electromagnets – factors effecting strength	Low voltage power pack – how to use
Miss Kilburn	CASE	Newton meter – how to read
Mr Rainton	Electrolysis – cathode deposits	Indicator paper – how to use
Mrs Risplith	Heart beat/pulse – numerical equivalence	Stethoscope – how to use
Mrs Uckerby	Current in series and parallel circuits	Voltmeter – how to connect
Mrs Ugthorpe	Food tests – test results	Chemical indicators – how to use
Mr Ulleskelf	Electrolysis – increase in cathode mass	Weighing scales – how to read scale Low voltage power pack – how to use

It should however be noted that familiarity with a piece of equipment, in the sense that it has been used before and is, therefore, recognised by the pupils, does not necessarily imply proficiency with its use. Indeed there was a relatively large amount of evidence to show that pupils who, whilst acknowledging their previous use of a particular piece of equipment over a number of years, lacked the proficiency needed to enable them to use it effectively in order to generate a particular phenomenon or collect the desired data. For example, whilst the actual construction of a basic series circuit containing a number of bulbs presented only minor problems for a few pupils taught by Ms Ferrensby and Mrs Duggleby, there was a widespread inability to obtain the current readings required to illustrate the conservation of current. There were a number of reasons for this, but all were indicative of a lack of proficiency with the use of an ammeter. When the reasons for this were examined it emerged that the most widespread problem was that the pupils did not understand that the polarity sign of the current, as indicated on an ammeter, was merely an indication of the direction in which the current was flowing and that it was the magnitude of the ammeter reading alone that measured the size of the current. However, a large proportion of pupils perceived any needle deflection to the left of the zero, when using analogue ammeters with a centre scale zero (CSZ), as being less than any deflection of the needle to the right of the zero, irrespective of its magnitude. For example rather than perceiving a reading of 0.8 amps to the right of the zero (CSZ) and a reading of 0.8 amps to the left of the zero as being indicative of a conserved current that, because of reversed polarity connections, was flowing in the opposite direction, the pupils perceived the latter as being 1.6 amps less than the former, suggesting that the current had been consumed. Similarly pupils using digital ammeters perceived a current of 0.4 amps as being 0.8 amps more than a current of (minus) – 0.4 amps, rather than as a current of the same magnitude that differed only in its direction of flow. In the case of analogue ammeters in which the zero was on the left of the scale (LSZ) and needle deflection could only occur in a clockwise manner, pupils perceived zero movement of the needle as being indicative of a broken ammeter (especially when they could see that current was flowing because a bulb in the circuit was on) rather than as an indication of incorrect polarity connections. Indeed from the comments made by the pupils, similar problems had also prevented some of them from obtaining results in previous practical tasks:

> FY3: Last week we couldn't get it to work.
> FY2: [Inserts a LSZ ammeter into circuit.] The ammeter wasn't working.
> Researcher: Is that reading anything, your ammeter, or not?
> FY3: No.
> FY2: No, we've got another one. [Replaces the first LSZ ammeter with another LSZ ammeter that also gives no reading. FY2 bangs the desk angrily with their hand.]

Researcher: Why didn't the ammeter read anything?
FY2: I don't know.
FYa: Ours is also broken. [FYa has come over with a LSZ ammeter and makes this comment whilst pointing to the zero deflection on the ammeter being used by FY2 and FY3.]
Researcher: Try again. [Pupils do and again obtain zero deflection.] So the lights are working but the ammeter isn't working. Is that what happened last week?
FY2: Yes.
FY3: Yeah.
FY2: Yeah the ammeter isn't working.
Researcher: Watch. I swap them around [the connections to the LSZ ammeter] and what happens?
FY3: It works. [Really excited.]
FY2: Thank you.

Researcher: Hello. So you're working on your own?
FY4: Yeah.
Researcher: What have you found?
FY4: That the ammeter isn't going up really.
Researcher: Is it not?
FY4: I don't know if it's not working. [Not only has the pupil connected the LSZ ammeter incorrectly but they have also connected both the a.c. and d.c. output sockets on the power pack to different parts of their circuit.]

The consequence for what pupils learn, or fail to learn, that can arise from a lack of proficiency with a basic item of equipment can be appreciable:

Researcher: What did you find?
DY5: We found it went there [points to the right of zero on their CSZ ammeter] now it's gone there. [Points to the needle that is now on the left of the zero.]
DY6: So it's gone down.
DY5: So it went more and then less [points with finger to indicate the flow of an electric current into and out of the bulb] so our prediction was right.
Researcher: Your prediction was right. Are you happy?
DY5: Yes.
DY6: Yeah.
Researcher: So you think you've found what you predicted? Now what happens if I do this? [Switches ammeter polarity so as to change the direction of needle deflection from the left of the zero to the right.]
DY5: Oh. [Said in a long drawn out manner.]
Researcher: Now what's happened?
DY5: It's where it was before. [Clear surprise in their voice.]
DY6: I know but have you done both ways? (*sic*) [DY6 who had

connected up the circuit in this group was unhappy at the alteration that the researcher had made and so reverses the polarity of the ammeter connection in order to restore the left of zero needle reading.]
DY5:It's gone up and then it's gone down.
DY6: So we've [strong emphasis on 'we've'] connected these up.
DY5: It doesn't matter which we done. (*sic*)
Researcher: So what has your practical showed you then?
DY6: We found that it goes up more before and then it goes down after so it uses quite a lot of current.
DY7: Yeah.

In addition to the problem of connecting the ammeter correctly with regard to polarity, a number of pupils also lacked the basic skill required to read it with sufficient accuracy to enable then to ascertain that the current had the same value at all points within the circuit:

FY9: It's reading the same as last time which is eight.
Researcher: How many?
FY8: That's nought point something.
Researcher: Nought point something?
FY8: Yeah.
Researcher: Nought point what?
FY8: Nought point two.
Researcher: [To FY9.] What do you think it reads?
FY9: There's one, there's five.
FY8: [Interrupting] It's nought point two.
Researcher: [To FY9.] What do you think it is?
FY9: [Shrugs to indicate that they do not know.]

Asked about this lack of proficiency, Ms Ferrensby claimed that the pupils had been explicitly taught, through the use of both a worksheet and a teacher demonstration, how to use an ammeter:

Mrs Ferrensby: Right the first lesson last week I showed them how to use an ammeter. They actually had a worksheet first of all which had various dials on and had a go at reading from them and then, that is when I had them around the front, and I demonstrated how to set it up.... I did show them, I didn't assume that they knew, I showed them exactly because an ammeter is a new word for them, a new concept, so I talked about ammeters in the lesson before this one.

Whilst there can be little doubt that pupils do need to be taught new practical techniques (Millar, 1991), such as measuring current with an ammeter to within 0.2 amps or using a millimetre scale, there is also a recognition (White, 1996) that improved proficiency with such techniques can only come about with actual practice. More recently it has been suggested (Masters and Nott, 1998) that if children are to become proficient practitioners they "need to be explicitly taught *and then* they need to practice so that techniques and tactics become implicitly known" (p. 214. Italics in original).

Indeed not only was it found that there was a need for the pupils to be taught how to use the various different types of ammeter, something that had not been done, but that they needed to be allowed to practice their technique in measuring electric current before having to use an ammeter in the context of a larger task. That is whilst pupils might be sufficiently proficient with the use of a CSZ analogue ammeter such proficiency is not necessarily directly transferable to either a LSZ, or digital, ammeter, a point borne out by the comments of one of the pupils:

> Researcher: [Points to analogue ammeter being used by the pupil.] Do you find these easy to read?
> FY9: The one I used last week [looks around the laboratory and points to a digital ammeter on the next bench] was easy because it was a bit different but this one is hard.

Whilst Ms Ferrensby was sufficiently proficient in the use of ammeters to be able to assist pupils who found them difficult to use other teachers were less able to help their pupils because they too were not proficient with all of the equipment being used. For example Dr Kepwick appeared, despite her research experience as a biochemist, to be unaware, and certainly did not inform the pupils, that the low voltage power pack being used, in addition to having an on/off switch that is illuminated whenever the device is turned on at the mains, has a re-settable fuse that can 'pop' out if too large a current is drawn. Yet with this type of power pack even if the fuse blows, preventing any current from passing through the circuit to which it is connected, the on/off switch remains illuminated as an indication that the device is still connected to the mains electricity supply. What became clear during the task was that none of the pupils, all of whom had used the device on numerous occasions over the previous two years, were aware of this fact. As a consequence of this there were pupils who continued to follow the procedural instructions through to the end unaware that, although the on/off switch was illuminated, the fuse had blown and so no electric current was flowing through their circuit. Whilst Dr Kepwick made no mention of the need to monitor the power pack at all, Mr Ulleskelf, a chemistry graduate with considerable experience, actually drew the pupils attention only to the need to " be very careful to make certain that the light [points to on/off switch] is on the lab pack" rather than of the need to monitor the fuse. The following discussion took place with two pupils who had spent most of the time allocated to the task actualisation using a power pack in which the researcher had observed that, as a consequence of the two electrodes touching soon after they had started to use it, the fuse had blown:

Researcher: What did you find?
UF14: They [the electrodes] stayed the same.
Researcher: They stayed the same?
UF15: Yes they did.
Researcher: Has that surprised you?
UF14: Yes.
UF15: Yes.
UF14: Because we thought one of them would have changed.
Researcher: Which one [points to the electrodes] did you think would change?
UF15: That one, [points to cathode] the cathode one I think
UF14: The cathode
Researcher: Would you want to do this practical again?

UF15: We did it in physics four weeks ago. [Both pupils laugh.]
Researcher: You've done the same practical, the same one?
UF15: Yeah.
UF14: Yes.
UF15: It worked that time.
UF14: It worked then.

At this point UF15, examining the circuit closely, offers an explanation for the failure of the cathode to increase in mass:

UF15: Maybe this, this [points in the general direction of the equipment] isn't working.

In response UF14, who was now also examining the equipment, refers to the fact that the on/off switch was, and continues to be, illuminated:

UF14: [Points to the power pack light.] No, because the light is on.
Researcher: Was the fuse in? [The fuse had 'popped' out, having blown previously, and needed resetting.] The light will stay on even if the fuse is out.
UF14: Ah. [Apparently unaware of this fact.]
UF15: Oh.

Similarly, despite the fact that Dr Kepwick moved from group to group – including groups in which the fuse had clearly blown - she seemed unaware of this problem. It became evident, when the pupils were questioned, that they had received no instruction in the basic use of the power packs:

Researcher: Ah you've got no power. [The pair had attracted one paper clip with a coil having two turns and no paper clips with a coil having either ten or twenty turns.] Now this thing here [points to the fuse button] is called the fuse and when it pops out there's no electricity going through it. [Researcher resets fuse and, in so doing, the twenty turn coil attracts four paper clips lying near to it.]
KK9: It works, it works.
KK10: [Hops about excitedly]

Two pairs of pupils, who had just been visited by Dr Kepwick, were then questioned:

Researcher: Your fuse has also popped out [points to fuse]. Did you notice that your power pack's not working? Have you not used this power pack before?
KK17: We have, but no one's ever told us that before.

Researcher: [Points to the blown fuse on their power pack.] Do you know what that black button sticking out is on the power pack?
KK11: [Reading the label above the button.] Reset.
Researcher: It means it's not working. So how long have you been doing your experiment without knowing that the electricity wasn't going through the electromagnet?
KK12: That must have just happened.
Researcher: No it only happens when the power was on. [The power pack was now turned off.]
KK11: [Turns on power pack and points to the illuminated on / off Switch.] See?
Researcher: No that light will be on even when that's [points to fuse button] out.

It also emerged that Mrs Kettlesing had introduced Dr Kepwick's Year 9 class to the use of the power pack during a lesson on making an electromagnets similar to the one observed in this study with Year 7 pupils (case study 12). Yet in this study, when Mrs Kettlesing introduced her current Year 7 pupils to the power pack for the first time, she made no mention about the fuse, its purpose, or how to re-set it. Indeed, in a manner reminiscent of Dr Kepwick's Year 9 class, the fact that the fuse had, unbeknown to some of the pupils, blown during the observation of the magnetic field generated by a coil with only a few turns meant that the larger coil, when subsequently tested, did not generate any magnetic field. This led some pupils to reject their initially correct hypothesis:

KG11: I thought the bigger one would work more.
Researcher: Why?
KG11: Because.
KG12: It's more…
KG11: Because you'd think it'd have more magnets, more magnetic, because it's bigger.
Researcher: So what have you learnt from this practical?
KG12: Little coils make better magnets out of electricity.

Even a very basic practical task, such as the one designed by Mrs Risplith, a biology graduate, to enable academically low ability Year 9 pupils to see that heart rate and pulse were the same, was ineffective because the pupils lacked sufficient proficiency with the use of a stethoscope and/or the technique to locate their own pulse that was needed to generate successfully the required data:

> Researcher: Did you manage to hear your heart beat with a stethoscope?
> RH6: Well ours certainly…
> RH7: [Interrupts.] No.
> RH6:…was certainly got bust (sic) we never heard no der-der-dum.
> Researcher: [Having checked that the stethoscope is working.] You didn't manage to hear it?
> RH6: Bloody waste of time.
>
> Researcher: What have you found?
> RH9: Nothing yet because I can't find my pulse. [The researcher demonstrates how to find a pulse.] Oh yeah.

The reason why pupils failed to produce the desired phenomenon was not that the use of stethoscope and/or the technique to locate their own pulse was an unduly difficult skill for the pupils to master. Indeed the researcher had found it relatively easy to teach the pupils how to do both. Rather the ineffectiveness of the task arose because Mrs Risplith had assumed that the use a stethoscope, a new and previously unused piece of equipment, and the location of a pulse, something that she did not ascertain that the pupils actually knew how to do, were so simple to use/do that specific instruction and practice were not needed before the pupils used both to generate the desired data.

In a similar manner Mrs Ugthorpe had also assumed that the use of chemical indicators to test for starch, protein and fat were so basic that, provided instructions were given to the pupils on how to use them, there was little need for any prior familiarity with their use. However, what was found was that the pupils' lack of familiarity with these indicators meant that what should have been a relatively quick and simple task, involving little more than commonsense, took an entire lesson in which many of the pupils failed, not only to complete the tasks, but also to see the desired phenomena:

> Researcher: So what have you got in there? [Points to a tray in which the pupils have been observed to mix iodine and starch solutions.] Explain to me.
> UE3: We've got some iodine solution and some of that stuff. [Points to bottle of starch solution on the Mrs Ugthorpe's bench.]
> Researcher: Iodine and starch [solutions] mixed together. Right so you've got a little tray of iodine and starch [already mixed together] and you're dripping that onto your bread.
> UE4: Yeah.
> UE3: Yeah.
> Researcher: And what's that going to tell you?
> UE4: I haven't got a clue.
>
> Researcher: Right, what's in there?
> UE6: It's two drops of iodine solution and the starch solution.
> Researcher: So you've mixed the iodine and the starch solution and you've got this nice [points to tray with bluish/black solution] and now you're adding your chocolate to it. Is that what you're meant to do?
> UE6: Yeah.
> UE7: Yeah, that's what we were told to do. [Mrs Ugthorpe had given no such instruction.]

Because the sole aim of the task used by Mrs Ugthorpe was for the pupils to produce and see the positive test results the lack of pupil proficiency in this task had the most noticeable effect on the overall effectiveness of the task in terms of getting the pupils to do what the teacher intended them to do with observables.

5.2.3 The unproblematic functioning of equipment

Even if the pupils are proficient in the use of the equipment they can still be hindered or prevented from doing what the teacher intended them to do if some of the equipment that they require for the task fails to function as it is designed to do. Here it must be stressed that such failure does not refer to any relatively small proportion of equipment that might, in any practical lesson, reasonably be expected either not to work or to malfunction. Indeed it might be expected that part of the role of the teacher (and in some cases the laboratory technician) during a practical lesson is to repair or replace those items that do fail or malfunction to ensure that they do not prevent the pupils from doing what is intended. Whilst equipment failure can occur in biology and chemistry, for example yeast can fail to activate and burette taps can leak it is in physics, with its dependency on a greater number of different pieces of apparatus, in which more failures might be anticipated. In this study, all of the equipment failures that were observed related to a relatively small number of basic pieces of apparatus such as bulbs, plotting compasses, ammeters, voltmeters and crocodile clips and all occurred within physics activities. Whilst such failures were relatively common they tended only to involve a relatively small proportion of the equipment provided. It was only in one task, that designed by Mrs Kettlesing to enable an academically mixed ability class of Year 7 pupils to observe that a current carrying coil of wire generates a magnetic field, that a large proportion of one particular piece of apparatus - the plotting compasses – were found to have failed. It was only because the pupils already expected the coil to act as a magnet when electric current passed through it that meant, when a plotting compass was not deflected when placed next to a current carrying coil, that they immediately suspected a faulty plotting compass rather than doubting that the coil had become magnetic. From the researcher's perspective, had the pupils not been expecting to see the plotting compass change direction, it is highly unlikely that many of the them would have discovered that the coil had become magnetic, simply because the vast majority of the plotting compasses provided were faulty:

KG9: Ours isn't working.
KG10: No, we can't get it to work.
KG9: It's either our battery, or our compass, aren't working on it.
Researcher: What should it do?
KG9: That [points to plotting compass] should change around.
KG10: It's just not moving and we've tried three or four compasses.
Researcher: Try using his compass, [points to another pupil], because I saw his work just before. [KG10 goes and borrows the pupil's compass.]
KG9: Ah, that's working.

Yet despite the fact that Mrs Kettlesing was clearly aware that "you've got the problem [points to a full box on her desk labelled 'faulty compasses'] with the plotting compasses that die on you" she chose not to forewarn the pupils about this. Generally speaking it was found that equipment failure was more prevalent in physics than in either biology or chemistry, a finding that seems to reflect the well known maxim that, 'if it looks horrid it's biology, if it smells horrid it's chemistry but if it doesn't work it's got to be physics'. Whilst it is possible that it was a feature of this particular sample of lessons, that all of the equipment failures involved only electrical apparatus, it is, in the opinion of the researcher, more likely to reflect the fact that the type of apparatus used in this area of physics is less robust and, as a consequence, is more susceptible to failure. Whilst equipment failure was sometimes frustrating for the pupils it tended only to slow down their progress rather than actually prevent them from successfully doing what the teacher intended them to do with the objects and materials provided.

5.2.4 Phenomena and their ease of generation

Even if pupils understand what they are required to do and are sufficiently proficient in the use of the equipment, all of which is in working order, they may still fail to do what the teacher intended unless the phenomena themselves are reasonably easy to generate or observe. Although it has been claimed (Hacking, 1983) that phenomena are inherently difficult to produce within the science research laboratory no appreciable difficulty was observed in any of the observed tasks at Key Stage 3 and 4 and if such a difficulty were to occur it might be expected to present more of a problem in practical tasks at 'A' level. Within the present study no phenomena were, in the opinion of the researcher, unduly difficult to generate although those associated with two tasks could be classified as being slightly problematic. There was no evidence, in any of the observed tasks, of teachers fraudulently producing the desired results, what has been termed "conjuring" (Nott and Wellington, 1997 p. 396). Likewise whilst some teachers openly, and judiciously, determined the value of variables to maximise the likelihood that the task would produce the desired result this differs appreciably from "rigging" (Nott and Wellington, 1997 p. 396) in which the adjustment of the variables is evidently made surreptitiously "we have heard of teachers doping water with sodium bicarbonate and/or using "grow lights" in photosynthesis experiments so that oxygen is reliably yielded" (p. 396).

The first of these two slightly problematic tasks was taught by Mr Oldstead, a biology graduate, that required Year 8 pupils to heat a sample of a waxy material, contained in a boiling tube, in a water bath to a temperature above its melting point. Having melted, the wax was to be removed from the water bath and its temperature recorded every minute as it was allowed to cool to room temperature and, in so doing, resolidified. The data collected was to be used to plot a change of state cooling curve, in which the teacher anticipated that a distinctive temperature plateau would be visible. Whilst the plateau can emerge as little more than an inflection in the cooling curve it is possible to ensure a more pronounced plateau through a judicious choice of the amount of solid to be used. That is the amount of material must be determined so that there is sufficient wax to prevent it from cooling too rapidly – a fact that results in little more than an inflection in the cooling curve - but not too much to prevent the liquid from completely solidifying within the time (approximately sixty minutes) allocated to a typical double lesson. This particular problem is, in the experience of the researcher, usually avoided by having a laboratory technician prepare the boiling tubes with the appropriate quantity of material before the lesson. Another problem that can occur is that the material can be heated to a temperature considerably above its melting point thereby extending the time required to cool and solidify beyond that available. However, the likelihood of this occurring can be reduced if the procedural information clearly states the temperature to which the material is to be heated before allowing it to start cooling, an approach used by Mr Oldstead:

> Mr Oldstead: Hopefully the temperature of the wax by the time you've heated it in pretty hot water will have reached about seventy or eighty degrees. So just make sure it's seventy to eighty degrees at the start. And then at the start of the experiment take it out. So just make sure it's seventy to eighty degrees at the start.

It was not possible to assess the extent to which the pupils undertaking this task had been able to generate the desired cooling curve plateau. This was because, rather than instructing the pupils to plot the cooling curve as they collected the data, Mr Oldstead had instructed them to collect all of the data first and, since this took most of the lesson, there was insufficient time before the end of the lesson for them to plot the cooling curve.

The second task, taught by Mr Ulleskelf, required the pupils to measure the change in the mass of the cathode and anode as a result of electrolysis. Whilst the pupils can, if proficient with the use of a top-pan balance, measure the resultant changes in the mass of the cathode and anode, problems can occur. The copper, which is deposited on to the cathode, can flake off during electrolysis and/or be inadvertently wiped off if the pupils dry the cathode prior to placing it back on the balance. There is also the potential problem that the anode can break up during electrolysis, making it difficult for the pupils to ascertain the total mass that remains. These problems, if left unresolved, can make it problematic for the pupils to obtain readings that are accurate enough to show that the loss in mass of the anode is equal to the gain in mass of the cathode:

> Researcher: What did you find?
> UF16: Got heavier.
> Researcher: Which one?
> UF16: Both of them.
> Researcher: Both of them?
> UF17: We think our results are a little bit wrong.
> Researcher: Why?
> UF17: Because we don't think they're meant to both, to gain the same amount.
>
> Researcher: What did you find?
> UF10: I don't know. [Points to bottom of beaker.]
> Researcher: Oh, it's at the bottom, [points to anode that has broken up and is now in pieces at the bottom of the beaker], so you haven't reweighed it?
> UF10: No, not yet.
> UF11: The problem is we can't reweigh it because that thing's snapped.

However, the likelihood of these problems occurring can be reduced if the procedural instructions stipulate clearly, as did those provided by Mr Rainton who undertook a similar, although not identical, task, that the supply voltage needed to be relatively low, the electrodes were not to be disturbed during the electrolysis process and that the drying of the electrodes was to be undertaken with great care:

> Mr Rainton: To work properly you've got to reduce the voltage so put it down to two volts....you've not got to move it, so once it's set up I want you to leave it there... Just put it onto the paper towel and just dry it a little bit, don't do anything else. Put it onto the paper towel, just dry it a little bit, don't [the word is strongly emphasised] rub it just leave it on the paper towel.

Both these tasks, whilst slightly more challenging than the others within the study, can, if the pupils are provided with sufficient procedural information, be used successfully to generate a desired phenomenon. Indeed, were they not a relatively reliable means of generating particular phenomena, it is highly likely that teachers would have ceased to use them.

5.3 Task closure

How teachers attempted to ensure that the pupils successfully did with the objects and materials what was required of them is the issue to which I now turn. A central feature of the lessons observed in this study has been the widespread use of what have been referred to as "cookbook" type (Tobin et al., 1994 p 51; Woolnough and Allsop, 1985 p 80), or "recipe" style (Clackson and Wright, 1992 p 41) tasks in which the focus is on the need to adhere rigidly to a set procedure in order to successfully generate a desired phenomenon or set of data:

> Laboratory activities tended to be of a "cookbook" type, with strong emphasis on following procedures in order to collect data. There was little emphasis on planning an investigation or on interpreting results. Teachers provided the procedures to be followed and a table in which to record data. Recipes for most experiments were in the textbook, in a manual, or on the chalkboard. (Tobin et al., 1994 p 51)

In order to analyse the extent to which different aspects of a recipe style task were open or closed, use was made of the practical task profile form developed by Millar et al. (1999). Within this profile form the degree of openness/closeness of a task is considered in terms of how much, or how little, responsibility for decision-making is transferred, by the teacher, to the pupils in terms of five specific issues:

(i) The question to be addressed and/or phenomenon to be generated.

(ii) The equipment to be used.

(iii) The procedure to be followed.

(iv) The method for reporting phenomena and/or handling any data collected.

(v) How the results are to be interpreted.

Using this task profile form means that the openness/closeness of a task can be thought of in terms of a continuum in which a task is said to be fully open, if complete responsibility for all of the five issues is transferred to the pupils, and completely closed if responsibility for all five is retained by the teacher. Between these two extremes there exists a range of possibilities in which partial responsibility for all, or some, of the issues and/or full responsibility for some of the issues is transferred to the pupils through the process of teacher-pupil discussion.

Before proceeding further it is necessary to distinguish between the transfer of actual responsibility and, what might usefully be termed, pseudo-responsibility. Within the context of this study the transfer of actual responsibility necessitates allowing the pupils to make decisions that have the potential to affect the effectiveness of the task. In contrast pseudo-responsibility transfers to the pupils responsibility for decisions that, whilst affecting the task in a superficial manner, have no potential to impact upon the effectiveness of the task itself. Two case studies that involved the chromatographic separation of inks are examples in which the teachers transferred pseudo, as opposed to actual, responsibility. In both tasks whilst the pupils were given responsibility for selecting a particular dye both teachers knew that, in terms of their suitability for generating the desired phenomenon, all of the dyes were reliable. In this respect, whilst the pupils' choice could affect the characteristics of the specific separation pattern that they would generate, it did not have the potential to affect whether or not the task was effective in enabling them to see the general phenomenon of separation.

5.3.1 The question to be addressed and/or the phenomenon to be generated

It was found in this study that the pupils were never given any responsibility for determining either the question to be addressed and/or the phenomenon to be generated. Frequently the explanation for this was that the teacher wanted to adhere to a particular scheme of work in which a practical task was the proposed method of addressing a particular question since they saw it as providing a particular advantage:

> Mr Overton: Yeah particularly the, I mean they're now structuring [commercial work sheets] so they have an analysis and evaluation section. I mean these are the new activity sheets from Heinemann so obviously this is going to give them an advantage later on and so by year 10 and 11 they'll know what an analysis is although I didn't actually say "this is what an analysis is" or "this is what an evaluation is".
> Researcher: So it's all part of a preparation...
> Mr Overton: [Interrupting.] Yeah for course work at GCSE.

However, whilst most of the teachers who used schemes of work and/or worksheets did so because they themselves wanted to, this was not always the case. In two cases teachers were required by their head of department to use a particular scheme of work even when, in one case, the teacher concerned specifically requested that she be allowed to use what she felt to be a more effective approach to teaching the material concerned:

> Mrs Ugthorpe: I asked the head of department to do the basic tests as a demo that would take ten minutes… but they said; "No, no, no, the kids enjoy doing it, the kids want to be doing it."
> Researcher: But if those basic tests weren't in the departmental scheme of work? [Devised and written by the head of department.]
> Mrs Ugthorpe: I wouldn't want them.

The adherence to a scheme of work was typical of the approach adopted by many teachers in the study; particularly those teaching outside of their subject specialism. Such an approach enabled them to devolve responsibility for the question to be addressed and/or phenomenon to be generated (as well as other issues relating to the task) on to a departmentally accepted scheme of work whilst retaining responsibility for ensuring that appropriate material was taught in their lesson:

> Researcher: Why did you choose to do this as a practical?
> Mrs Ramsgill: It was part of the new scheme of work [a commercially produced scheme that the department had recently purchased]we are now using.
> Researcher: So it wasn't really your choice?
> Mrs Ramsgill: No, no it wasn't.
> Researcher: Is that the same for the work sheets?
> Mrs Ramsgill: Yes, they are part of the same scheme.

Mrs Ugthorpe: Oh yes, it's all in the scheme of work that they have to do food tests.
Researcher: So is the choice of using a practical, or not using a practical, determined by you or the scheme of work?
Mrs Ugthorpe: By the scheme of work.

Possibly, although unsurprisingly, it was found that the common requirement to cover the content specified by the National Curriculum meant that teachers from different schools were employing the same practical tasks (Wellington, 1998), and in some cases the same commercially produced work sheets, in order to address identical questions and/or to generate the same phenomena. That is whilst the questions to be addressed were, in all of the case studies, completely closed, the responsibility for the actual choice of a specific question and/or phenomenon to be generated, and this was particularly the case with teachers teaching outside of their subject specialism, lay not with the individual teacher but with the scheme of work being followed. Indeed it can be seen (Table 5.4), that compared to four out of the nine teachers teaching in their subject specialism who followed a scheme of work, this rose to ten out of sixteen when the teachers were teaching outside of their subject specialsim. Whilst acknowledging the relatively small size of the sample (N = 25) this represents an increase from 44 % to 63% respectively. Similarly whilst only two out of nine, or 22%, of teachers teaching within their subject specialism used worksheets, this rose to seven out of sixteen, or 44%, for those teaching outside of their subject specialism.

Table 5.4 The use of schemes of work and worksheets by teachers teaching in and out of their subject specialism

Teaching within their subject specialism: Yes / No	Following a scheme of work: Yes / No	Using a guiding worksheet: Yes / No	Task
Yes	Yes	Yes	20
Yes	Yes	Yes	23
Yes	Yes	No	18
Yes	Yes	No	25
Yes	No	No	4
Yes	No	No	12
Yes	No	No	16
Yes	No	No	21
Yes	No	No	22
No	Yes	Yes	1
No	Yes	Yes	6
No	Yes	Yes	8
No	Yes	Yes	10
No	Yes	Yes	15
No	Yes	Yes	17
No	Yes	No	2
No	Yes	No	7
No	Yes	No	9
No	Yes	No	13
No	No	Yes	11
No	No	No	3
No	No	No	5
No	No	No	14
No	No	No	19
No	No	No	24

In addition, the frequently observed need to pre-book all of the equipment for a particular task, sometimes up to a week in advance, meant that even if a teacher had wanted to transfer responsibility for the question to be addressed to the pupils, it was unfeasible to do so, since there was no opportunity to change the equipment from that booked, in the light of any suggestions that the pupils might make.

5.3.2 The equipment to be used

Responsibility for the choice of the equipment was, in all cases, fully retained by the teacher. The main reason for this was that once the teacher had decided on the task to be undertaken, either for themselves or as a consequence of their adhering to a particular scheme of work, they had to ensure that the equipment necessary for that task was booked so as to ensure its availability for the lesson in question. It was observed that in all of the case studies most of the equipment required for a particular task was prepared, and brought into the laboratory usually in trays or on trolleys, by the laboratory technicians before the start of each lesson. With all of the equipment necessary for a particular task available within the laboratory, the teacher had to draw the pupils' attention to where specific pieces of equipment were to be found, a task that usually occurred during the task presentation stage of the lesson:

> Mr Drax: I'd like you to use the stuff on the front [points to front bench] the hardware, the Bunsen's, your goggles of course, things like that are on the front.
>
> Mrs Ferrensby: Ok the apparatus is exactly where you found it last week [Points to a trolley at the side of the laboratory.] I'll put the power packs at the side. [Points to desk at side.]
>
> Mr Dacre: Now it's going to be crowded along here, [points to bench with all of the materials set out for the pupils] so be patient everything's there.

In four cases whilst the teachers; Mr Overton, Miss Nunwick, Mr Saltmarsh and Mrs Ugthorpe retained full responsibility for the equipment used the pupils were allowed to select which of certain materials they would use within these tasks. In the sense that the teachers did not envisage that the pupils' selection of materials would affect the effectiveness of the task, in terms of the generation of the desired phenomena, but only the characteristics of the phenomena, the intention in each case was only to transfer pseudo-responsibility. Whilst Mr Overton, Miss Nunwick, Mr Saltmarsh, provided a range of materials, all of which were known to generate reliably the desired phenomena, from which the pupils were required to make their selections, Mrs Ugthorpe had asked the pupils to select their samples from foods that they had at home and to bring these into the laboratory. Despite the opportunity to take responsibility for part of a practical task, many of the pupils appeared, having forgotten to bring in any food samples from home, to have collected a selection of vegetables from the school canteen. Whilst Mrs Ugthorpe had evidently expected that the pupils would bring in a wide variety of foods that would have allowed them to observe positive test results for protein, starch and fat, the fact that many of the samples used were foods such as carrot, lettuce, radish and cucumber meant that many pupils were unable to generate the desired phenomena for themselves and so the effectiveness of the practical task was adversely affected.

5.3.3 The procedure to be followed

In all of the tasks observed the procedure to be followed was fully determined by the teacher with the pupils required to adhere to the "recipe" (Clackson and Wright, 1992 p. 41). Teachers saw this adherence to a set of procedural instructions as essential if the pupils were to be able to do what was required of them in the time available:

> Mr Sewerby: Right we've got a heck of a lot to do today. I'm going to give you a lot of instructions. I need you to listen to them, assimilate them, you know straight away. I haven't got time to repeat myself.

Whilst the teachers frequently emphasised the need to work quickly there was no evidence to support the claim by Edmondson and Novak (1993) that the pupils themselves worried about time management. Indeed, even in those cases where it transpired that there was insufficient time to complete all aspects of the task, this fact had to be brought to the attention of the pupils by the teacher.

Whilst the duration of lessons varied slightly from a minimum of fifty-five to a maximum of sixty minutes (a few teachers exceeded the allocated lesson time but by no more than four minutes) and different teachers allocated different amounts of time to different parts of a lesson, most used a five stage generic lesson structure:

1. Registration: The period of the lesson devoted to the formal taking of a register and recapping material covered in previous lessons.
2. Presentation: The period of the lesson from being introduced to the practical task to being told to collect the equipment.
3. Actualisation: The period of the lesson between collecting and packing away of the equipment.
4. Summary: The period of the lesson used by the teacher to summarise the task.
5. Other: Any period of time during, or after the practical task itself, devoted to other matters e.g. writing up, filling in work sheets or beginning a new topic.

The most frequently observed variation to this five-stage structure occurred when, in four of the lessons, the teachers chose to provide no summary either during, or at the end of, the task. Even in the two cases in which the teachers chose to divide the lesson into a number of smaller sub-units, the teachers used the same five-stage structure for the first sub-unit after which the structure was repeated without the initial first stage.

5.3.4 The method for handling data and/or recording phenomena

When the pupils were required to handle data and/or record phenomena the method to be used was, in almost all of the tasks observed, decided by the teacher. It can be seen (Table 5.5) that of the fourteen tasks observed, in which the pupils were required to handle numerical data, all specified where the data was to be recorded. Of these thirteen tasks seven also specified the structure that was to be used for recording the data. The most frequent approaches observed involved the teacher either providing a worksheet, in which space for numerical data was provided, or the table structure to be used for recording data was drawn on to the board, during the task presentation, and the pupils were required to copy this down and use it. It should be noted that in the six tasks in which the structure for recording the data was not specified the pupils had been informed that they would need to record the specified data for use later in the lesson and, in these cases, the pupils recorded the very basic numerical data as a list.

Table 5.5 Tasks in which pupils were required to handle numerical data

Teacher	Is the data to be recorded in a specified place e.g. exercise book / worksheet? Yes / No	Is the structure for recording the specified or provided e.g. on a worksheet? Yes / No	Is the data required in that lesson for a specific purpose e.g. calculations / discussion / obtaining a class average? Yes / No	Are pupils required / expected to draw a graph of their data? Yes / No	Are pupils provided with instructions on how to draw the graph? Yes / No
Mrs Duggleby	Yes	Yes	Yes	No	No
Ms Ferrensby	Yes	Yes	Yes	No	No
Dr Kepwick	Yes	Yes	Yes	No	No
Mrs Kettlesing	Yes	Yes	Yes	No	No
Miss Kilburn	Yes	Yes	Yes	No	No
Mrs Ramsgill	Yes	Yes	Yes	No	No
Mrs Uckerby	Yes	Yes	Yes	No	No
Mr Normanby	Yes	Yes	No	No	No
Mr Oldstead	Yes	No	Yes	Yes	Yes
Mr Drax (Y7)	Yes	No	Yes	No	No
Mrs Risplith	Yes	No	Yes	No	No
Miss Sharow	Yes	No	Yes	No	No
Dr Starbeck	Yes	No	Yes	No	No
Mr Ulleskelf	Yes	No	Yes	No	No

It should however be pointed out that although Mr Oldstead instructed the pupils to draw a graph of their data, in order to see the temperature plateau, this was abandoned when it became evident to him that the data collection phase was going to require all of the available lesson time.

In the eight tasks in which the pupils were required to record non-numerical details of the phenomena observed, it can be seen (Table 5.6), that both where the information was to be recorded, and the manner in which was to be done, was fully specified by the teachers.

Table 5.6 Tasks in which pupils were required to record details of a phenomena

Teacher	Is the record to be made in a specified place e.g. exercise book / worksheet? Yes / No	Is the manner in which the record is to be made specified or provided e.g. on a worksheet? Yes / No	Is the record required for a specific purpose in that lesson e.g. discussion? Yes / No	Are pupils required / expected to write-up the entire task? Yes / No	Are pupils provided with instructions on how to write up the task? Yes / No
Mr Sewerby	Yes	Yes	Yes	Yes	Yes
Mr Rainton	Yes	Yes	Yes	Yes	No
Mr Dacre	Yes	Yes	Yes	No	No
Miss Kilburn	Yes	Yes	Yes	No	No
Mr Normanby	Yes	Yes	Yes	No	No
Mr Overton	Yes	Yes	Yes	No	No
Mr Drax (Y10)	Yes	Yes	No	Yes	Yes
Mr Keld	Yes	Yes	No	No	No

5.3.5 How the data and/or phenomena are to be interpreted

The interpretation of the results was normally provided by the teacher and took place during the task summary. Although teachers frequently tried to use results obtained by the pupils, these were judiciously selected to ensure that they corroborated the scientific interpretation and/or explanation of the data that the teacher wanted to present. The more effective the task at getting the pupils to produce the phenomena, or generate the data, the larger the pool of 'correct' results that were available for the teacher to draw on and the more discerning they could afford to be. In the case of Dr Starbeck almost every pupil got the results he wanted and the results that he selected to use as class examples were chosen because of his desire to use results in which a mathematical relationship was as clearly evident as possible:

> Researcher: Now I don't know if you were lucky or whether you picked those results?
> Dr Starbeck: No I picked those results. I selected those results very carefully.
> Researcher: Were they genuine results obtained by some of the pupils or did you…
> Dr Starbeck: [Interrupting] No, no they are genuine results but I picked them to use as examples.

In contrast the fact that almost all of the pupils did not succeed in generating the desired phenomenon in a task designed to investigate the requirements for starch production in green leaves meant that Mr Sewerby had no alternative but to use the results of the one pair of pupils who had managed to generate the desired phenomenon. In order to justify the scientific interpretation that he wanted the task results to reinforce, Mr Sewerby had to account for the overwhelming number of results that did not generate the desired phenomena, what Nott and Wellington (1997 p. 396) refer to as "talking your way through it":

> Mr Sewerby: [Examining the leaf] That's it, I think that's what's happened, [points to slight marks on the leaf] you can almost see, you know, the shape of these leaves, kind of like little round bits. If you look at that [points to a vague mark on their leaf] you can almost see where the little round bits [the shadow cast by another leaf]. That's what might have happened with that. But that, [places a spotting tile from another pair of pupils on which is a leaf that illustrates a good result next to their result] what, cor. Ah, how disappointing for you. [Points back and forth between the good result and the one they had produced to emphasise the difference]. But that [points directly at the good result] is superb isn't it?

During the brief summary at the end of the lesson, the general lack of success on the part of the other pupils was explained, not on the basis that the procedural information that he had provided had lacked sufficient detail on leaf selection, but on the unpredictable nature of biology *per se:*

> Mr Sewerby: Sometimes things don't work out like you want them to, that's biology for you. I always envy physicists because you know when strings stretch they do it in hugely predictable way. When you drop things they accelerate in a hugely predictable way. But in biology things don't happen, it's living things, they're vicarious (sic) aren't they.

In effect what emerged was that, whilst teachers did attempt to use results generated by the pupils themselves, they were used very selectively and in such a way as to ensure that they corroborated the interpretation that the teacher wanted to provide.

5.3.6 Doing with objects and materials: A summary

Despite the sometimes competing pressures on science teachers to educate and motivate (Lunetta and Tamir, 1979) and the fact that closed 'recipe' style tasks are likely to be perceived as dull and demoralising (Arons, 1993) and are unlikely to be perceived as either meaningful or engaging (Wallace, 1996) all of the tasks observed were at, or close to, the closed end of the continuum. Some of the teachers explained this use of closed tasks on the basis that there was, in their view, simply insufficient time, within a typical hour long practical lesson, to be confident that most of the pupils, irrespective of their academic ability, would successfully design, set-up and produce a particular phenomenon and analyse the results, if the task were presented in an open and unstructured manner:

> Mrs Ramsgill: There just isn't time in an hour to do a proper [fully open] practical. You just can't do it.
>
> Miss Kilburn: We tend to do less open investigations, that I think the kids prefer, because we don't have the time.

In addition, whilst there was no evidence to suggest that teachers saw the successful generation of a particular phenomenon as the sole aim of any practical task, the point was made that tasks were, in fact, frequently designed to maximise the likelihood that the pupils undertaking the task would generate a particular phenomenon within a particular lesson:

> Mr Normanby: Often the practicals are designed to be pupil friendly. You know, to make sure that within your double they'll see, at least most of them will, what you want.
>
> Dr Kepwick: I think they need to come in, be told how to do it, and get a result.

The fact that *all* the tasks were closed, and in most of these the pupils succeeded in doing with the objects and materials what the teacher intended, strongly suggests that the teachers saw the effective generation of a particular phenomenon, and/or set of results, by the majority of their pupils as being their first priority.

5.4 Doing with ideas

Practical tasks, as Millar et al. (1999) have pointed out "do not [or should not] only involve observation and/or manipulation of objects and materials. They also involve the students in using, applying, and perhaps extending their ideas" (p. 44). Having analysed what pupils did in the domain of observables, I now want to consider what they did in the domain of ideas. Whilst 'doing' with objects and materials are relatively self-explanatory, what 'doing' with ideas means is less obvious and needs to be clarified before proceeding further. The theoretical 2 x 2 matrix representation of practical work, discussed previously in chapter 3, distinguishes in the horizontal dimension between *doing* and *learning* and in vertical dimension between *observables* and *ideas*. In this context the two quadrants on the right-hand side of the matrix refer only to ideas that, in contrast to observables, cannot be directly measured or observed. Doing with ideas therefore refers to the process of 'thinking about' objects, materials and phenomena in terms of *theoretical entities that are not directly observable*. Clearly not all thinking is synonymous with 'doing with ideas' – far from it. For example whilst a pupil can observe, and think about, the readings on a voltmeter in terms of *observables* – in this case numbers on a scale - thinking about those readings in terms of their being a measure of the voltage – a non-observable property of batteries and other circuit components – is what constitutes 'doing' with ideas.

Having clarified what doing with ideas entails it is important to remember that task effectiveness, in the context used here, is a measure of what pupils do with ideas relative to what the teacher intended them to do with them. Although Millar et al. (1999) have pointed out that "the selection of features to *observe* and record is inevitably influenced by the teacher's and/or the student's ideas about the task" (p. 44. Italics added), the issue here is not what ideas influenced the pupil's selection of what to observe, as this was largely done by the teacher as discussed earlier, but whether, having made their selection, they thought about their observations using the ideas intended by the teacher. In this respect whilst the pupils can think about a task in any way that they wish, the task only has the potential to be effective (or ineffective) if the teacher actually *intends* the pupils to think about the observables using specific ideas.

5.4.1 Evidence for doing with ideas

Before proceeding further it is important to recognise that because ideas, unlike objects and materials, cannot be observed, evidence of the ideas that the teacher intended the pupils to use, and whether or not the pupils used those ideas, had to be inferred mainly from what they were heard to say. In this respect what pupils say and how they say it is an indication not only of the ideas that the pupils are using to think about the task but how those ideas are being presented to them by the teachers. Whilst pupil actions can also be indicative of what they were thinking, any inference from observed action to implied thought would essentially have necessitated the researcher in second guessing the very issue that was being investigated, namely what the pupils were thinking.

Since what pupils say is important in assessing whether or not they used the ideas intended by the teacher, their comments were assessed using a five-point scale. The scale ranged from lack of any appreciable use of scientific terminology (level i) to the full and coherent use of scientific terminology in discussing all aspects of the task (level v). In addition the scale also distinguishes between talk that relates solely to observables (levels i-iii) and talk that also relates to doing with ideas (levels iv-v) (Table 5.7). It is however important to stress that whilst the use of scientific terminology provides a useful guide to the ideas that the pupils might be using it does not mean that pupils who express themselves solely in terms of colloquial terminology are not thinking about the task. What it does mean is that those pupils are, for whatever reason, unfamiliar with the accepted scientific terminology.

Table 5.7 Scientific terminologies: Different levels of use

Level i	Pupils do not use even basic scientific vocabulary but talk about all aspects of the task using colloquial terminology.	SH4: That purple colour sucks all the water, the water goes up, meets the black blobs, and it separates all the colours in the ink. KN10: We've got to identify which one's got Vaseline on and which one hasn't.
Level ii	Pupils use scientific vocabulary only to identify specific observables.	OD3: Can we have a heatproof mat? UF2: It's copper sulphate solution. UE2: It's iodine solution with starch.
Level iii	Pupils use scientific vocabulary only when talking about observables and procedures.	DE17: Copper sulphate and ammonia, well we didn't have the ammonia, so we just heated the copper sulphate. NK5: Like you've got a delivery tube which went down into a beaker which had a test-tube in.
Level iv	Pupils use scientific terminology when talking about observables and procedures and a mixture of scientific and colloquial terminology when talking about ideas	RN15: All the copper will get attracted to it 'cause it's negative, so it'll like it. FS12: The water's going to evaporate and the salt's going to be left behind. Researcher: Left behind? FS12: It's too heavy.
Level v	Pupils use scientific terminology when talking about all aspects of the task.	Researcher: What type of circuit is this? SK18: It's a series circuit. Researcher: So what's the voltmeter measuring? SK22: How much energy is going in and how much energy is coming out. Researcher: And what will that tell you? SK22: How much energy it has lost.

This scale also provides a means of analysing whether the method of task presentation, in terms of any difference in emphasis placed by the teachers on getting pupils to do with objects and materials compared to getting them to do with ideas, is reflected in the language levels subsequently used by the pupils.

5.5 What is required if pupils are to think about the observables using specific ideas?

Getting pupils to think about objects, materials and phenomena, in terms of specific ideas can be difficult, if for no other reason than the fact that ideas do not present themselves directly to their senses. If, in the researcher's own teaching experience, the issue of pupil motivation (which will be considered in chapter 7) is put to one side, then there are two requirements that need to be met if a task is to be successful in getting the pupils to think about the observables in terms of ideas and/or models:

(i) The pupils must be familiar with, and know how to apply, the ideas that the teacher intends that they use to think about the observables.

(ii) The task must provide the opportunity for pupils to think about the observables using scientific ideas and/or models appropriate to the age range of the pupils undertaking the task.

Whilst the second of these requirements is a characteristic of the task itself and is, therefore, something over which the teacher has little influence the former is certainly something over which the teacher can exercise considerable control. However, despite the fact that the overwhelming majority of tasks in this study provided an opportunity for pupils to think about observables using specific scientific ideas, many of the pupils were observed, during the course of the observation, to be unfamiliar with the ideas that the teacher intended them to use. This disparity between the extent to which the observables could be thought about using such ideas and, where appropriate, the extent to which the pupils actually appeared familiar with those ideas can be seen in table 5.8.

Table 5.8 Extent to which observables could be thought about using scientific ideas

Could the observable features of the task be thought about using scientific ideas / models appropriate to the age range of the pupils? Yes / No	To what extent were the pupils familiar with the ideas that the teacher intended them to use to think about the observables? Inapplicable/ Fully / Partially	Teacher	Task
No	Inapplicable	Miss Nunwick	Chromatography - separation of inks
No	Inapplicable	Mr Saltmarsh	Chromatography- separation of inks
No	Inapplicable	Mrs Ugthorpe	Food tests – test results
Yes	Partially	Mr Dacre	Chemical reactions – how to identify
Yes	Partially	Mr Drax	Heat absorption – colour as a variable
Yes	Partially	Mr Drax	Acid + Base = Salt + Water
Yes	Partially	Mrs Duggleby	Electric circuits - current conservation
Yes	Partially	Ms Ferrensby	Electric circuits - current conservation
Yes	Partially	Dr Kepwick	Electromagnets – factors effecting strength
Yes	Partially	Mrs Kettlesing	Electromagnets – factors effecting strength
Yes	Partially	Miss Kilburn	CASE
Yes	Partially	Mr Overton	Magnetic permeability of materials
Yes	Partially	Mr Rainton	Electrolysis – cathode deposits
Yes	Partially	Mrs Ramsgill	Voltage in parallel circuits
Yes	Partially	Mrs Risplith	Heart beat/pulse – numerical equivalence
Yes	Partially	Mr Fangfoss	Separation - sand and pepper
Yes	Partially	Mr Oldstead	Cooling curve – characteristic plateau
Yes	Partially	Mr Normanby	Lenses and eyes – similarities
Yes	Partially	Mr Normanby	Refraction – ray paths
Yes	Partially	Mrs Uckerby	Current in series and parallel circuits
Yes	Partially	Mr Ulleskelf	Electrolysis – increase in cathode mass
Yes	Fully	Mr Keld	Separation – iron, salt and sand
Yes	Fully	Mr Sewerby	Starch production – factors that effect
Yes	Fully	Miss Sharow	Work done in raising mass
Yes	Fully	Dr Starbeck	Current and voltage in series circuit

Two facts emerge from the data in table 5.8. Firstly, twenty-two of the tasks, 88% of the sample, were ones in which the observables *could* be thought about using scientific ideas that were appropriate to the age range of the pupils undertaking the task. Secondly, although twenty-two of the observed tasks had the potential to be thought about using specific scientific ideas, eighteen of them, or about 82% of this sub-set, were those in which the majority of pupils observed were either unfamiliar or only partially familiar with the ideas that the teacher intended them to use.

5.5.1 Tasks that provided an opportunity to 'do with ideas'

Although the overwhelming majority of tasks were found to be effective, in terms of enabling the pupils to do what was intended with objects and materials, there was considerably less evidence that they were as effective in getting the pupils to think about those same objects and materials using the ideas intended by the teacher. One possible reason for this was that, in a large proportion of the tasks observed, the pupils were relatively unfamiliar with the ideas (Table 5.8) that the teacher intended them to use. It is however important to recognise that a lack of familiarity with an idea did not necessarily mean that the idea had not been taught. For example, despite it having been confirmed by Mrs Uckerby that the pupils in her Year 11 class had been taught about electric circuits over a period of five years, some of the pupils were still evidently unfamiliar with the basic idea that a voltmeter measures a difference of some kind between two points, an understanding of which would have made placing the voltmeter in parallel, rather than series, commonsense:

> Researcher: [Observing as UY7 places the voltmeter in series.] So how have you got your voltmeter connected? [UY7 ignores the question.] How would you say your voltmeter is connected in the circuit?
> UY8: [Interrupting] It needs to be on parallel lines doesn't it.
> Researcher: [To UY7.] So how have you got it?
> UY7: I'm not sure. I don't know.

In two practical tasks, those used by Mr Drax and Mrs Risplith, whilst they provided the opportunity for the pupils to think about the observables using scientific ideas, ideas that would have made their observations far more meaningful, the practical tasks were used solely to enable the pupils to generate and see a pattern between observables. The practical task used by Mrs Risplith required the pupils to measure and then compare their pulse rate (observable) with their heat rate (observable) in order to recognise, hopefully by a similarity in these values, that these were one and the same. Whilst the practical task would, arguably, have made more sense to the pupils had the idea of the circulatory system been discussed before they undertook the practical task Mrs Risplith chose not to introduce this idea, believing instead that the connection would emerge from the data. Unfortunately, by the end of the lesson, when the pupils' results had been put up on the board - many pupils had obtained different values for these two readings – the desired result failed to emerge. Indeed, having not discussed the circulation of blood within the body, the pupils had no clear idea why the pulse rate should be the same as the heart beat and some clearly disbelieved any attempt on the part of Mrs Risplith to imply that two different numerical values were essentially the same:

> Mrs Risplith: The question is [points to data on board], is the pulse rate the same as the heart beat?
> RH15: No.
> RH16: No, no.
> Mrs Risplith: Right, near enough, who said that? [No response from the pupils and nobody could be heard saying it on the audiotape.]
> RHa: [Calling out] But 106 and 90 are miles apart.

By the end of the lesson one pupil (RH19), who appeared confused by the data on the board, asked " What is pulse?" to which Mrs Risplith, without any further explanation as to why this was the case replied "Your pulse is your heart, is your heart beat". Had this task started with a discussion of the idea that blood, pumped by the heart, circulates around the body and that the pulse, is a sort of 'echo' of heart that can be felt at various points on the body, should therefore – if measured at the same time – have the same value, it would, arguably, have been a far more meaningful and successful task. Certainly differences in these values could have then been thought about in terms of the readings having been taken at different times – one possibly after running around the class to borrow a stethoscope – which, because exercise leads to an increase in heart rate, might explain the observed differences in the readings.

In the case of Mr Drax the aim of the practical task was explained to the pupils as being to find "what effect does the colour of a can have on its ability to take in heat or not take in heat". Whilst expressed in rather colloquial terminology this is a scientific idea since heat, unlike temperature, is not directly observable. However, having tentatively mentioned this idea he made no further reference to any scientific ideas about heat, or energy moving from the lamp into, and out of, the cans. Indeed the actual task was undertaken purely at the level of observables and might more accurately have been described as being designed to compare which of a number of differently coloured cans (observable) produced – all else being equal - the greatest change in temperature (observable) when heated with a lamp – here the term 'heated' implies a causal effect that 'brings about' an increase in temperature, rather than an idea about the movement of energy. Mr Drax later explained to the researcher that, in fact, this was precisely what his aim had been, since he saw the purpose of this particular practical lesson as being to enable the pupils to successfully carry out a procedure in order to generate, and record, data from which "the ideas of absorption and reflection will be developed in subsequent lessons". Because of his desire to ensure that the pupils understood what to do with objects and materials, and could succeed in generating the data, all of the procedural instructions were given using descriptive colloquial terminology. Having explained the procedure he paused briefly, before the start of the task actualisation, to reminded the pupils that they had previously used the term 'absorb' to mean 'taking in heat' and 'reflect' to mean 'not taking in heat'. Yet despite this brief reminder of relevant scientific vocabulary and its meaning, none of the pupils was heard to use either of these terms during the course of the task. Indeed almost all of the pupil discussion, observed by the researcher, focused on the practicalities of carrying out the task and, in particular, who would do what with which piece of equipment and when they could swap roles. In the few cases in which pupils were heard to talk about their observations, other than simply in terms of calling out the numerical readings being taken from a thermometer, their comments made reference to directly experienced tactile sensations (level i):

> DX4: [Feeling the black can.] The black can is very hot.
> DX5: Let me feel it.
> DX6: Let me feel it too.
>
> DX10: [Feeling the black can.] I think the black feels hotter than the green did.
> DX11: [Feeling the black can.] Yeah, you're right.

Given that all of the teachers devoted 'whole class' time to ensuring (generally very successfully) that the pupils did what the teacher intended them to do with the observables, it might have been expected that similar 'whole class' time would have been devoted to familiarising the pupils with, and getting them to use particular ideas or models in order to think about what they were doing and seeing. However, it can be seen below (Table 5.9) that in only five tasks, or 20% of the total sample, did teachers devote any 'whole class' time to the discussion of the ideas in an attempt to get the pupils to successfully do what they intended them to do with ideas.

Table 5.9 Whole class time devoted to getting the pupils to 'do with ideas'

Teacher	Could the observable features of the task be thought about using scientific ideas/models appropriate to the age range of the pupils? Yes / No	Did the teacher devote any 'whole class' time specifically to getting the pupils to successfully 'do objects' what they intended them to do? Yes / No	Did the teacher devote any 'whole class' time specifically to getting the pupils to successfully 'do with ideas' what they intended them to do (or might reasonably have been expected to have intended)? Yes / No	Did the teacher devote any time to the discussion of relevant ideas? Yes / No
Miss Nunwick	No	Yes	No	No
Mr Saltmarsh	No	Yes	No	No
Mrs Ugthorpe	No	Yes	No	No
Mr Dacre	Yes	Yes	No	No
Mr Drax (Y10)	Yes	Yes	No	No
Mrs Duggleby	Yes	Yes	No	No
Mr Fangfoss	Yes	Yes	No	No
Ms Ferrensby	Yes	Yes	No	No
Dr Kepwick	Yes	Yes	No	No
Mrs Kettlesing	Yes	Yes	No	No
Mr Normanby	Yes	Yes	No	No
Mr Overton	Yes	Yes	No	No
Mrs Ramsgill	Yes	Yes	No	No
Mrs Risplith	Yes	Yes	No	No
Mrs Uckerby	Yes	Yes	No	No
Mr Drax (Y7)	Yes	Yes	No	Yes
Mr Normanby	Yes	Yes	No	Yes
Mr Rainton	Yes	Yes	No	Yes
Mr Sewerby	Yes	Yes	No	Yes
Mr Oldstead	Yes	Yes	No	Yes
Mr Keld	Yes	Yes	Yes	No
Miss Kilburn	Yes	Yes	Yes	No
Miss Sharow	Yes	Yes	Yes	No
Mr Ulleskelf	Yes	Yes	Yes	No
Dr Starbeck	Yes	Yes	Yes	Yes

This is not to say that these five teachers were the only ones who intended the pupils to think about the observables using specific ideas, but they were the only ones to use a planned 'whole class' strategy designed to achieve this aim. In contrast to this planned 'whole class' strategy some teachers, such as for example Mr Oldstead, who. having become aware during the later stages of the practical task that the pupils were not thinking about the temperature plateau using the ideas that he intended them to use, began to assist the pupils on a 'group by group' basis providing what Wood, Bruner and Ross (1976) have termed a *scaffold.* Scaffolding being that process which "enables a child or novice to solve a problem, carry out a task, or achieve a goal which would be beyond his unassisted efforts" (p. 90):

> Mr Oldstead: Here's a liquid. [Stands in front of a small group of pupils, who had been unable to explain to him the reason for the temperature plateau, and moves his arms about erratically and energetically making a noise like a steam train.] And here's a solid [Arms held, and moved, rigidly in front of him whilst making a low humming noise.] I want to change this liquid [waves arms energetically again] into a solid [arms moved rigidly and less energetically]. What's this [arms go from moving energetically and erratically to being held rigidly] got to lose [places strong emphasis on the word 'lose'] to change into a solid?
> OD3: Energy.
> OD1: All its movement.
> OD2: Energy.

It was not possible, when the lessons were analysed using the time indexed flow diagram records made of each task, to ascertain the time spent on anything other than 'whole class' activities. Whilst such data excludes details of time that might have been spent by teachers in providing information on, for example, 'doing with observables' or 'doing with ideas', if this occurred other than on a 'whole class' basis it does provide a useful illustration (Table 5.10) of the appreciable imbalance between the 'whole class' time devoted specifically to getting the pupils to think about the task using the ideas intended by the teacher and that devoted to 'doing with ideas'.

Table 5.10 Whole class time spent on 'doing with observables' and 'doing with ideas'

Teacher	Time spent on providing whole class information on what to do with objects/materials - including teacher demonstration of procedure (minutes)	Time spent on providing whole class discussion of ideas and/or models to be used (minutes)	Time pupils spent on whole class 'doing with objects' (minutes)
Mr Dacre	4	0	46
Mr Drax (Y7)	9	0	28
Mr Drax	11	0	40
Mrs Duggleby	8	0	23
Mr Fangfoss	11	0	20
Ms Ferrensby	10	0	28
Mr Keld	17	20	14
Miss Kilburn	9	4	25
Dr Kepwick	14	0	26
Mrs Kettlesing	6	0	34
Mr Normanby	2	0	7
Mr Normanby	33	0	10
Miss Nunwick	3	0	30
Mr Oldstead	15	0	40
Mr Overton	10	0	20
Mr Rainton	14	0	23
Mrs Ramsgill	5	0	34
Mrs Risplith	13	0	10
Mr Saltmarsh	14	0	18
Mr Sewerby	21	0	33
Miss Sharow	11	5	15
Dr Starbeck	7	29	14
Mrs Uckerby	10	0	24
Mrs Ugthorpe	13	0	28
Mr Ulleskelf	9	5	33

Clearly whilst all of the teachers observed devoted 'whole class' time, and in some cases this was an appreciable proportion of the total lesson time, to ensuring that the pupils were able to successfully produce the phenomena and/or collect the data many teachers did not give comparable, and in many cases any, time to discussing the ideas that would be necessary if the task was, arguably, to make sense to the pupils and constitute more than just a simple mechanical procedure. It was only Dr Starbeck who, whilst also using a 'recipe' style task, devoted more 'whole class' time to getting the pupils to think about, and use, the ideas and models he intended them to use than to 'doing with observables'. It is for this reason that later, when considering how teachers might get pupils to do as effectively with ideas as with objects and materials, a disproportionate amount of material is drawn from the task used by Dr Starbeck.

5.5.2 Tasks that provided no opportunity to 'do with ideas'

Having discussed the vast majority of tasks in which, whilst there was an opportunity to 'do with ideas', many pupils did not do so because they remained unfamiliar with the ideas, I want now to consider the relatively small number of tasks in which the nature of the phenomenon was such as to provide no opportunity for the pupils to engage with appropriate scientific ideas.

Of the twenty-five tasks observed three, the two involving the chromatographic separation of dyes used by Miss Nunwick and Mr Saltmarsh and the testing of food samples used by Mrs Ugthorpe, provided no opportunity for the pupils to do with ideas and were designed only to let pupils carry out, and see, a phenomenon. Indeed, as Miss Nunwick informed the researcher, the aim of her task was to let the pupils "look at how well the separation worked and at the colours they got". Similarly Mrs Ugthorpe, in her comments to the researcher, emphasised that "all I wanted them to get was the positive results for protein, starch and fat". Since none of the teachers intended the pupils to think about the phenomena using specific scientific ideas and/or models there was no need for, and indeed there was no evidence of, the use of either scientific terminology and/or models of any kind by any of the three teachers. In fact throughout each of these practical lessons the teachers used only colloquial terminology (level i) with the only evidence of the use of any scientific term – more appropriately a piece of scientific vocabulary – by any teacher being when, during the presentation of some procedural information, they referred to words such as 'chromatography paper', 'copper sulphate' and 'sodium hydroxide' in order to identify one, or more, of the materials that they, the pupils, would be using (level ii). The emphasis placed by the teachers on doing things with objects and materials, so as to produce a phenomenon – successfully achieved in both chromatography tasks but relatively unsuccessfully in the food test – coupled with a lack of any relevant scientific ideas or terminology, meant that when the pupils discussed the tasks they did so, as might be expected, using of descriptive colloquial terminology (level i) similar to that used by their teachers:

Researcher: Do you know why you're doing it?
SH7: To get lots of colours, pretty colours.
SH8: To see the colours that come from the pen.

Researcher: And do you know what will happen?
NK9: Yeah it would like all, all the, it'd go up and change colour.

Researcher: So you knew what to expect?
NK16: We used different pens and got different colours.

UE16: I've found out that iodine's purple

Mr Saltmarsh who, during the summary of the lesson, encouraged the pupils to describe what they thought their results meant, in terms of the colours that they had seen, reinforced this descriptive approach:

Mr Saltmarsh: Look at your experiment that you've done and you can see, hopefully, and you can see the colours have moved up the paper… What do your results mean?
SH10: That two colours are coming out from the ink.
Mr Saltmarsh: Good. There's a mixture of colours in there isn't there yeah? Maybe two, maybe three, maybe half a dozen but there is clearly, in some of these dyes, a mixture of colours to make up that single colour.

Despite the fact that chromatographic separation is only a part of a relative small section on 'separation' in the National Curriculum and has little, if any, conceptual value, Mr Saltmarsh allocated three successive double periods to the topic. During the first double lesson, the previous week, the pupils had watched and discussed a video on the chromatographic separation of dyes. This had then been followed by the observed practical lesson in which the pupils had successfully produced and observed the phenomenon for themselves. In the following double lesson Mr Saltmarsh was keen for the pupils to undertake the same procedure in order to observe how chromatographic separation could be used to solve a problem set in a non-scientific context:

> Mr Saltmarsh: Tomorrow, sorry next week…we'll do a piece of detective work about a garage that has been forging some cheques and you want to find out who the person is who's been forging cheques. You'll use chromatography to do that job because you have to identify which ink has written the forged cheques.

Although Miss Nunwick did not, as the scheme of work she followed suggested, contextualise the task as a murder mystery – the pupils had already undertaken chromatographic separation as a murder mystery during a Year 6 Induction Day – she did believe that such an approach served to illustrate "uses for science, which is perfectly legitimate". Whilst Miss Nunwick only devoted the one observed double period to chromatographic separation in Year 8, all of the pupils had also previously undertaken an identical task in Year 7 and almost the entire class had, as mentioned above, carried out chromatographic separation during their Year 6 Induction Day, albeit in the context of a murder mystery.

Whilst none of Mrs Ugthorpe's Year 8 pupils had carried out food tests previously she informed the researcher that, as a consequence of the problems encountered during the observed practical task, "tomorrow one of the first things we'll have to do is just redo the whole thing [the same practical task] again."

What these three tasks illustrate is that there are situations in which teachers knowingly use (and re-use) a practical task to illustrate a phenomenon, or to generate data, even though the task itself presents no opportunity for the pupils to think about those observables using appropriate scientific ideas.

5.6 Strategies for getting pupils to think about the objects and materials using the ideas intended by the teacher

One way in which Dr Starbeck tried to ensure that the pupils would still produce the desired phenomena, despite his devoting a large proportion of the lesson time to familiarising the pupils with the ideas that he intended them to use, was to use a short and relatively simple task that required very little in terms of procedural information:

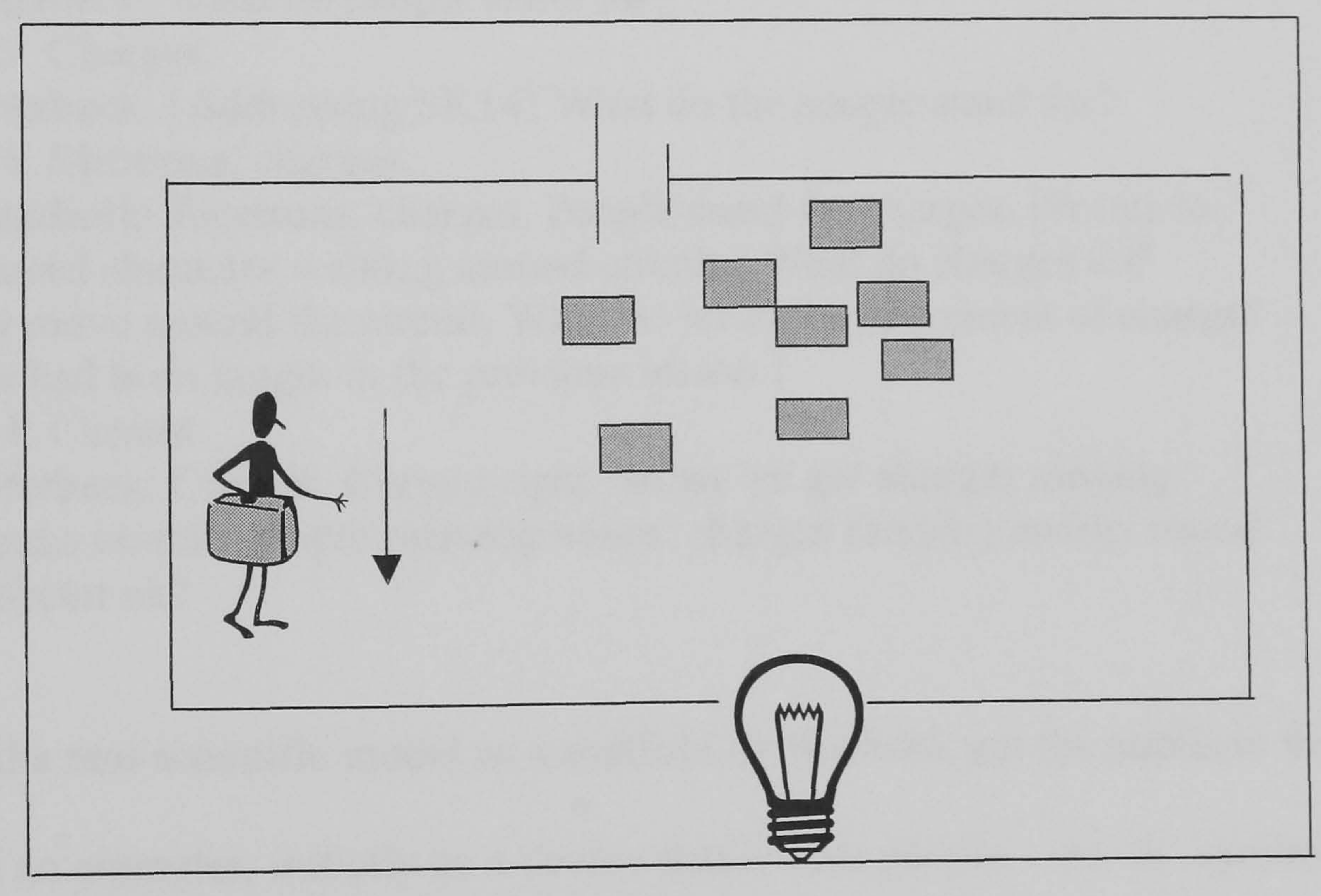
> Dr Starbeck: The point of it really is not that it's a complicated piece of practical work but it gives them a vehicle to use that thinking model.

Furthermore the task presentation, although relatively short in duration, was directed specifically at those areas that experience had shown Dr Starbeck were liable to perceived as problematic by the pupils. In this respect the procedural instructions focused on the use of power packs, ammeters and voltmeters - including how to connect them into the circuit and the need to ignore any minus signs that appeared when taking ammeter and/or voltmeter readings:

Researcher: You stressed [to the pupils] that the minus sign wasn't important.
Dr Starbeck: Well that's me trying to clear away the clutter so they can focus on what I want them to focus on which is the model. And I know the minus sign is clutter and I know they'll spend ages worrying about it.
Researcher: How do you know that?
Dr Starbeck: Because in the past, when I've done it badly, they've worried about the minus signs. Minus signs are clutter.

Time saved by using this strategy was devoted to the development of a non-scientific model that provided the pupils with the opportunity to think about and discuss the task using ideas and language with which they were already familiar. In this case the non-scientific model involved an animated cartoon character (Figure 5.11) who walked around a rectangular path and, as he did so, had to pass through a giant light bulb.

Figure 5.11 A diagram of the animated circuit model



At the top of the path, under the circuit symbol for a cell, was a pile of boxes. Each time the person walked under the symbol for the cell he picked up a box and carried this with him as he walked around the path. As the person walked through the giant bulb the box that he carried vanished and the bulb emitted a flash of light. The person then continued around the path back to the symbol of the cell where, having picked up another box, the cycle is repeated.

In the first part of the lesson Dr Starbeck devoted 'whole class' time to discussing the objects in the non-scientific model and used this to scaffold (Wood, et al., 1976) the corresponding entities within the scientific model of a simple series circuit (level iv):

> Dr Starbeck: [Points to the animated character moving around a stylised circuit on the whiteboard.] Right so we've got something moving around a circuit, a person moves around the circuit. What's moving around a real electric circuit?
> SK4: Electrons.
> Dr Starbeck: Ok, electrons, electric charges. So the person, [points to character on screen], stands for?
> SK5 Charge.
>
> Dr Starbeck: What do people stand for?
> SK13: Charges.
> Dr Starbeck: [Addressing SK14] What do the people stand for?
> SK14: Electrons, charges.
> Dr Starbeck: Electrons, charges. People stand for charges. [Points to animated character walking around circuit.] What do charges do? They move around the circuit. What do we call a movement of charge? [This had been taught in the previous lesson.]
> SK14: Current.
> Dr Starbeck: Current. Current right. So we've got charges moving around a circuit, people carrying boxes, charges carrying energy round the circuit ok?

By using the non-scientific model as a scaffold Dr Starbeck got the pupils to think and talk about an ammeter, initially as a device that counts people - the 'A' symbol for an ammeter is drawn on the blackboard like a person with arms and legs - and then, drawing on the analogy in which people correspond to charges within the scientific model, to think about the function of the ammeter as being to count charges.

The issue here was not whether the pupils made correct predictions about what they thought they would observe when they undertook the task. In fact initially many of their predications reflected an attenuation model (Shipstone, 2000) in which current is consumed, but whether they thought about the task using the ideas intended by the teacher. What was found, as the researcher moved around the laboratory, was that as the pupils' familiarity and confidence with the use of the scientific ideas/terminology increased many of the pupils began to replace colloquial terms, used in the non-scientific model, with the appropriate scientific terminology used within a scientific model (level iv), as the two following examples illustrate:

> Researcher: What's your prediction?
> SK7: Well I thought it would be all the same.
> Researcher: Why is that?
> SK7: It's the people [pauses], like the charge just keeps going round and then collects energy at the battery.
> Researcher: So you don't expect any change?
> SK7: No, not really.
>
> Researcher: What have you found?
> SK5: I was wrong. [Their initial prediction was based on a current attenuation model.] They all stayed the same except for one where it went up a tiny little bit.
> Researcher: So what's that told you?
> SK5: That amps don't really change.
> Researcher: And what are the amps measuring in the model you're using?
> SK5: The amount of charge going round. The number of people's not changing.

Although the majority of pupils continued to use a mixture of scientific and colloquial terminology (level iv) there were a small number of pupils whom, by the end of the task, were able to discuss all aspects of the task using the appropriate scientific terminology, a feature associated with language usage at level v:

> Researcher: So what's the voltmeter actually measuring?
> SK21: The energy.
> Researcher: [Directing the question to SK22.] So this voltmeter that

> you've connected across a bulb, what's it measuring?
> SK22: How much energy is going in, and how much energy is coming out.
> Researcher: And what will that tell you?
> SK22: How much energy it has lost.

Whilst Dr Starbeck was not unique in intending for the pupils to think about the task using specific ideas he was the only teacher, amongst all those observed, who devoted so much of the lesson to ensuring that the pupils were not only introduced to the appropriate scientific terminology but that they understood what they meant and were able to use it appropriately (levels iv and v). Compare this with the lesson taught by Miss Kilburn within the Cognitive Acceleration through Science Education (CASE) programme (Adey et al., 1989) that was a clear example of a practical lesson designed to help pupils make links between some abstract ideas and some concrete examples. Here, although Miss Kilburn briefly explained to the pupils what the central terms 'input variable' and 'output variable' meant, pressure to ensure that the pupils understood the procedure meant that the pupils' comments (or the lack of them) indicated that many of them did not fully understand their meaning:

> Miss Kilburn: Now what we're going to do today is take variables a bit further and we're going to decide whether a variable is an input variable or an output variable. Now and input variable is always going to be one that you change. Ok that is going to be your input variable. Now your output variable is going to be the one that changes as a result of what you've. So if we go back to our indigestion powder [a practical task undertaken two week earlier] which one did you change in this experiment? [No response from the pupils.] Which one did we decide was a factor and change? [Still no response from any of the pupils.] In order to work out the best way to cure indigestion?
> KN4: The acid. Was it the acid that we changed?

Despite many of the pupils' evident lack of familiarity with, and understanding of, the terms 'input' and 'output' variable, in a task that was primarily designed to get the pupils thinking about and using these terms, Miss Kilburn made no further attempt to clarify them. Indeed it was observed that it was their lack of familiarity and understanding of these terms that meant that many of the pupils were simply unable, and/or unwilling, to think about the task using these ideas:

> Researcher: So what's the outcome variable?
> KN4: What does that mean?
>
> Researcher: So for you this lesson is all about how many weights it takes to pull this [the pulley] down to the bottom and it doesn't have much to do with input and output variables.
> KN15: It'd help if we knew what they were.
>
> Researcher: Ok, can you tell me what's the input variable in this task?
> KN13: No.
> KN12: [Shakes head in the negative.]
> Researcher: You don't know, that's ok. What's the outcome variable? [Both pupils shrug and shake their heads in the negative.] Could you explain what they [an input and output variable] are to me?
> KN13: I don't know.
> Researcher: [To KN12.] Do you know?
> KN12: No.
>
> Researcher: What are you thinking of when you're doing this task?
> KN11: Nothing really.
> KN10: It's boring.

Given that many of the pupils were unclear about what the terms 'input' and 'output' variable meant their discussions tended to focus on observables and procedural issues (level iii) with none of the pupils being heard to use the term 'input' and 'output' variable when talking about their observations unless prompted to do so by the researcher:

> Researcher: [Addressing pupils who had, after almost four minutes of the five allocated, still not managed to obtain any readings.] Right, what have we got here?
> KN6: [Points to pulleys] We're doing pulleys.
> KN7: [Points to scale on Newton-metre.] We haven't really started yet, were just trying to get some weights on 'cause at the moment it isn't at zero and we don't know how to change it back? [Pupils appear unaware that the hook that holds the weight has a mass of 50 grams and it is this that is causing the non-zero reading.]

Researcher: Must it be at zero?
KN6: Yes because then it'll give you an accurate reading.
Researcher: [Points to hook.] What if you take that off?
KN7: [Removes hook.] Oh yeah it's on zero.

Indeed even when the pupils did try to use scientific terminology to refer to observable objects (level ii) their lack of familiarity with these terms meant that these labels were sometimes applied incorrectly:

KN15: It takes [points to the 5 kilograms suspended from the Newton-meter]
five hundred kilometres *(sic)* to pull it down
KN16: That's five hundred kilograms *(sic)*.
KN15: No kilometres *(sic)*.
KN14: [Points to the letters gm stamped on each mass.] G, m, that's grams to gilometers *(sic)*.

It must be emphasised that, whilst Dr Starbeck was the only teacher observed to use a strategy to ensure that most of the pupils were fully familiar with the ideas that he intended them to use, his was not the only task in which pupils talked about the observables using relevant scientific ideas intended by the teacher (level iv):

Researcher: [Points to pupils' results] And what does that show you?
RL10: That it don't matter where you put the volt meter in parallel circuits it'll always have the same pressure on it as the voltage is the same.
Researcher What about series circuits?
RL10: That, that if you use the voltage to connect on one bulb it'll be half what it is taken off by the whole thing (*sic*).

Whilst no firm conclusion can be drawn from the way in which one task was, relatively speaking, far more effective in getting the pupils to think using the ideas intended by the teacher, it does suggest that it might be possible to make tasks more effective in terms of doing with ideas if the lesson time was divided more equitably between issues relating to doing with observables and doing with ideas. Certainly, in the case of the task used by Dr Starbeck, the time devoted to the development of the non-scientific model provided the opportunity for the pupils to familiarise themselves with the terms and ideas with which he wanted them to think about the task.

Having focused in this chapter on 'doing' with objects, materials and ideas, I now move on, in the next chapter, to focus on 'learning' about them.

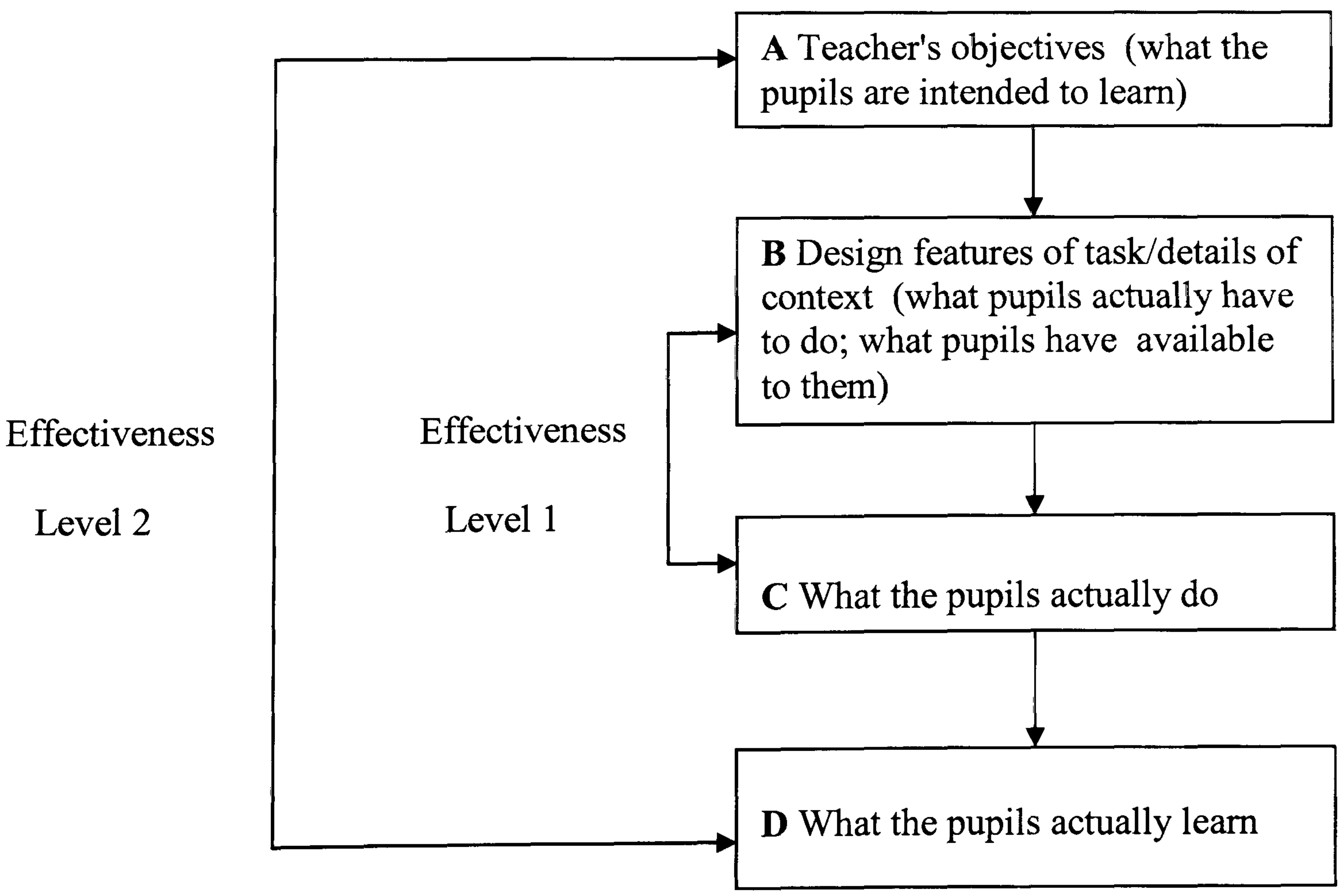
Chapter 6

What pupils learn about objects, materials and ideas

6.1 Introduction

Having analysed what pupils *did* with observables and ideas in the previous chapter I want now to consider what they *learnt* about them. The aim of this chapter is therefore to consider practical work in terms of its effectiveness in getting pupils to learn what the teacher intended about both observables and the scientific ideas used to understand them. This form of effectiveness, referred to as 'level 2 effectiveness' in the theoretical model being used, relates to the relationship between a teacher's objectives – what the teacher intends them to learn – and what the pupils actually learn, that is the relationship between boxes A and D (Figure 6.1):

Figure 6.1 A model of the process of design and evaluation of a practical task (From Millar et al., 1999, p.37)



6.2 Intended learning outcomes (learning objectives)

Before proceeding further it is important to clarify what learning in each of the two domains entails. The theoretical 2 x 2 matrix representation of practical work (Figure 6.2), discussed previously in chapter 3, distinguishes in the vertical dimension between *observables* and *ideas* and in the horizontal dimension between *doing* and *learning*.

Figure 6.2 A 2x2 effectiveness matrix

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	1:o Set up the equipment and operate it in such a manner as to see what the teacher intended.	1:i Think about the task using the ideas intended by the teacher.
at level 2 (what pupils learn)	2:o To set up and operate equipment. Discover patterns within their observations/data.	2:i To understand their observations/data by being able to link them, using the ideas intended by the teacher, with the correct scientific theory.

The two lower quadrants in the central column of the matrix therefore refer solely to objects and properties that can all be directly measured or observed. In this respect learning in the domain of observables refers to an understanding about objects, materials, phenomena, and the relationships between them that is expressible *only* in terms of their observable properties. Conversely the two lower quadrants on the right hand side of the matrix refer solely to ideas, none of which can be directly observed or measured. As such, learning and understanding in this domain is expressible *only* in terms of currently accepted scientific ideas, and the relationships between them, where the term 'ideas' includes concepts, theories and models.

This distinction, between learning about observables and learning about ideas, becomes clearer when considered within the context of possible learning outcomes (learning objectives) intended by the teacher. Table 6.1 shows possible learning objectives as well as the domain(s) to which they relate.

Table 6.1 Categorisation of possible intended learning outcomes (learning objectives) and the domains to which they relate (From Millar et al., 1999)

Intended learning objective	Domain
1. Identify observables and become familiar with them	Observables
2. Learn a fact	Observables
3. Learn how to use and/or set up equipment	Observables
4. Learn how to carry out a standard procedure	Observables
5. Learn a relationship	Observables/Ideas
6. Learn a concept	Ideas
7. Learn a theory/model	Ideas

Whilst these learning objectives are, for the most part, self-explanatory some of the objectives need to be clarified before proceeding further. In this respect, in the second learning objective, a 'fact', using the pragmatic distinction between observables and ideas discussed in chapter 3, is what Feyerabend (cited in Maxwell, 1962) refers to as:

> [A] singular, nonanalytic sentence such that a reliable, reasonably sophisticated language user can very quickly decide whether to assert or deny it when he is reporting on an occurrent situation. (p. 13).

In other words, as Millar (2004) succinctly states, a 'fact' is "an observation statement that can be readily agreed, and is expressed in everyday language" (p. 9). Examples of 'facts' are that liquids take up the shape of the bottom of their container, and that ice turns to water when heated.

In the fifth learning objective the term, 'to learn a relationship', relates to learning objectives that can exist in both the domain of observables and the domain of ideas. It is important here to point out that this is, in itself, not a controversial claim but simply one that recognises that a particular practical task can provide the opportunity for learning about relationships to occur in two domains rather than just one. In the domain of observables this relationship refers to learning about the connection between objects, materials and phenomena in terms of their directly *observable* properties whilst in the domain of ideas it refers to learning about the connection between theoretical entities that are themselves not directly observable. That a practical task can provide learning opportunities with regard to relationships in both domains can be illustrated by reference to a simple practical task designed to investigate Hooke's law. In the domain of observables this practical task, in which one end of a spring is suspended from fixed point whilst weights are attached to the other, provides an opportunity for the pupils to learn about the relationship between the length of that *specific* spring, as it is measured with a ruler, and the weights that are suspended from its free end. In terms of learning in the domain of ideas the same practical task also provides the opportunity for the pupils to learn about the relationship between the applied force and the extension – both of which are continuous variables and are applicable to *all* springs – and which, within a certain range, produce a relationship known as Hooke's law. Whilst recognising that there can be grey areas between a relationship between observables and one between ideas it is felt that this distinction provides a useful means of assessing what pupils learn and, if the distinction is unclear in a specific practical task the issue will be looked at more clearly within that particular context.

Objective 7 refers to learning that is intended to develop the pupils' conceptual understanding of a model or theory. This would include, for example, understanding the attraction of a piece of paper to a rubbed polythene rod in terms of the negatively charged polythene rod repelling electrons in the paper thereby forming a local area of positive charge that, because unlike charges attract, is attracted to the rod.

Although this study looked at the effectiveness of practical tasks in terms of whether they enabled pupils to do, and/or learn, what the teacher intended, it should be noted that many of the observed practical tasks were embedded within extended sequences of lessons that the teachers claimed involved a variety of teaching strategies. Here it should be noted that whilst it might have been informative to observe an entire teaching sequence on a particular topic this was simply not feasible since to do so would have required the researcher to have spent a considerably larger proportion of the time available for data collection observing a much smaller sample of teachers and a far more limited range of teaching topics something that it was felt would adversely effect representative nature of the study. Furthermore, it is arguably the case that, whatever factors are found to affect the effectiveness of specific practical tasks within this study, both in the domain of observables and ideas, will also affect the effectiveness of similar practical tasks when used within an extended sequence of lessons. Because of this it might be anticipated that teachers would place a greater emphasis on the use of practical tasks in order to achieve those learning objectives that depend primarily on the pupils' observation of objects, materials, phenomena and procedures (objectives 1 – 4 and, when it relates to the domain of observables, objective 5) rather than on the development of conceptual understanding. This is not to say that teachers might not also use practical tasks with the intention of developing their pupils' scientific knowledge (objectives 6, 7 and, when it relates to the domain of ideas, objective 5), although many science educators (Lazarowitz and Tamir, 1994; Hodson, 1991; Mulopo and Fowler, 1987; Hofstein and Lunetta, 1982; Blosser, 1981; Bates, 1978) have questioned its effectiveness to do so. Rather, it suggests that these latter objectives are more likely to be met through the use of a combination of teaching strategies, something that will be considered in more detail in chapter 8, in which practical tasks contribute towards, or help in (Millar, 2004), the development of conceptual understanding. Indeed it might be, as White (1979) has suggested, that the potential value of a practical task is that it provides an effective anchor, a "memorable event" (p. 385), onto which scientific ideas, possibly learnt through other teaching strategies, can, by association, be recollected.

6.3 Assessing what pupils learn

The difficulties associated with devising and administering pre and post-tests for such a wide range of topics, along with the access constraints discussed in chapter 3, meant that it was simply not feasible to pre and post-test the pupils' understanding of observables or ideas that the observed practical lessons were designed to develop. Similarly it was not feasible, for the same reasons, to assess any *change* – and in particular possible improvement – in the pupils' proficiency with equipment and/or familiarity with standard procedures arising from undertaking the task. Whilst such testing would have provided useful information it was, nevertheless, felt that to undertake such tests effectively would have necessitated an appreciable reduction in the size of the sample used – something that would have had an adverse effect on the representative nature of the study. In this study the effectiveness of practical lessons for learning is therefore based on an analysis of what the pupils said during, or immediately after, the completion of a practical task. Whilst such an approach does not provide any direct evidence for what the pupils will at any subsequent time be able to recollect it does provide what is arguably an upper limit as to what they are likely to be able to recollect. This is because whatever pupils are able to say, or recollect, about a particular task is likely to be at its clearest and most detailed during, or immediately after, undertaking the task when everything is still fresh in their minds. Therefore if there is little evidence in the short term for the pupils having learnt what the teacher intended, and by having 'learnt' what is actually being assessed is their ability to 'recollect', then it is unlikely that their recollections about that task will, at a later date, be any clearer or more detailed. Indeed it is arguably very likely that they will be less so. It is important to recognise that although what pupils are able to recollect, without prompting, is not necessarily the same as what they have learnt, what they are able to recollect is *all* that they are *aware* of having learnt.

Because it has been suggested (Brooks and Brooks, 1993) that teachers "everywhere lament how quickly students forget and how little of what they initially remembered they retain over time" (p. 39) it was considered necessary not only to assess pupil recollections in the short-term, but also over the medium to long-term. However, due to access constraints it was not feasible to revisit each class, at various future dates, to assess the pupils' medium and long-term recollections about the observed tasks. As such pupil recollections about other practical tasks, that they had undertaken during previous (unobserved) science lessons, were probed, during the task observation, to ascertain not only what they were able to recollect over the medium to long-term but whether, as White (1979) has suggested, such recollections provide a memorable event onto which the pupils are able, by association, to anchor scientific ideas. It might be argued, given the view expressed by Dr Starbeck that "what I hope is when they do it [again] in Year 10 although they'll have forgotten it they'll go 'oh yeah, I remember that' and they'll get it faster the second time", that a measure such as 'time needed to re-learn the same material' might provide a better indicator as to whether, and to what extent, 'learning' had occurred, than the analysis of the ability to recollect without (or even with) prompting. Although such a measure does initially appear to offer potential advantages over a straightforward 'ability to recollect' it is difficult to conceptualise not only what 'time needed to re-learn the same material' would mean, with regard to a class of twenty-five or more pupils of differing academic ability, but also how it could, in practice, be measured. Furthermore the spiral nature of the National Curriculum, in which pupils 'revisit' topics in different academic years - frequently with different teachers – renders it impossible to separate the contribution made to any reduced 'time needed to re-learn the same material' arising from their having previously undertaken the task from that due to a range of other factors such as, for example, differences in teaching style, whether the teacher was teaching in their subject specialism as well as changes in the developmental age of the pupils (Schaffer, 1987; Piaget, 1952; 1929) that such an approach would necessarily entail. Given these problems it was felt, on balance, that the ability to recollect previous practical tasks provided not only a useful indication of what had been learnt but also had the additional advantage of being relatively simple to use.

6.4 Pupil recollections

A frequent claim made by those pupils questioned in this study was that practical tasks helped them remember and similar findings have been reported by Denny and Chennell (1986). However, when these claims were investigated further it was found that, for most of the pupils questioned, practical tasks were, in fact, not easy to recollect and many of the pupils found, as has previously been reported by Berry et al. (1999), task recollection relatively difficult. However, whilst some pupils were initially unable to recollect any practical tasks they had done in the past, and some claimed (erroneously according to their teachers) not to have done any practical work for over a year, it was found that they too were often able to recollect a particular task after having their memory 'jogged' by the comments made by other pupils. The following extracts are examples of this:

> Researcher: Can you remember any other practicals that you've done? [Pupils shake their heads to indicate no.] Even in Year 7?
> DE9: Oh yes we did this, made this, cell bag thing.
> DE10: Oh yeah [nodding head to indicate that they too now remember] with wallpaper paste.

> Researcher: Can you remember any practicals you've done this year? [No response.] Or last year?
> DX4: Oh, I remember, we did these like bridges.
> DX5: Oh yeah. [Nodding in agreement.]
> DX4: We had to make bridges out of bits of wood. We wanted this car to…
> DX5: [Interrupting.] Yeah it was a kind of suspension bridge and we had to get this car over.
> DX4: One sheet of paper and see if it would hold the car.

One pupil who was unable to recollect any specific practical tasks when asked to do so by the researcher explained that this was because they needed something to act as a 'trigger' for their recollections:

Researcher: What other practical do you remember?
RN11: I don't really know, it's just that when you get a question it comes back.

In fact what it appears the pupils were actually claiming was not that they found *all* practical tasks easy to recollect but rather that they found *some* tasks – and then only a relatively small number - *easier* to recollect than *lots* of material taught using certain, although not all, non-practical teaching strategies:

UF5: It's much better than doing it without no experiment because you're doing it like and you'll remember it more.

NK9: Because that way [teacher-demonstration] you wouldn't remember as much because it wasn't you that did it.

UF8: It's better to do things practically because then I've actually seen it work, I'll remember it, instead of just being told.

OD4: You'll remember the experiment more than a piece of paper

Yet the possibility that such claims were simply rhetorical is exemplified by one of the pupils who, having claimed to recollect more by being allowed to actually undertake a practical task, was, when asked, unable to recollect anything about any practical task that she had undertaken. Evidently realising that this inability to recollect anything about previous practical tasks was inconsistent with her previous claim the pupil (OD4) offered the following by way of an explanation: "Ok, you might not remember it more, but it's less boring than just writing stuff down". Indeed, although this will be discussed more fully in chapter 7, many of the claims made by the pupils about practical work involved statements of *relative* preference in which practical lessons, possibly because of the frequent use of worksheets, were frequently seen as a preferable option because they provided an opportunity to avoid the need for too much writing.

Pupils were not however alone in claiming that practical tasks were easier to recollect than alternative teaching methods. In findings similar to those reported in two large-scale national survey studies into the nature and purpose of practical work in science education (Thompson, 1975; Beatty, 1980) this study also found that some of the teachers believed that practical tasks, especially when they generated the 'correct' results, provided an effective way of helping pupils to recollect facts and ideas:

> Mr Saltmarsh: I think if things have gone well, in a specific practical, it does help the children to understand and remember what they've done, rather than just writing it down.
>
> Dr Kepwick: I do feel, in my limited experience, that often practical will help them remember so much more than just being told or shown pictures or something like that.
>
> Mr Oldstead: I think I believe strongly that by doing things you're more likely to remember it. I mean if I look at my own kids they're more likely to remember stuff and be able to do things if they have a go at it, they're practising and I believe the kids here are the same.

Previous research (Ward, 1956; Newbury, 1934) has found that teacher "demonstration lesson is, of necessity, more definite in content than individual experiments. Thus, whilst it is effective for all pupils, it is particularly helpful to the weaker pupils" (Newbury, 1934 p. 99). However, some teachers in this study believed that actually allowing academically weaker pupils to undertake practical tasks for themselves was especially helpful in enabling them to recollect information:

> Mrs Kettlesing: I think the low ability [pupils] are more likely to remember it because they've done it themselves.
>
> Mr Drax: I think that some [academically weak] pupils are helped to remember by doing it themselves.

Yet despite the claims of pupils and teachers alike most of those pupils questioned, irrespective of their academic ability, found it difficult to recollect even three tasks from throughout their *entire* period of secondary education that, in some cases, was almost five years. In fact many pupils were only able to recollect even this relatively small number of tasks because their memories were 'jogged' by comments made by other pupils or, in three cases, because the task that they were undertaking was similar to, and 'triggered' a recollection of, a task that they had previously undertaken. For example, whilst many of the pupils undertaking the chromatographic separation of dyes, with Miss Nunwick, recollected having previously undertaken a similar task, tasks involving chromatographic separation were not recollected by any other pupil in the study even though, and the researcher ascertained this from the respective heads of department, it was carried out regularly in most of the schools within the study. Likewise pupils in Dr Kepwick's practical lesson, undertaking a task that involved electromagnets, were the only ones in the study who recollected having previously carried out a task that involved electromagnets even though it is highly probable that pupils in other schools would have undertaken similar tasks. Similarly it was only Mr Normanby's Year 11 pupils, observed undertaking a task that involved the refraction of light through glass blocks, who recollected undertaking the same task on a previous occasion even though, in the researcher's experience, this is a commonly used practical task at Key Stage 3.

Even when pupils' memories were 'triggered', by the similarity between the observed task and a previous one, their recollections were vague and frequently involved little more than a recollection that they had set up the equipment and undertaken the task. The following extract is an example of just such a 'vague' recollection which might arguably have been be expected given the relatively uninspiring nature of the practical task and the fact that it took place two or three years earlier:

> Researcher: Have you undertaken this experiment before? [Mr Normanby had informed the researcher that the task had been undertaken by these pupils when in Year 8.]
> NY5: No I don't think so.
> NY6: Yeah we have, a couple of years ago.
> Researcher: Do you remember what happened?
> NY5: No not really no.
> NY6: No I don't [pause] I remember setting it up, but I don't remember the exact lines [the observable ray paths].

Similarly whilst the head of physics confirmed that most of the pupils in Dr Kepwick's class had carried out an identical task in Year 7 (Dr Kepwick was repeating the task as a means of revision for Year 9 SATs), most of those questioned had no recollection of having done so or, if they did, could recollect little more than the fact that they had undertaken something similar previously. The following examples, in which the pupils respond without any sign of hesitation or uncertainty, show the extent to which there was no recollection of their having previously undertaken the same task:

> Researcher: Were your predictions based on your year 7 results?
> KK2: I haven't done it before.
>
> Researcher: Have you done this task before?
> KK4: No.
> KK5: No.
>
> Researcher: Have you done this before, in year 7?
> KK8: I don't think we've done this experiment before.
> KK7: No.
>
> Researcher: Have you done anything on electromagnetism before?
> KK13: In year 7, but I think I might have been away.
> KK14: I might have been away also, I don't know.

Of the two pupils questioned who did recollect having carried out the task in year 7, both felt that repeating the task provided an opportunity to go over/revise the material and, in so doing, it served to refresh their memories:

> Researcher: You've done this before?
> KK3: Yeah.
> Researcher: So if it helps you remember, do you remember it from last time?
> KK3: Yeah. When you do it once and then you do it again you sort of like remember it.
>
> Researcher: Have you done this before?
> KK1: Yeah I did it in year 7.
> Researcher: You've done the same thing?
> KK1: Yeah.
> Researcher: So is this going to help you?
> KK1: Revision.

When questioned about what they thought they would remember about this task in six months time the pupils' responses did not coincide with the intended learning objectives stated by Dr Kepwick – the factors that effect the strength of an electromagnet – but to the procedure used to demagnetise nails and paperclips that the pupils, judging from the amount of laughter during the lesson, had found very amusing. These unplanned incidents, peripheral to the main task, had involved pupils climbing up onto their stools in order to drop magnetised nails on to the floor or, in some cases, placing them on the floor and stamping vigorously (in some cases overly so) on them so as to demagnetise them. In one particular case, that aroused a lot of laughter from those who witnessed it, one pupil apparently trying to demagnetise their paperclips, threw a handful of them up into the air and allowed them to rain down onto the surrounding pupils, benches and floor:

> Researcher: If I was to come back, in say half a year, what do you think you'd remember about this?
> KK12: I've learned that you have to drop the magnets [nails] to get the magnetic field out of it.
> KK11: Yeah I'll remember that bit. [Both pupils are laughing]

In this respect the findings appear to support a view expressed by one of the teachers in the study who, commenting on the extent to which he thought his Year 10 pupils undertaking a practical task would be able to recollect practical tasks on the same topic undertaken in Year 8, suggested that:

> Dr Starbeck: Most of the stuff will have faded. What I hope is when they do it in Year 10, although they'll have forgotten it, they'll go 'oh yeah, I remember that', and they'll get it faster the second time and, with a bit of luck, it might last a bit longer.

It is important to emphasise at this point that these findings are not intended to suggest that practical work is necessarily any less effective, in terms of what pupils recollect, than other teaching tactics: indeed it would, arguably, have been just a likely that pupil recollections of non-practical science lessons would also have been found to have faded over the same time period.

Tables 6.2, 6.3 and 6.4 summarise, by subject, not only all of the tasks that the pupils were able, when questioned, to recollect but also what it was about those tasks that they actually recollected.

Table 6.2 Details of biology tasks recollected by pupils

Pupil	Description of practical task	Pupil's recollections	Year when pupils claimed to have undertaken the task	Year when recollected
DE9	Making a model cell	That they did it and that it 'looked like sick'.	Year 7	Year 8
DE10	Making a model cell	That they did it.	Year 7	Year 8
SW6	Dissecting a pig's eye	That they nearly fainted.	Year 10	Year 11
RH7	Dissecting an egg	That it was hard-boiled. That they had to find a membrane.	Year 7	Year 9
RH6	Dissecting heart and lung	That they had to smash them because they were 'pulsing'.	Year 7	Year 9
DX2	Bread making	Getting a letter from a woman called Brown that asked them to investigate whether it was better to use room temperature or a proving oven for making bread. Making and eating the bread.	Year 6	Year 7
NK18	Energy in food	That they burnt popcorn. That they burnt sugar and saw it caramelise.	Year 8	Year 8
SH8	Bacteria	Putting samples of pond water and sterilised water onto a 'gel -thing' to see bacteria and 'stuff'. That bacteria are colonies.	Year 7	Year 8
SY11	Decay	Putting bread into bags and opening the bag at a later time and noticing a 'really bad smell'.	Unsure	Year 10
SY12	Diffusion	How the water, starch or 'something' can move through the wall of a potato chip and that some were soggy some were hard.	Unsure	Year 10
UF5	Enzymes	That they did it.	Unsure	Year 10
SY9	Conditions for starch production in green leaves	Putting the leaf on the tile with iodine and that it didn't produce the correct colours.	Year 9	Year 10
SW9	Testing reaction times dropping a ruler	That they did it on more than one occasion.	Years 6 and 7	Year 11

Table 6.3 Details of chemistry tasks recollected by pupils

Pupil	Description of practical task	Pupil's recollections	Year when pupils claimed to have undertaken the recollected task	Year when recollected
RH7	Evaporation	That it was 'amazing'.	Year 7	Year 9
DX4	Test for hydrogen	It gave a 'squeak'.	Year 7	Year 10
FY14	Test for hydrogen	A 'squeaky-pop' noise.	Year 7	Year 7
KD4	Separation of soil, salt and 'something else'	The procedure used. [However, the pupil could not provide any details of this.]	Year 7	Year 9
KD9	Separation of salt from salt water by evaporation	Seeing the salt	Year 6	Year 9
KD13	Separating things	There are different ways to separate things.	Year 8 and 9	Year 9
OD2	Making a match stick rocket	Wrapping the end of the match in silver-foil then lighting them and shooting them across the room.	Year 7	Year 8
KD12	Burning magnesium ribbon	The brightness.	Year 7	Year 9
OD4	Burning magnesium ribbon	It was 'spectacular'.	Year 7	Year 8
NK12	Burning magnesium ribbon in a crucible	The procedure. Watching it flare, a slight increase in mass.	Year 7	Year 8
SH8	Distillation	That it was a blue liquid and that they got water from it.	Year 8	Year 8
SH7	Distillation	They used a thermometer, a tripod and a Bunsen burner and hot water went through the tubes into a beaker.	Year 8	Year 8
DX1	Reactivity of group 1 metals	The teacher dropped it into the water.	Year 7	Year 10
DX2	Reactivity of group 1 metals	That they saw it.	Year 7	Year 10
NK13	Reactivity of group 1 metals	It exploded.	Year 7	Year 8
NK14	Reactivity of group 1 metals	We had a big tub of water and the teacher put potassium in the water and it went round and burst into flame. It looked 'impressive'.	Year 7	Year 8
RN8	Reactivity of group 1 metals	It was 'violent', it was potassium or phosphor.	Year 7	Year 10
RN9	Reactivity of group 1 metals	It was ox (*sic*) reaction, it reacts with oxygen.	Year 7	Year 10
SY5	Reactivity of group 1 metals	We had a big tub of water and the teacher put sodium or 'something' in the water and it 'whizzed' around.	Year 7	Year 10
DX4	Reactivity of group 1 metals	That they saw it.	Year 7	Year 10

Table 6.3 (Continued)

NK4	Chromatographic separation of dyes	The procedure and the phenomenon.	Year 6, 7 and 8	Year 8
NK11	Chromatographic separation of dyes	That it was set up like a murder mystery.	Year 6, 7 and 8	Year 8
NK13	Chromatographic separation of dyes	That it was set up like a murder mystery.	Year 6, 7 and 8	Year 8
NK14	Chromatographic separation of dyes	That it was set up as if an unknown pupil had drawn with ink on another pupil's shirt.	Year 6, 7 and 8	Year 8
SH9	Heating oil	That they heated oil to 200 degrees and someone knocked it off the table and it spilt on the table and they had to move to another table.	Year 7	Year 8
UF17	Electrolysis	That they did it with a metal a few weeks ago.	Year 10 (Twice)	Year 10
UF15	Electrolysis	That they did it in physics four weeks ago.	Year 10 (Twice)	Year 10
UF4	Measuring gas	Collecting gas and measuring.	Year 10	Year 10
UF2	Measuring gas	Collecting gas over water to see how quickly 'it' reacts.	Year 10	Year 10
UF3	Measuring gas	Collecting gas over water to see which metal chips were more vigorous.	Year 10	Year 10
DE16	Using indicators	The colour scheme 'thing'.	Year 7	Year 8
FY11	Making indicator from red cabbage	How it was made.	Year 7	Year 7
FY14	Test for carbon dioxide	Used limewater.	Year 7	Year 7
DY22	Practicing to use a thermometer	Used a Bunsen burner and then recorded the temperature of the water as it cooled.	Year 7	Year 7
RN9	Flame tests	Iron filings sparkled in a flame.	Unsure	Year 10
FY10	Putting hydrocholic (sic) acid with vinegar	It fizzed.	Year 7	Year 7
RL7	Thermite reaction	There were sparks and it went 'bang'. There were iron filings in it because it made those little sparks.	Year 9	Year 10
RL8	Thermite reaction [demo]	It was powerful.	Year 9	Year 10
RL9	Thermite reaction	Used a brick, loud bang, sparks 'what was the most reactive', Lithium, iron filings making little sparks.	Year 9	Year 10
RN18	Thermite reaction	He used a brick and we had to go outside.	Year 9	Year 10
RN17	Thermite reaction	He put loads of different 'stuff' in it, set light to it and there was a 'loud whoosh'. It was 'exciting'.	Year 9	Year 10

Table 6.4 Details of physics tasks recollected by pupils

Pupil	Description of practical task	Pupil's recollections	Year when pupils claimed to have undertaken the task	Year when recollected
RH6	Compasses	A magnet always turns north.	Year 7	Year 9
SW9	Series circuits (drama with Dr Starbeck)	Walking on the tables.	Year 10	Year 11
SW8	Series circuits (drama with Dr Starbeck)	Walking on the tables pretending to be electrons.	Year 10	Year 11
SW4	Series circuits (drama with Dr Starbeck)	Tables were wires.	Year 10	Year 11
SW5	Series circuits (drama with Dr Starbeck)	Tables were wires pupils pretended to be voltmeters.	Year 10	Year 11
NY6	Shone a light through a prism	That they did it.	Year 10	Year 11
DX4	Making a bridge	Using bits of wood and paper to make a bridge over which toy cars with weights could pass.	Year 6	Year 7
DX5	Making a bridge	That it was a suspension bridge.	Year 6	Year 7
SY4	Making a bridge	Using straws and paper to make a bridge over which toy cars with weights could pass.	Year 9	Year 10
SW1	Wiring a plug	That they did it.	Year 10	Year 11
KG5	Magnetic poles	Like repel, unlike attract.	Year 7	Year 7
KD3	Shone a light through a prism	That they did it.	Year 9	Year 9
SW11	'Car and weights'	That they did it to work something out.	Year 11	Year 11
UY5	Van de Graaff generator	It was static electricity.	Year 9	Year 11

One of the findings to emerge from the data was that of the sixty-eight recollections relating to practical tasks 60% of them (forty-one recollections) related to practical tasks undertaken in chemistry whilst physics and biology accounted for only 21% (fourteen) and 19% (thirteen) of the recollections respectively. In all of the cases although the pupils were asked what practical tasks they recollected their recollections were in no way prompted by the researcher nor were they guided towards recollecting only those practical tasks that related to the same science subject as the practical task they were observed undertaking. However, what can also be seen (Tables 6.2, 6.3 and 6.4) is that even in those cases were the practical tasks were in a sense 'memorable' pupil recollections tended to be descriptive accounts of what they did with objects and materials and/or the phenomena that they observed. There was little, if any, clear reference in their recollections to the associated scientific ideas that would have enabled them to understand their observations:

An analysis of these recollections shows there to be, broadly speaking, two distinct types of task that pupils are able to recollect and that these can be categorised as being:

(i) Tasks about which the pupils can recollect some specific detail.

(ii) Tasks that pupils simply recollect 'having done' – and little else.

Those tasks about which the pupils were able to recollect specific details, rather than simply that they had a vague recollection of 'having done it', tended to be those that were, in some sense, unusual. Without attempting to rigorously define 'unusualness' it can be seen (Tables 6.2, 6.3 and 6.4) that, generally speaking, unusual tasks were those that exhibited one or more of the following three characteristics:

1. A distinctive visual/aural/olfactory component.
2. A 'gore' factor
3. A novel context

Of the sixty-eight tasks recollected twenty-seven (twenty-three chemistry and four biology), or 40% of the sample, were ones in which the pupils' primary, and in most cases only, recollection related to a distinctive visual/aural/olfactory component within the task. The 'gore' factor was evident in three of the most vividly recollected biology tasks, whilst in a further eighteen (three biology, eight chemistry and seven physics) the recollections involved tasks that were presented in what was, relatively speaking, an unusual context. Although it has been suggested (Gagné and White, 1978) that it is the act of undertaking a task, rather than merely reading about it or having it demonstrated, that makes its recollection more likely this study suggests that task recollection depended, to a much greater extent, on the presence of at least one of the above three characteristics. Indeed, like White (1979), who describes the visually spectacular ignition of carbon monoxide, that was *demonstrated* to him by his teacher, as an example of a practical task that he vividly recollects, many of the tasks recollected by the pupils in this study, in fact 21% them, were visually spectacular teacher demonstrations. In a subsequent discussion White (1996) describes memorable episodes as "recollections of events in which the person took part *or at least observed*." (p. 765. Italics added), a view that appears to acknowledge that it is what it is that is observed, and/or how it is presented, rather than necessarily who undertakes the tasks that determines whether or not the task becomes a memorable episode.

6.5 Learning about observables

One of the findings that emerged in chapter 5 was that practical tasks were, generally speaking, very successful in getting pupils to do with the objects and materials what the teacher intended them to do in order to produce a particular phenomenon. Indeed in only a few cases, which were discussed in detail in the previous chapter, were the pupils unable to produce the intended phenomena. It can be seen (Tables 6.2, 6.3 and 6.4) that what most of the pupils were able to recollect, and therefore what they themselves were aware of having learnt, related to what they had done (or observed their teacher doing) with observables. Yet whilst many had evidently learnt something about observables as a consequence of having undertaken a practical task, or having had it demonstrated to them, their recollections frequently involved little more than their being able to describe what they had done and/or seen. For example consider the practical task used by Mr Dacre to get the pupils to learn about the directly observable signs of a chemical, as opposed to a physical, reaction. Yet, as he made clear to the researcher after the lesson, the pupils had failed to make this distinction:

> Mr Dacre: Actual smoke comes out, not steam, or water vapour, but actual smoke. So it must be burning and I don't think anyone did [write it down]. So that's something we might go back to and revisit.

Contrast this with what one pupil (DE9) informed the researcher that they had learnt from their observation of heating (vigorously) some sugar in a boiling tube which was, and this was also written on their work sheet, that the "smell makes you feel sick". It might therefore appear reasonable to assume that if a teacher wants, as Mr Dacre did in this case, for the "pupils to 'see' phenomena and experimental situations in particular ways; to learn to wear scientist's 'conceptual spectacles'" (Driver et al., 1985 p. 193), a teacher would need to 'steer', or 'guide', them towards thinking about what they were doing and seeing in a particular way – in fact in the way that the teacher themselves sees it (Ogborn et al., 1996) – using appropriate scientific ideas and/or models. In this particular task this would have required getting the pupils to 'see' the significance of the fact that it was smoke, an indicator of combustion and therefore chemical change, that was being given off rather than steam or water vapour.

It might therefore have been anticipated, as Wickman and Östman (2001) have suggested, that the pupils would have been told "what to observe and how to talk and act in relation to observations" (p. 468). Yet neither during his task presentation, which at only four minutes was the briefest of those observed (Table 5.1), or in the worksheet that he provided, was any mention made of what the pupils should specifically be looking at or for. Indeed when the pupils were asked by the researcher about what signs of a chemical reaction they were expected to note, many, as the following examples illustrate, simply did not know:

> Researcher: Ok, so how would you know if a chemical reaction had occurred with this one? [Water and anhydrous copper sulphate]
> DE11: Look for the signs.
> Researcher: Ok, what are the signs?
> DE11: I don't know.
>
> Researcher: Ok, now on this one you've put sodium carbonate and iron chloride [pointing to, and reading from, the pupils' worksheet] 'it bubbled up and over the top'. So there's lots of bubbles but you've said it wasn't a chemical reaction
> DE18 [Addressing the researcher.] Why, is it a chemical reaction?
> Researcher: I don't know I'm not a chemist.
> DE18 [Addressing DE17.] Is it a chemical reaction?
> DE17: What?
> DE18: If it bubbles up and over the top.
> DE17: We're only supposed to…[Shrugs to indicate that they do not know.]

Yet without specific guidance to ensure that the pupils think about what they are doing and seeing in a particular way, the fact that they are successful in producing the phenomenon does not, in itself, ensure that they will learn, what the teacher intended, from undertaking the task. It can, for example, be seen that despite the pupil (DE18) having successfully produced the desired phenomenon, and their recollection of having seen lots of bubbles, they did not know, because Mr Dacre had not steered them towards thinking along those lines, to associate an observation of bubbles with the production of a gas and so to see it as it being a sign of a chemical reaction. Instead what many of the pupils in this study appeared to have learnt, at least in terms of what they were able to recollect, was what it was about a particular task that made it, in some sense at least, unusual. Many of the tasks recollected (Tables 6.2, 6.3 and 6.4) were sufficiently unusual – in the sense that they exhibited one, or more, of the three characteristics listed above – to avoid the criticism of practical tasks made by one pupil (SW6) who claimed "I don't remember very many chemistry ones because they all seem the same to me". Certainly the Thermite reaction, in terms of being 'unusual', provides both a striking visual and aural component and, in the case recollected here, also involved a novel context – not only out of the laboratory but also out of doors and, due to the very high temperature of the reaction, it was ignited on a brick that had to be carried out by one of the pupils specifically for this purpose. The task itself is designed to show that finely powdered aluminium, if mixed with powdered oxide of iron and ignited with burning magnesium ribbon, will, because it is a more reactive metal than iron, reduce the latter in a highly exothermic reaction. Yet what was found, amongst those pupils who recollected this task, was that their recollections focused only on the visually and aurally spectacular nature of the reaction itself and the fact that it was undertaken outside the laboratory on a brick:

> Researcher: What other practicals do you remember?
> RN18: That one with the brick that we did outside that was quite good.
> RN17: Yeah he put loads of different stuff in it, set light to it, and it just whoosh, that was pretty exciting
>
> RL9: Well can you [addressing pupil RL7] remember that experiment that we had to do with a brick outside?
> Researcher: Was that with Mr Rainton?
> RL9: Yeah.
> Researcher: What do you remember?
> RL9: A big bang and all that.

RL7: Yeah and sparks.
Researcher: What did you learn from it?
RL7: That it went bang.

Pupil recollections about the Thermite reaction exemplify a general finding from within this study that memorable episodes, rather than acting as an anchor for the associated scientific ideas (White, 1979), merely provide an anchor for a descriptive, non-scientific, account of the task in which the memorable event itself occurred. It is important to stress again that an inability on the part of the pupils to recollect anything other than a fragmentary description does not necessarily imply that they might not have learnt more than this from the task. What it does however indicate is that frequently what the pupils are *aware* of having learnt – that is, what they are able to recollect without assistance – differs markedly from what the teacher had intended them to learn (and hopefully recollect). In the following example, of a task that had been used by Miss Nunwick three weeks prior to the lesson that she was observed teaching, the pupils had been looking at observable differences between physical and chemical reactions. One of these reactions had involved the pupils heating sugar in a boiling tube in order to observe the changes that occurred. Miss Nunwick, when questioned about this later by the researcher, pointed out that her intended learning objective had been for the pupils to see the burning of the sugar as a sign of an irreversible chemical reaction. However, what the pupil who recollected this task was aware of having learnt (arguably they might already have known this because of their use of the term 'caramelise') was that sugar, when heated, is caramelised and other than the fact that they burnt the sugar this was the only part of the task that they claimed to be able to recollect:

Researcher: What practical do you remember?
NK18: Burning sugar.
Researcher: What did that show?
NK18: Nothing.
Researcher: Nothing?
NK18: It went caramelised.
Researcher: But what was it meant to show you?
NK18: I don't know, I can't remember.

This recollection of a solitary image with little, if any, associated scientific understanding of what the phenomenon was intended to show has also been reported by Berry et al. (1999) who found that whilst practical work can provide pupils with images of particular phenomenon these images had limited value and were not necessarily indicative of high-level mental engagement with the practical task.

Similarly pupil recollections about procedures (Tables 6.2, 6.3 and 6.4) tended to relate to *what* they had done rather than *why* they had done it:

Researcher: Do you remember any practical that you did longer ago?
SH5: Yeah we got like different chemicals in the tubes like blue liquids and then put like a red in with them and see what they turned out like.
SH6: Yeah you mix a and b, like copper sulphate and something else, and you mix it like together.
Researcher: And that was to help you learn what?
SH6: I don't know really. [Both pupils are laughing loudly.]
SH5: [Shrugs shoulders and shakes head to indicate that they do not know.]

Researcher: What practicals do you remember doing?
SH7: Distilling stuff.
SH8: Yeah.
Researcher: What did you distil, crude oil?
SH7: Yeah a blue liquid.
SH8: Yeah it was a blue liquid.
SH7: Just a blue liquid, we don't know what it was, just a blue liquid and we got water out of it.
Researcher: You got water out of it, how did that work?
SH7: Well we got a bottle.
SH8: We put a liquid in it, put a thermometer in it, put it on a tripod, put a Bunsen burner under it and it went through all the tubes in place and it went into a test tube in a beaker.

SH7: Hot water went into a beaker.
SH8: Yeah.
SH7: And if the temperature goes over too far, over a hundred, you had to take it out and then hold on a bit and then have another go.

In this respect their recollections, and in the later example these are relatively detailed procedural recollections, appear to reflect the emphasis – particularly in terms of time (Tables 5.9 and 5.10) – placed by many of the teachers on getting the pupils to successfully *do* what they intended with objects and materials, in order to produce a particular phenomenon, rather than on ensuring that they necessarily understood *why* they were doing it in the manner specified by the teacher and/or worksheet. What the last example illustrates is that whilst one of the pupils (SH7) was able to recollect a precise temperature range – a range that the teacher might have been expected to emphasise in order to ensure that the pupils produced the desired phenomena – there was no evidence that they understood *why* this temperature range was required. A similar lack of understanding was observed in the task used by Mr Oldstead in which he intended the pupils to produce a change of state cooling curve for a waxy material (octadecanol) by recording its temperature on a regular basis as it cooled and then plotting the data on a graph. Here, although the pupils followed a completely closed "cookbook" (Tobin et al., 1994 p. 51) type task, the procedure, as it appeared on the blackboard, differed from that provided verbally during the teacher demonstration. The written instructions specified that the wax was to be heated to seventy-five degrees Celsius (a temperature just above its melting point) and for the temperature to then be recorded every minute until it had cooled to thirty-five Celsius. In contrast the verbal instructions stipulated that the wax was to be heated until it melted and went clear and for the pupils to seek the teacher's advice on when to stop recording the temperature. Whilst a quarter of the lesson (Table 5.1) was devoted to ensuring that the pupils knew what they were to do with the objects and materials, no time was devoted to getting them to think about the initial heating simply as a means to liquefy the wax, or to understand that the value of seventy-five Celsius was simply a guide temperature that corresponded to liquefied wax slightly above its melting point. The fact that the written and verbal instructions were essentially the same, albeit expressed in a slightly different manner, was not understood by all of the pupils, many of whom saw the value of seventy-five Celsius as critical and devoted considerable time to ensuring that the wax was at, or as near as possible to, this temperature before starting to record their data. In the following extract it can be seen that whilst one of the pupils (OD3) attached greater importance to the written instructions another pupil (OD2) argued that there was no need to get the wax to exactly seventy-five Celsius. However, it is important to note, and can be seen from their comments, that their primary – if not sole – reason for doing so was that they attributed greater significance to the teacher's verbal, as opposed to written, instructions and there was no evidence that they understood *why* the starting temperature was not critical:

> OD1: Tell me when to start the timing.
> OD2: I will.
> OD3: Has it actually melted yet?
> OD2: It's melting look it's getting a lot smaller, when it gets to seventy.
> OD3: [Addressing OD2] No, no, not seventy [points to the blackboard] seventy-five, it says on the board.
> OD2: One, it doesn't need to be exact just as close as we can get it to seventy-five or when, no he [Mr Oldstead] said when it gets to a clear liquid not seventy-five.
> OD3: Ok, alright then [raising voice] turn it off then. [Shakes their head to indicate that they still disagree with this course of action.]

As a consequence of this lack of understanding, and the fact that many of the pupils devoted considerably more time to getting the wax to within a degree or two of the suggested temperature than was really necessary, Mr Oldstead had to abandon his aim of getting the pupils to plot their data in order for them to observe (and subsequently explain) the characteristic plateau shape of a change of state cooling curve.

Whilst the above example illustrates how a failure to adequately explain *why* something is being done, in contrast to *what* is to be done, can prevent pupils from learning what the teacher intended, so too can a failure to produce the desired phenomena and/or data. What this study has found is that, whilst the successful production of a phenomenon is a necessary condition for learning to occur, it is not, by itself, sufficient to ensure that the pupils learn what the teacher intends them to learn about observables. Certainly those tasks in which the teacher intends the pupils to learn about relationships between observables (Table 6.1) are particularly dependent upon the need to ensure that they successfully produce the desired phenomena. In those tasks in which the phenomena were not, for one reason or another, produced – and these have been discussed in detail in chapter 5 – the tasks were ineffective in getting the pupils to learn about a particular relationship between the observables. In a task where the pupils appeared to have no idea as to what to expect, as was the case with pupils in Mrs Risplith's class who gave no indication of knowing that pulse rate and heart rate should have the same value, the fact that many of the pupils did *not* find these values to be clearly and unambiguously the same meant that they were resistant to the teacher's claims that they were:

> Researcher: Do you think your heart and pulse rate will be the same?
> RH6: I think not.
> Researcher: What has this practical helped you understand?
> RH6: That we're alive and that we've got a pulse.
> Researcher: What has this practical helped you understand?
> RH2: It's helping me to see that the heart beat is beating more than the pulse (*sic*).

Researcher: Were you expecting the heart rate and the pulse to be the same?
RH5: I didn't know really.

Yet there were tasks in which the pupils clearly did have initial ideas about what they thought they would observe and these expectations were not supported by the data that they produced. Consider, for example, the task on electromagnets in which Dr Kepwick's intention was for the pupils to learn about the relationship between the number of turns on an electromagnet coil and the number of paperclips that it would be able to support. Here the expectation of many of the pupils prior to their undertaking the task was, if only on the basis of the generic idea that 'more of x means bigger and/or stronger y' (Stavy and Tirosh, 1996), that the number of paperclips that could be suspended by the electromagnet would increase as the number of turns on the coil was increased.

What was found, and similar findings have been reported in previous studies (Driver et al., 2000; Gunstone and Watts, 2000; Shipstone, 2000; Solomon, 1988), was that the idea, in this case that 'more of x means bigger and/or stronger y', was sufficiently resilient that the pupils' observation of a "discrepant event" (Nussbaum, 2000 p. 143), whilst confusing, did not generate any cognitive conflict (Driver et al., 1985). Instead what was found was that the pupils explained the 'discrepant results' away by suggesting that the equipment was not working properly, in a manner reminiscent of the way in which Millar (2004) suggests that some teachers "engage in the rhetoric of 'explaining away' the observations, perhaps appealing to notions of 'experimental error' or poor equipment" (p. 5):

Researcher: How's yours going?
KK9: We've just got one.
Researcher: What's your question? [KK10 had raised their hand]
KK10: Why's it [points to equipment] not working?
Researcher: It's not working?
KK9: Well it's working, but not as you would expect it to.
Researcher: How would you expect it to?
KK9: Well with more coils you'd have more magnetism yeah because there's more energy going around the thing so it's more magnetic.
Researcher: But you haven't found that?
KK9: No.
Researcher: Now does that confuse you when it doesn't work?
KK9: Yeah.
KK10: Yes because it's the same for all of them. [Each coil had only attracted one paper clip.]
KK13: It's broken [indicates equipment].
Researcher: It couldn't have been broken because it has worked hasn't it?
KK14: We think it might not have worked as well as it could do.
KK13: Yeah there's something wrong with it. [Points to electromagnet.]
KK14: That one [pointing to result for twenty turn coil] should have been more than that one [pointing to identical result for two turn coil] because there's more energy but it didn't.

Although Driver et al. (2000) have suggested that the observation of a discrepant event "is not necessarily followed by a restructuring of that student's ideas – such restructuring takes time and favourable circumstances" (p. 6), this clearly does not preclude the possibility that some pupils will restructure their ideas – unfortunately not always to ones that are scientifically correct – on the basis of a single (sometimes discrepant) event. The following transcript illustrates how two pupils, who had initially believed that an electromagnet with more coils would support more paperclips, restructured their ideas claiming to have learnt, as a direct consequence of failing to produce the results intended by the teacher, that fewer coils would support more paperclips:

Researcher: How's yours going?
KK7: Not very well.
Researcher: What have you found?
KK7: We haven't.
Researcher: So [looking at their table of results] with ten coils you held

three paper clips and with twenty you held one now is that what you predicted?
KK8: Well we thought that with more coils it would be more magnetism but it's obviously not.
Researcher: Why did you think that?
KK8: Because I thought if there were more wire there'd be more electricity.
Researcher: But you don't think that's right now?
KK7: No.
Researcher: So by using this practical you now know that more coils is less powerful [points to table of results] whereas you had thought that it would have been more?
KK7: Yes.
KK8: Yeah.
Researcher: [Watching them test an electromagnet with two coils.] Now you've managed to get one [paperclip] with two coils.
KK8: Now I can't understand that.
Researcher: What don't you understand?
KK7: Well that with only two coils it's one [paperclip] and with twenty it's one and with ten it's three.
Researcher: Why's that confusing you?
KK7: Because I would have thought it would have been more for two.
Researcher: Why?
KK7: Because if it's going [they have identified a trend albeit an incorrect one] up I'd have thought it would have been more for that [points to two coil result] instead of that [points to ten coil result].

The problem in this task, as with a small number of others, was that relatively few pupils managed to produce the desired phenomena and/or data. In these situations it was very difficult for the teacher "to appeal to the norm within the class: what did *most* students find?" (Millar, 2004 p. 5) as a means of 'averaging away' the few 'problematic' results. Yet in one such task the teacher, Mrs Risplith, whilst keen to avoid the introduction of "exemplary data" (Gott and Duggan, 1996 p. 801) to replace that generated by the pupils, also wanted to avoid the confusion that would arise regarding the relationship between two observables - pulse rate and heart rate – were they each to use their own results. To overcome this problem Mrs Risplith, having placed all of the results on the board, began to 'explain away' those results that were most notably at odds with the relationship that she intended them to 'discover' between observables:

> Mrs Risplith: What do you notice about these two? [Points to 106 and 90 and then 97 and 108.] We're not happy with these results, they seem way out. What do you notice about the figures compared to the others?
> RHa: They're really high.
> Mrs Risplith: Really high. Well done. So when your heartbeat is high…
> RHb: [Interrupting] You're dying.
> Mrs Risplith: Do you think it's easier or more difficult to measure it?
> RH19: More difficult.
> Mrs Risplith: It'll be more difficult, which might explain the difference in these readings. [Draws a line through these two pair of 'problematic' results to indicate that they can be disregarded as well as another pair of dissimilar results although no reason for doing this is given.]

In contrast Dr Kepwick, who was aware that the overwhelming majority of pupils had failed to produce the desired data, judiciously selected the results of one pair of pupils that she knew exemplified the desired relationship:

> Dr Kepwick: Unfortunately some people [in fact almost all] had problems with the fuses on their power packs, but other people managed to get quite dramatic results. So [addressing KK19 by name] can you tell me what you got?
> KK19: Two [paperclips] for two [turns], twelve for ten and twenty-three for twenty.

These results, that showed the relationship between the observables that Dr Kepwick was keen for the pupils to discover, were then entered on to the results table on the board (Table 6.5) that the pupils were then required to copy down:

Table 6.5 Dr Kepwick's completed results table

<table>
<tr><td></td><td colspan="2">Number of coils</td><td>2</td><td>10</td><td>20</td><td></td></tr>
<tr><td></td><td colspan="2">Number of paperclips picked up</td><td>2</td><td>12</td><td>23</td><td></td></tr>
<tr><td></td><td>Metal core</td><td colspan="4">No metal core</td><td></td></tr>
<tr><td>Number of paperclips picked up</td><td>Better</td><td colspan="4">Worse</td><td>{ 10 coils
6 V</td></tr>
</table>

Whilst Dr Kepwick subsequently asked other pupils to state their results, she made no comment about the fact that most of these showed no discernible correlation between the number of turns on the core and the number of paperclips picked up. Rather than stating, in the face of what was clearly the overwhelming evidence to the contrary, that the number of paperclips that could be suspended from the end of the electromagnet increased with the number of turns on the coil, Dr Kepwick asked the same pupil, whose results she had used for the data in the table, to summarise what they had learnt from the task:

> Dr Kepwick: So [addressing KK19 by name], what are we going to take away from this lesson remembering about electromagnets?
> KK19: The more coils you have the more electricity, the higher the number of paper clips.

Dr Kepwick appeared reluctant to either accept or reject this summary because, as she made clear in the interview after the lesson, she did not fully understand the underlying physics:

> Dr Kepwick: Like when the lad [KK19] said about more current flowing through the wires. Well the current doesn't actually change, does it? In that the current coming out of the power pack is still the same and all these things I'm like asking myself, and thinking 'just don't focus on that' because I'm not entirely sure.

The above examples illustrate how, in a small number of tasks, the pupils were unable to *learn* what the teacher intended about observables simply because the task was ineffective in terms of getting them to produce the desired phenomena. However, as has been reported in chapter 5, most of the tasks observed were effective in getting the pupils to do what the teacher intended with observables and, as such, enabled the overwhelming majority of them not only to produce the desired phenomena and or data but to learn what the teacher intended them to learn about observables.

Yet what can be seen (Tables 6.2, 6.3 and 6.4) is that even if it is assumed that most of the tasks undertaken by the pupils prior to this study were as effective in enabling the pupils to successfully produce the intended phenomena as most of those observed – arguably a reasonable assumption given the widespread and frequent use of closed tasks – this success was not reflected in the pupils' medium or long-terms ability to recollect what the teacher had intended them to learn about observables. Pupil recollections therefore provide an insight into what they retain from a learning activity: something that can subsequently be compared to what it was that the teacher intended them to learn (and hopefully be able to subsequently recollect) from that task.

Consider, for example, the two tasks – those involving the chromatographic separation of dyes – in which the intended learning objective was simply for the pupils to produce and witness a phenomenon. In both tasks what the teacher intended the pupils to learn was, as Mr Saltmarsh informed the researcher, "for the pupils to see that food dyes, that appeared to be only one colour, were in fact made up of a mixture of different colours". Given that both tasks were effective in enabling the pupils to successfully produce the phenomenon of chromatographic separation all of the pupils were able to 'see' what their teacher intended. Indeed, when these pupils were questioned to ascertain what they had learnt (in the case of Miss Nunwick, the learning related not only to this particular task but also to two, and in some cases three, previous occasions on which they had undertaken the chromatographic separation of dyes), all of their responses suggested that these relatively simple learning objectives had been achieved:

> NK8: I expect it to go up with the water until it's almost at the top. It should change colour, each pen should give a different type of streaks of colour.
>
> Researcher: Why did it change colour?
> NK9: Is it 'cause there's different colours made of black, there's different colours going into black, making black, and they're just separating.
>
> Researcher: What have you learnt?
> NK15: There's different inks in different pens [of the same colour].
>
> Mr Saltmarsh: What do your results mean? But already you can say something can't you about these lines and colours. What can you say about those colours even now before we've finished the experiment?
> SHb: Two colours are coming out from the ink.

However, not only did the pupils appear to learn what the teacher intended about observables but it appeared, from the comments of some of the pupils, that some of this knowledge was being recollected from previous tasks on chromatographic separation – tasks that had been presented in the novel context of a murder mystery:

> Researcher: Have you done this before?
> NK11: Yeah, we did it on induction day.
> Researcher: So you've done this before, do you remember it?
> NK11: Yeah, quite well.
> Researcher: What do you remember about it?
> NK11: They made it up to be like a crime investigation thing.
> NK12: A murder thing.
> Researcher: What do you think this practical [they had yet to produce a chromatogram]is meant to show you?
> NK11: That you think something's pure but it's not actually pure.
> NK12: All the different elements in it have different colours I think.
> NK11: Yeah, that are making it up are separating as the water's going up it's gathering them apart.
>
> Researcher: What do you think this is going to show?
> NK3: That different, different pens have different mixtures of colours in them
> Researcher: Right. Why do you expect that? I mean how do you know that?

NK3: Did it before.
Researcher: You've done it before?
NK3: Yeah.
Researcher: Oh, when have you done this before?
NK3: We did it on our induction day as a murder thing [end of Summer term Year 6] and last year [Year 7] and in year three. [The pupil claimed that their teacher had demonstrated this at primary school.]
Researcher: Really? So you've done this three times before this and so you already know what you're going to get. Is this [addressing NK4]the same with you?
NK4: Yeah.

What the above examples illustrate is how the novel context of a murder investigation provides an effective anchor for the recollection, not of ideas as White (1979) has suggested, but of the observable features of the phenomenon itself. This finding was supported by the fact that other pupils, undertaking what were arguably 'ordinary' tasks - 'ordinary' is used here as the antonym of 'unusual' - whilst able to recollect having previously undertaken the same practical were unable to recollect the phenomena and/or data that they had produced:

Researcher: Now have you done this experiment before? [Mr Normanby had informed the researcher that they had.]
NY5: No I don't think so.
NY6: Yeah we have a couple of years ago.
Researcher: Do you remember what happened?
NY5: No not really, no.

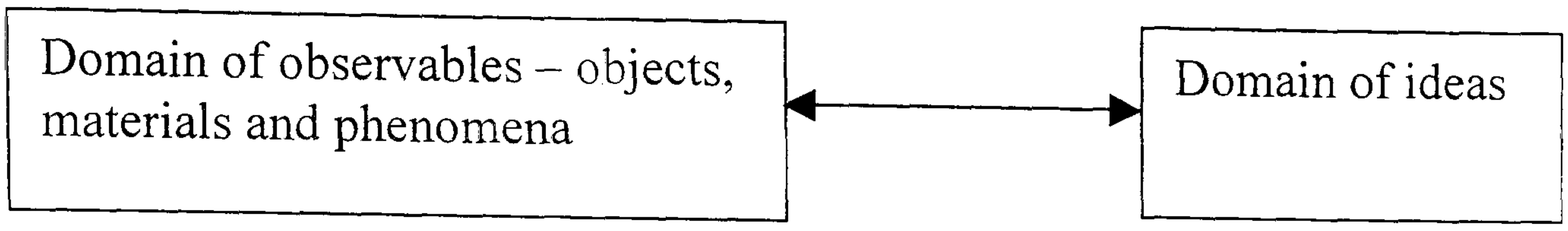
Researcher: Have you done this experiment, or a similar one to this, in physics a few weeks ago?
UF16: Yeah.
UF17: Yes, yeah we did actually but it was with erm, I've forgotten which metal and what we found.
Researcher: But you did it?
UF17: Yeah I remember we did it.

Whilst the successful production of a particular phenomenon and/or data is a necessary requirement if the pupils are to *learn* what the teacher intended about observables, the ability to *recollect* what has been learnt appears, as can be seen in tables 6.2, 6.3 and 6.4, to be correlated with whether or not the task was in some sense unusual. Indeed, as previously discussed, some of the most frequent and vividly recollected tasks were those relating to the visually spectacular teacher demonstrations of the reactivity of group one metals and the Thermite reaction in which the phenomena, successfully produced by the teacher, were observed by all of the pupils. Yet it is important to recognise, given that the pupils were just as able to recollect the visually spectacular burning of magnesium ribbon, or the making of a model suspension bridge, which they carried out for themselves, that it was the 'unusualness' of the task, rather than whether it was demonstrated by the teacher or undertaken by the pupils, that appears to be the critical factor in determining whether or not it is recollected. In this respect the relevance of 'unusualness', rather than the teaching tactic itself, may help to explain why previous studies (Thijs and Bosch, 1995; Garrett and Roberts, 1982; Kruglak and Wall, 1959) found no significant difference in retention rates between pupils undertaking small-group practical work and those observing the same tasks as teacher demonstrations.

6.6 Learning about ideas

Learning in the domain of ideas, as Millar (2004) suggests, "is not discovery or construction of something new and unknown; rather it is making what others already know your own." (p. 6). In this respect the role of practical work in the teaching and learning of science content is to help pupils develop a link (Figure 6.3) between the domain of observables and the domain of ideas (Millar et al., 1999; Brodin, 1978).

Figure 6.3 Practical work: Linking two domains (From Millar et al., 1999 p.40)



Yet in order to succeed in linking these two domains of knowledge it is necessary for pupils to have access to both and, in order for this to occur, they must be helped. not only to produce the phenomenon, but, equally importantly, to think about their observations in a particular way (Lunetta, 1998; Gunstone, 1991). Yet what was found, Tobin (1990) has also reported similar findings, was that because "most teachers seem to be preoccupied with management in laboratory activities" (p. 414) frequently little, if any, time was devoted to helping pupils to think about the phenomena using the ideas that the teachers intended them to use. And yet as Gunstone (1991) makes clear, "for practical work to have any serious effect on student theory reconstruction and linking of concepts in different ways, the students need to spend more time interacting with ideas and less time interacting with apparatus" (p. 74). Certainly because many of the pupils lacked, or did not know how to apply, the relevant scientific ideas that the teachers intended them to use, they were unable to form the link between the phenomena and associated scientific ideas that would have enabled them to understand the former in terms of the latter. As Hodson (1992) has pointed out "It is clear that a child who lacks the appropriate theoretical understandings will not know where to look, or how to look, in order to make observations appropriate to the task in hand, or how to interpret what she/he sees"(p. 68).

The lack of an effective link however between these two domains of knowledge may help to explain why the recollection of an observation in the domain of observables (Tables 6.2, 6.3 and 6.4) did not provide, as White (1991) has suggested that it could, "a strong peg which maintains... the easy recallability of the associated verbal knowledge" (p. 385). Hart et al. (2000) have also reported finding little evidence amongst Year 10 pupils of any attempt to link and explain their observations using scientific knowledge that they already possessed. Whilst the findings of Hart et al. relate specifically to practical tasks in which the pupils have been taught about the scientific ideas needed to help them understand their observations *before* undertaking the practical task, they too suggest that even when pupils have (or are assumed to have) access to the two domains of knowledge they still find it extremely difficult to form links between them.

6.6.1 What did pupils learn about ideas?

Even when the pupils were guided towards forming links between the two domains, as was the case with Dr Starbeck who devoted more time in the lesson in question to 'doing with ideas' than to 'doing with observables' (Table 5.10), there was no evidence that any of the Year 11 pupils, all of whom had undertaken the same task the previous year, were able to recollect either the observables, or ideas, or the links between them. However, many of these same Year 11 pupils were able to recollect an 'unusual' practical activity, also on the topic of current conservation and voltage, that they had undertaken at about the same time the previous year. It should be noted that whilst this task was referred to by the pupils in their recollections as a 'practical', it was a non-practical activity because at no point were the pupils required to observe, or manipulate, real objects. This task was unusual in so far as it required the pupils to form 'circuits' by rearranging the laboratory tabletops on which they were then required to walk or stand, using a form of drama referred to as 'acting out' (Braund, 1999), in order to 'act out' the role of electrons, ammeters, voltmeters, a battery and lamps, with a pile of cardboard boxes being used to represent the energy supplied by the battery to the electrons. This activity, one of the most frequently recollected, supports the view of the National Curriculum Council (1989) that "When pupils act out incidents the experience can help them to remember" (Section C16, 9.3). However, their recollections related only to the unusual nature of the activity – especially being allowed to walk on the tables – and/or to what they themselves had been required to do in terms of acting out, and provided no link to the scientific ideas that both this task, and the one that immediately preceded it, were designed to help develop as the following examples illustrate.

> SW4: One to do with electric circuits. We put all the tables together so that they made, so that they made, they were the wires.
> SW5: Yeah we had to walk on the tables with boxes and people had to pretend to be voltmeters.
> Researcher: What did it show you?
> SW5: [Laughter] I don't know.
> SW4: [Shakes head to indicate that they too do not know]

> SW7: One practical I do remember was an investigation of electrons and he [Dr Starbeck] put all the tables in a big square and he made us lot be like electrons. And that's, that's made me, made me remember it because of how different it was to just er practical.

> SW9: Last year we did this unusual one where we put the tables together and we had to be electrons and walk around on the tables.
> SW8: When we were doing circuits we joined all the tables together and used those boxes there [points to a pile of boxes under a side bench] and we had to be electrons on tables and when you walked past the person who was supposed to be the battery they gave you the box and you walked around and you came to the lamp and you gave it to the lamp and you walk back round and got another box from the battery, and you walked round and you gave it to the lamp and when all the boxes are gone the battery's dead.

It should be noted that, other than in the case of one pupil (SW5) where it was possible that their recollection of this activity was triggered by the recollection of their partner (SW4), all of the other pupils recollected this activity without having heard the recollection of any other pupil during interviews during a practical lesson that had no connection to that topic. However, even though many of the Year 11 pupils, who had undertaken the task in Year 10, were able to recollect what they *did*, generally without any 'triggering', none was able to recollect the scientific ideas that Dr Starbeck had informed the researcher he intended the task to develop: namely that electric charge is conserved and that these charges transfer energy from the battery to the bulb where it is transformed into light and heat energy. Whilst one pupil (SW8) was able to describe the non-scientific model of the electric circuit, there was no evidence of their being able to link this with the appropriate, though relatively difficult (Shipstone, 2000; Driver, et al., 1994), scientific ideas that the task had been designed to develop. Even those pupils who were able to recollect the term 'electron' only used it to describe their role within the drama rather than to represent, as the teacher intended, the idea of a negatively charged particle, the movement of which constitutes an electric current.

Indeed many of those pupils who made the general claim that practical tasks helped them to recollect information did so because they appeared to equate 'learning' with the ability to provide a very brief qualitative description of what they had done and/or seen with observables in a few tasks that contained a memorable episode:

> DE10: I learn more if I do rather than watching someone else.
> Researcher: Can you remember any other practicals that you've done? [Pupils shake their heads to indicate no.] Even in Year 7?
> DE9: Oh yes we did this, made this, cell bag thing.
> DE10: Oh yeah [nodding head to indicate that they too now remember] with wallpaper paste.
> DE9: I learnt loads from that.

Researcher: Wallpaper paste?
DE9: Oh yeah. [Grimaces and indicates manipulating something sticky with their fingers.]
DE10: Yeah, you had to make these cell bags.
DE9: Yeah and I learnt loads from that.
Researcher: What did you learn?
DE9: Everything.
Researcher: What?
DE9: 'cause I got top marks.
Researcher: Ok, but what did you learn, can you tell me?
DE9: Well I've forgotten.

Pupils undertaking food tests, who had initially claimed to learn more from practical tasks than from alternative teaching strategies, still thought it unlikely that they would recollect details of the test for starch after a period of as little as six months:

Researcher: Do you like doing practical work?
UE6: Yeah because I think you learn more than writing out of a textbook.
Researcher: Do you think if I was to come back in six months time and ask you how do you test for starch, what do you use? [Pupils laugh.]
UE7: We'd probably have forgotten.
UE6: Yeah.

Although the teachers' intended learning objectives for most of the tasks recollected by the pupils (Tables 6.2, 6.3 and 6.4) must remain a matter of conjecture, many of these would, it seems reasonable to assume, have included learning objectives within the domain of ideas. However, whilst the teachers might have intended the pupils to learn about certain ideas, and indeed in some cases they might actually have been successful in getting the pupils to do so, there was no evidence that they were able to subsequently recollect these ideas and so the pupils were unaware of having learnt them. These findings support previous claims (Gott and Duggan, 1996; Watson et al., 1995; Clackson and Wright, 1992; White, 1991; Gunstone and Champagne, 1990; Brophy, 1983; Moreira, 1980; Solomon, 1980) that have reported that pupils appear to learn relatively little about the ideas that the practical tasks were designed to illustrate.

6.7 Review

Whilst these findings are by no means a resounding endorsement of the use of practical work, as a means of teaching and learning science content (scientific ideas), it must be recognised that such teaching and learning is likely to be difficult to achieve no matter what tactic is used. Indeed, as Hofstein and Lunetta (1982) have emphasised, many studies that have compared practical work "with more conventional classroom teaching over relatively short periods of time... have reported nonsignificant results, meaning that the laboratory medium was at least as effective in promoting student growth on the variable measured as were more conventional modes of instruction." (p. 212). It might therefore be argued that although practical work may be no more (or less) effective at getting the pupils to learn about science content than other teaching tactics, the very fact that pupils frequently claim to find it less boring, and more enjoyable, than such non-practical alternatives is, in itself, a positive factor in its favour. However, given the disproportionately high cost of providing practical work in secondary schools (Clackson and Wright, 1992) and the claim by White (1996) that "whether laboratories enthuse students or not, few governments, private societies or individuals run schools to provide enjoyment" (p. 761) means that claims regarding its affective value, made by teachers and pupils in this study, need to be examined and it is to this that I now turn.

Chapter 7

The role of practical work in the affective domain

7.1 Introduction

The aim of this chapter is to examine whether practical work can be said to have affective outcomes, and, if so in what sense. The term 'affective' is used here to refer to the emotions, or feelings, engenderd amongst pupils towards science in general and/or one of the sciences in particular.

Hodson (1990) suggests that there are five reasons that teachers might be expected to give for using practical work, one of these being "To motivate by stimulating interest and enjoyment" (p. 34). Hodgson (1998) illustrates this with a quote from a physics teacher who claims that "It [practical work] increases motivation, it increases their understanding, and it backs up what is being taught, it just stimulates more interest in the subject" (p 93). A similar view is expressed in The House of Commons Science and Technology Committee (2002) in which it is claimed that "practical work is absolutely essential in creating enthusiasm" (Question 514).

Some of the teachers in this study certainly used the term 'motivate', when describing the value of practical work and similar claims, by teachers, about the motivational value of 'hands-on' work in mathematics have been reported by Middleton (1995). Yet when two of the teachers, who had each used the term 'motivation', were asked to clarify what they meant by this term they responded:

> Mr Rainton: I think in most instances it's short-term engagement for that particular lesson rather than general motivation towards science. In general I think it's very difficult to motivate kids in year 10 and 11 into

thinking about engaging in science and thinking about science in terms of 'that's a career that I want to follow'.

Miss Sharow: A little bit of practical to motivate them so to speak.
Researcher: So the purpose of the practical was to motivate?
Miss Sharow: Yes.
Researcher: When you say motivate is that more of a long-term thing, to encourage them to like science, or is it to engage them in that particular lesson?
Miss Sharow: Probably just in the lesson, probably yes.

Are then teachers, we might then ask, using this term in its strict psychological sense or as a 'catch-all' term that embodies elements of interest, enjoyment and engagement?

Bandura (1986) suggests that the terms 'motivate' and 'interest' have been used, in the literature (and by teachers involved in this study), to mean the same thing, even though "there is a major difference between a motive, which is an inner drive to action, and an interest, which is a fascination with something" (p. 243). For example Woolnough and Allsop (1985) report that the findings of Kerr (1964) and "others [possibly Thompson, 1975]" (Woolnough and Allsop, 1985 p. 5) have "shown how highly teachers rate *motivational* factors" (p. 5. Italics added). Yet neither Kerr (1964) nor Thompson et al. (1975) makes any reference to the issue of motivation or motivational factors, suggesting only that one of the aims of practical work is to "arouse and maintain *interest*" (Kerr, 1963 p. 21; Thompson et al., 1975 p. 10. Italics added). Similarly Lazarowitz and Tamir (1994) claim that practical work motivates pupils, citing in support of this the findings of Ben-Zvi et al. (1977), Henry (1975) and Selmes et al. (1969) although all of these studies focused almost exclusively on the issue of pupil *interest* rather than *motivation*. Of these three cited sources it is only in one (Henry, 1975) that the term 'motivation' is mentioned, and even then it appears only once in the final paragraph, when Henry, citing no sources, simply states that "In addition, psychological reasons can be proposed which relate to the improved motivation of pupils by the inclusion of laboratory exercises in the science program" (p. 73).

Furthermore the frequent claims made about the affective value of practical work, both in the literature and amongst teachers, make it necessary to consider how terms such as 'motivation', 'interest' and 'engagement' can be effectively operationalised. It is, after all, relatively easy to make general claims about the affective value of practical work. It is quite another to state what such claims actually mean in terms of specific observable consequences.

7.2 Motivation

In order to distinguish clearly between 'motivation' and 'interest', the term 'motivation' will be used to refer to that which engenders "an inner drive to action" (Bandura, 1986, p. 243) whilst 'interest' will, following the definition proposed by Krapp et al. (1992), be used to refer "to a person's interaction with a *specific* class of tasks, objects, events or ideas" (p. 8. Italics in original). Motivation, in the context used here, is an enthusiasm for and/or curiosity about science that, in terms of observable consequences, might manifest itself in a pupil's decision to actively pursue the study of one, or more, science subjects in the post-compulsory phase of their education or in additional voluntary actions undertaken by the pupil. Such actions might include participating in a science club, doing more than required for homework (or, at the very least, doing all that is required well), reading science books/magazines, watching science programmes on television, viewing science based web sites, visiting places of scientific interest and the like. The comparison of claims regarding the motivational value of practical work, with pupils' actions both in and out of the laboratory, and their stated intentions as to whether they intend to pursue science in the post-compulsory phase and, if so, in which of the three sciences (and the reasons for this), provides a useful means of appraising the extent to which such claims are supported by the evidence. If, as has been claimed (Hannon, 1994; Lazarowitz and Tamir, 1994; Ames, 1992; Henry, 1975), practical work does motivate then, given that biology offers the least amount of practical work of any of the three sciences, it might be expected that it would be the least popular science to be pursued post-compulsion. The findings of the House of Commons Science and Technology Committee (2002) suggest that in fact the converse is true and "the proportion of A level entries accounted for by chemistry and physics is falling…while biology has largely retained its popularity" (p. 23). Echoing this point a head of department (Mr Normanby) drew specific attention to the fact that "more of our pupils do biology [at A-level] although, if I'm not mistaken, there is a lot less practical work in biology [at Key Stages 3 and 4] than in say chemistry or even physics". A similar, albeit more general, point was made by another teacher (Mr Saltmarsh) who claimed that "A lot of kids that I teach do probably less practical in biology than any other of the sciences but a lot of them prefer biology to chemistry and physics". Logically speaking it could be argued that without the frequent use of practical work in chemistry and physics throughout Key Stages 3 and 4 the number of pupils pursuing these two subjects might be even lower. However, the increased use of practical work that accompanied the Nuffield inspired changes to the curriculum during the 1960's did not, as Hodson (1990) has pointed out, result in any reported increase in the number of pupils choosing to pursue science post compulsion, as might have been expected had practical work been an effective motivating factor. Similarly a report by the Department of Education and Science (1968) (The Dainton Report), produced at a time when Nuffield inspired changes to the curriculum might have been expected to increase the uptake of science at 'A' level, found that the number of pupils pursuing science at this level had actually *decreased* – a finding that subsequently became known as the 'swing from science'. There is however a need to recognise that the educational system in England, in which pupils are required to specialise at the end of Key Stage 4, must result in some pupils not pursuing their study of science because of positive choices in favour of other subjects, rather than negative views of, or a lack of motivation towards, science. However, the old adage that 'actions speak louder than words' lends credence to the claim by Bennett (2003) that, whilst certain practical tasks can generate interest and/or engagement within a particular lesson, there is little evidence to suggest that they motivate pupils towards science in general or even towards one of the sciences in particular.

7.3 Interest

Prenzel (1992) suggests that the term 'interest', as commonly used, "describes preferences for objects" (p. 73), where the term 'objects' is used in a very broad sense as, for example, when someone claims to have an interest in sport. Within the psychological literature the term 'interest' is used more precisely to refer to "a person's interaction with a *specific* class of tasks, objects, events, or ideas" (Krapp et al., 1992, p. 8. Italics in original). An example of which would be the interest shown by some people in solving cryptic crosswords. Whilst it has been claimed (Hidi and Harackiewicz, 2000) that this description of interest is widely accepted, many psychological theorists make a distinction between what have been termed 'personal' and 'situational' interest (Hidi and Harackiewicz, 2000; Bergin, 1999). In order to evaluate what is actually meant by claims that 'practical work generates interest' it is necessary to understand that these two types of interest differ appreciably from one another and that each has its own set of characteristics. These will now be explored in a little more detail.

7.3.1 Personal interest

Personal interest, sometimes referred to as 'individual' interest, is primarily concerned with the relative ranking of an individual's preferences. Indeed, as Bergin (1999) makes clear, the "individual approach [to interest] asks what dispositional preferences people hold, or what *enduring* preferences they have for certain activities or domains of knowledge" (p. 87. Italics added). Recent studies in the area of personal interest (Renninger, 1998; Schiefele, 1996; Ainley, 1994) have found that children who undertake a particular activity, or study a subject, in which they already have a personal interest will, relative to children with no prior personal interest, be observed to pay closer attention to, learn more from, and engage for longer with, any new material that they are presented with. The relationship between personal interest in, and knowledge of, a subject or activity arises because individuals prefer, when given a choice, to study what already interests them (Bergin, 1999). By increasing their knowledge of that subject, or activity, they increase their personal interest in it yet further (Alexander, 1997; Alexander et al., 1995; Deci, 1992) developing what might usefully be thought of as a system of positive feedback.

There are numerous factors that can stimulate personal interest. Bergin (1999) suggests relevance, competence, identification, cultural value, social support, background knowledge and emotions, all of which are, generally speaking, beyond a teacher's immediate domain of influence. Whilst personal interest can be an important factor in effective learning (Schiefele et al., 1992), one that is characterised by a positive feelings towards, and an increased knowledge of, a subject or activity (Bergin, 1999; Schiefele, 1998, 1991), it is not something that is, in the short-term, susceptible to teacher influence (Hidi and Harackiewicz, 2000; Bergin, 1999).

7.3.2 Situational interest

Situational interest refers to the interest that is stimulated in individuals as a consequence of their being in a particular environment or situation (Hidi and Harackiewicz, 2000; Bergin, 1999; Krapp et al., 1992) such as, for example, when pupils undertake a practical task within a science laboratory. Unlike personal interest, situational interest *is* susceptible to teacher influence in the short-term (Hidi and Berdorff, 1998; Hidi and Anderson, 1992). Whilst it is far less likely than personal interest to endure over time (Hidi and Harackiewicz, 2000; Murphy and Alexander, 2000), it does provide an opportunity for teachers to influence the effectiveness of pupil learning in specific lessons in a positive manner (Hoffmann and Häussler, 1998; Mitchell, 1993). Furthermore, it has been suggested (Hidi and Harackiewicz, 2000; Hidi 1990) that the stimulation of situational interest would be of the greatest benefit in influencing learning amongst pupils with little or no personal interest.

Whilst this distinction, between personal and situational interest, is useful in considering the type of interest that practical work might stimulate it must be recognised that whilst personal interest is relatively stable, and hence resistant to influence by the teacher, it is not immune to situational influence. In discussing the generation of personal interest Bergin (1999) stresses that "personal or individual factors always interact with situational factors to create interest, or lack of interest" (p. 89). Hidi and Harackiewicz (2000) illustrate this interaction by way of the following example:

> [S]tudents who are exposed to an exciting lecture in psychology may be stimulated and pay more attention in class than they ever have before. For some students, this interest may evaporate as soon as the lecture ends. For others, the interest triggered in this situation persist over time and may develop into individual [personal] interest in psychology. (p. 155)

Despite the possible role of practical work in stimulating situational interest there has been no specific research to ascertain what particular situational factors, if any, make a practical task appear more, or less, interesting to the pupils. To date the only studies that have been undertaken on the issue of how to increase pupil interest have been those that have examined the factors that influence the degree of situational interest stimulated by different types of text (Hidi and Anderson, 1992; Hidi, 1990; Wade and Adams, 1990; Garner et al., 1989; Anderson et al., 1984). These studies have shown that situational interest is stimulated to a greater extent by texts that were characterised by the researchers as surprising, vivid, intense and novel. This is corroborated by the findings of this study. Practical tasks that formed memorable episodes (White, 1996, 1991) also shared these same characteristics (Tables 6.2, 6.3 and 6.4).

Furthermore it should also be recognised that, whilst it has been reported that pupils' themselves claim to like practical work (Ben-Zvi et al., 1977; Hofstein, et al., 1976; Henry, 1975), or that teachers' claim that their pupils like practical work (Bryant and Marek, 1987; Jakeways, 1986), claims such as these do not necessarily imply that the pupils are in fact interested in it. Schiefele (1991) has claimed that a necessary feature of any personal interest in a subject or activity is that the individual also likes that particular subject or activity. Hidi and Anderson (1992), however, have argued that this is not necessarily the case for situational interest as both 'interest in' and 'liking of' a subject can arise independently of each other. This distinction is succinctly illustrated by Iran-Nejad (1987) who points out that a "snake can be interesting without being liked, and a particular soft drink may be liked without being interesting" (p. 121).

Having distinguished between 'interest in' and 'liking of', it is also necessary to recognise that 'interest in' doing a particular practical task – as evidenced by the pupils' apparent involvement with the objects, materials and phenomena – does not imply cognitive engagement with any, or all, of the intended ideas or concepts. Blumenfeld and Meece (1988) have reported finding that pupils could be fully engaged and seemingly interested in what they were *doing* without their being cognitively engaged with the task in a manner that would have been necessary for them to have learnt what the teacher intended. This suggests that, in terms of the two domains of knowledge (section 3.8), pupils may be interested only (or mainly) in the objects, materials and phenomena and not the ideas. As Kerr (1964) reports "We were repeatedly told by teachers and students that they had been so engrossed in what they were *doing* and how it was done that they had given little thought to why they did it" (p. 20. Italics added). This finding is supported by this study in which it was frequently observed that doing with objects, materials and phenomena, whilst generating short-term engagement (situational interest), did not lead to a similar level of involvement with the relevant scientific ideas. Bergin (1999) has cautioned that although "most teachers aspire to increase the interest of their students, they should keep in mind the fact that interest enhancement does not necessarily lead to learning enhancement" (p. 96).

Having distinguished between motivation and interest, personal interest and situational interest, and between an 'interest in' and a 'liking of' practical work, I now want to examine whether practical work can be said to have affective outcomes in light of the views, actions and intended actions of the pupils involved in this study.

7.4 Pupils' claims to like practical work

Almost all of the pupils questioned in this study said that they liked practical work. When these responses were probed further, during discussions with the pupils, it was however found that in many cases it was not that the pupils actually liked practical work *per se* – although some pupils in Year 7 did appear to and these will be discussed later – but rather that they liked it *better* than most alternative, non-practical, methods of teaching science. In contrast to Head (1982), who reported finding an appreciable minority of pupils who expressed a dislike of practical work, in this study one pupil (DY22) claimed to dislike practical work because they found it boring whilst ninety-six claimed to like practical work. It was not possible, because of time constraints, to question all of the pupils, but there seems no reason to believe that the responses obtained are not representative of the pupils involved in the study as a whole. Pupils' reasons for claiming to like practical work are presented in Table 7.1 in which there are two types of claim: those indicative of a relative preference (containing comparative terms such as; better than, less than, more than), and what might be termed 'absolute' claims (such as: it is fun, it is exciting, I just like it). An asterisk indicates all relative preferences.

Table 7.1 Pupils' reasons for claiming to like practical work

Pupils' reasons for claiming to like practical work	**Number of pupils offering such a response**	**Pupils (N=96)**
* Because it is less boring than writing	47	DE10, DE9, DE11, DE14, DX2, DX3, DX4, DX7, FS9, FS15, FS16, FY3, FY11, FY14, FY15, KD1, KD2, KD7, KD8, KG9, KG10, NK9, NK10, NK16, NK15, NK18, NY2, NY1, NY3, RH2, RH6, RL7, RN3, RN8, SH4, SH5, SH8, SH9, SK1, SK5, SK28, SW1, SY4, SY14, UE1, UE16, UF1,
Because it is fun	16	DE13, FS7, FS9, FS9, FS10, FS11, FY3, KN2, KN7, RH7, SH2, SK8, SK18, SK28, UE12, UY6,
Because you get to make/do things	10	DE6, DX4, DY2, KD8, KG5, KN9, RL7, SH3, SH8, SY14
* Because it is better than listening to the teacher	4	DX7, KK5, NK11, NK15
* Because you will remember it better	3	NY1, RN4, UY5
* Because it is better than reading from a textbook	3	NK11, NK15, NY5
* Because you learn more	3	RH2, RN4, UE6
Because you can see what happens	2	UF1, UE12
* Because it helps you understand better	2	SK1, SY1
Because you get to find things out	1	KG7
* Because it is better than theory	1	SY11
Because it is exciting	1	KN9
* Because it is more believable	1	DE12
Because you gain an experience	1	NK13
* Because it is better than work	1	SH7

Of the ninety-six claims, sixty-five (68%) are indicative of a 'relative' preference for practical work, whilst thirty-one (32%) are 'absolute'. In order to analyse whether there were any trends with age in the views expressed by pupils about practical work, Tables 7.2 and 7.3 show the breakdown of their 'absolute' and 'relative' preferences by Year group.

Table 7.2 Pupil's 'absolute' responses by Year group

Response type 'absolute'	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**
Because it is fun	8	3	1	3	1
Because you get to make/do things	4	3	1	2	0
Because you can see what happens	0	1	0	1	0
Because you gain an experience	0	1	0	0	0
Because it is exciting	1	0	0	0	0
Because you get to find things out	1	0	0	0	0
Total number of responses	14	8	2	6	1

Table 7.3 Pupil's 'relative' responses by Year group

Response type 'relative'	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**
Because it is less boring than writing	12	15	6	10	4
Because it is better than listening to the teacher	0	3	0	1	0
Because you will remember it better	0	0	0	1	2
Because it is better than reading from a textbook	0	2	0	0	1
Because you learn more	0	1	1	1	0
Because it helps you understand better	0	0	0	2	0
Because it is better than theory	0	0	0	1	0
Because it is more believable	0	1	0	0	0
Because it is better than work	0	1	0	0	0
Total number of responses	12	23	7	16	7

Whilst there are no obvious patterns in Tables 7.2 and 7.3 it can be seen that the claims 'because it is less boring than writing' and 'because it is fun' were the most common 'relative' and 'absolute' responses respectively in every Year group.

Whilst the sample size (N=96) was relatively small, and not all Year groups were equally represented, it is still possible to compare the proportion of 'absolute' and 'relative' responses given by pupils in each Year group and these results are presented in Table 7.4.

Table 7.4 A comparison of 'absolute' and 'relative' responses by Year group

Group	Number of 'absolute' responses	Number of 'relative' responses	Percentage (%) of 'absolute' responses	Percentage (%) of 'relative' responses
Year 7	14	12	54	46
Year 8	8	23	26	74
Year 9	2	7	22	78
Year 10	6	16	27	73
Year 11	1	8	13	87

What emerges clearly from table 7.4 is that after Year 7, in which the majority of pupil responses were 'absolute', the situation reverses to one in which the majority of claims, to like practical work, have become statements of relative preference that stays much the same in Years 8, 9 and 10 before shifting even further towards 'relative' in Year 11. One possible explanation for this is that amongst Year 7 pupils many of these practical tasks provide the first opportunity to use scientific equipment and/or materials and this is something that the pupils appear to like in an 'absolute' sense. Many Year 7 pupils spoke excitedly simply about being allowed to use standard pieces of laboratory equipment and/or materials such as Bunsen burners, electrical wire and acids - something that was not observed amongst pupils in later Years. The following extracts are a sample of the comments made by Year 7 pupils.

> FS11: At the beginning of the year we got red cabbage liquid and…
> FS10: [Interrupting.] Yeah it was great fun.
> FS11: We was adding acid to it and different kinds of real chemicals and seeing what colour it turns stuff. It were fun.

Researcher: Do you like practical work?
KG5: Yeah because we get to use proper wire for the first time and we get to use a six vec (*sic)* [volt] battery thing which is very powerful.

Researcher: Do you like practical work?
KN9: Yeah.
Researcher: Why?
KN9: Because you get to make things and do exciting experiments that are exciting.
KN11: And at primary school you didn't get to do anything exciting.
Researcher: You didn't? So you come to secondary school and you can do exciting practical work.
KN9: We did experiments, but nothing that involved Bunsen burners.

What the data in Table 7.4 suggest is that an 'absolute' liking of practical work, that arises out of the fun, enjoyment and excitement that pupils appear to associate with using new equipment and/or materials in what is a novel environment – the science laboratory – starts to wane, for many pupils, during the latter part of their first year at secondary school. Whilst the onset of a decline in pupil interest in science from Year 7 onwards has been previously reported (Bennett, 2003; Doherty and Dawe, 1988; Johnson, 1987; Yager and Penick, 1986), the fact that almost half (46%) of the Year 7 claims (Table 7.4) were already claims of relative preference lends credence to the findings of Pell and Jarvis (2001) that a decline in interest may start *before* pupils reach secondary school.

Because many pupils do not appear, especially after Year 7, to like practical work in itself, the interest that it generates seems to be situational rather than personal (Schiefele, 1991). Situational interest does not persist beyond the period of an individual's interaction with the subject or activity (Hidi and Harackiewicz, 2000; Murphy and Alexander, 2000), in this case a particular practical task. It might therefore be expected that without the regular use of practical work – to re-stimulate situational interest – pupils will perceive science, and/or non-practical science lessons, as boring, *despite* their having used practical work on numerous previous occasions. This does, in fact, seem to be what was observed in this study. The following extracts illustrate how an underlying view that science is 'boring' emerged as soon as it was suggested that practical work, the source of situational interest, be either reduced or removed from science lessons:

> Researcher: What would you think about science if you didn't have practicals?
> RH6: Boring. [Said in a very slow drawn out manner.]
> RH7: Boring. [Said in a very slow drawn out manner.]
>
> Researcher: How do you think a science lesson would be if it didn't have much practical?
> SY3: Well for the majority of last year we didn't have much practical and it got really boring and it started getting [*sic*] complaints to the teacher.
>
> Researcher: What would science be like without practical?
> FY14: Boring.
> FY15: Yeah most of the time.
>
> Researcher: What do you think science would be like if there was less practical?
> KD13: Boring. If you come in and there's no practical it's not as fun, you're just sitting down writing stuff from the textbook.

Such views suggest that whilst practical work can stimulate situational interest this is not being translated into a personal, and enduring, interest in science - one that can be maintained without the continual need for regular practical work. Indeed, the fact that these pupils thought of science without practical work as boring reinforces the view that, whilst practical work might be preferred to 'theory' (Table 7.1), it is not, as the following extracts illustrate, necessarily succeeding in motivating pupils towards science as a subject.

> Researcher: Do you like doing practical work?
> SK15: Yeah.
> Researcher: Why?
> SK18: 'cause it's fun.

Researcher: Would you hope to do any of the sciences after GCSE?
SK18: No not really.
SK19: No nor me.
Researcher: Why's that?
SK18: I'm not into science.

Researcher: Is it that you like practical science or is it that you just like it better than other things?
NK15: Like it better than other things in science.
Researcher: Would you think you'd be doing science after GCSE?
NK15: No. [Shakes head from side to side vigorously to indicate no.]
NK16: No.

Researcher: Have you enjoyed this practical?
SK28: Yeah it was all right; it wasn't as fun as other ones we've had though.
Researcher: Are you going to take science at 'A' level?
SK28: No not really I'm not really in to it all.
Researcher: But you did say you liked practical.
SK28: Yeah but, 'cause sometimes it's fun, and practical's easier than, well, writing.

These claims suggest that some pupils perceive the liking of practical work as separate to, and distinct from, a liking of science. As Kelly (1986) points out, 'science' is used as a generic term for biology, chemistry and physics, and, therefore, pupils' liking for each specific science may be very different. What also emerged was that preference for practical work *within* science did not always imply a preference for science over other school subjects. And whilst there has been relatively little research into subject preferences amongst pupils (Osborne et al., 2003) dispositional preferences are an indication of personal interest (Bergin, 1999) and, as such, indicate how an individual's personal interest in one subject compares with their interest in another. Whitefield (1980) has reported that when pupils were asked to rank their liking of school subjects (practical work in science was not considered separately) chemistry and physics, the two sciences that arguably offer the most practical work, were amongst the least popular school subjects. Yet biology, the school science that arguably provides the least amount of practical work, was ranked as one of the most popular subjects (Whitefield, 1980). The point to emphasise here is that neither the amount of practical work, or pupils' preference for it, seems to provide an explanation for the relative popularity of the subjects. One possible explanation for this is that whilst pupils might prefer practical work they are, as the House of Commons Science and Technology Committee (2002) has reported, "frequently motivated by a longer term ambition to follow a particular career" (p. 23). This is corroborated by the findings of this study. The following example illustrates how one pupil's (SK26) future career aspiration, rather than their preference for a particular subject (chemistry), influences their choice to pursue biology and not chemistry during the post-compulsory phase of their education.

> Researcher: Are any of you three planning on doing science after GCSE?
> SK27: No.
> SK25: No.
> SK26: I might, might probably do biology because I want to do something in sport.
> Researcher: Do you like doing practical?
> SK25: Yeah.
> SK27: Yeah, me too.
> SK26: I prefer chemistry to any of the other sciences.
> Researcher: Why?
> SK26: I find it more interesting, I just like the practical lesson bits, the experiments you do.
> Researcher: Do you like the practicals in biology?
> SK26: They're all right; I don't mind them.
> Researcher: What's different about the practicals in chemistry and the practicals in biology?
> SK26: Well, it's like sorta, chemical reactions.
> SK25: Well you can do more practicals in chemistry can't you.
> SK26: Yeah and there's explosions and fires and stuff like that.
> Researcher: [To SK26] But now you've said you'd like to study biology.
> SK26: Ah yeah, but I'm thinking about what I want to do in later life.

Again career requirements, rather than the amount of practical work, were also, as the following example illustrates, found to be more influential in determining which of the science subjects to pursue post-compulsion.

> Researcher: Which science do you like best?
> KD1: Biology.
> KD2: Biology.
> Researcher: Which science has the least practical in it?
> KD1: Biology.
> KD2: Yeah.
> Researcher: So the fact that you like biology has got no connection to the amount of practical?
> KD2: But if I want to be a nurse I need to do biology.
> KD1: Yeah, and I want to be a vet.

Although preference ranking does not provide an absolute measure of a pupil's liking for a particular subject or activity (Osborne et al., 2003), it does provide a means of comparing an individual's personal interest in a range of subjects and/or activities and – given the claims as to the motivational value of practical work (Hannon, 1994; Lazarowitz and Tamir, 1994; Ames, 1992; Henry, 1975) – of exploring how personal interest in subjects relates to the amount of practical work that they offer.

> Researcher: How do you rate practical work compared to other things that you do at school?
> DX4: I think practical work is better than English because you get to do stuff and experiment and you don't have to write stuff down.
>
> Researcher: If someone said to you that you could do practical science or you could do P.E. what would you do?
> NK16: P.E.
> NK15: P.E.
> Researcher: Practical science or geography?
> NK16: Practical science.
> NK15: Practical science 'cause geography's boring.
> Researcher: Practical science or English?
> NK16: English because we do other stuff. [On later questioning this 'other stuff' was found to be drama.]
> NK15: I don't know which one I'd do.

The implication here is that even when pupils claim to prefer science *practical work* to other subjects, and it must be emphasised here that the preference is not for science as a subject but only for the practical work component within it, their reasons for doing so appear to have little to do with personal interest in the subject *per se*. Many who teach science will probably be aware of pupils who, whilst claiming to find practical work interesting, fun and enjoyable, lack any motivation to do more than the minimum required of them (Brophy, 1983) and, as the following example illustrates, show no interest in science as a subject.

> Researcher: Do you think that practical work encourages you to study science?
> SY13: Yeah.
> Researcher: Are you going to study science after GCSE?
> SY13: Definitely not.

This study has found, as have previous studies, that generally speaking, pupils do not like practical work *per se* (Edwards and Power, 1990; Gardner and Gould, 1990; Hodson, 1990; Denney and Chennell, 1986; Hofstein and Lunetta, 1982). Rather they "regard practical work as a 'less boring' alternative to other methods" (Hodson, 1990 p. 34). Because personal interest entails a liking of the subject or activity for itself (Schiefele, 1991), the kind of liking that leads to preferring practical work to non-practical alternatives is likely to produce, at best, situational interest.

Another way to look at the data in Table 7.1 is to divide the reasons pupils gave for liking practical work into three broad categories:

(i) Reasons that related to their affective response to practical work.

(ii) Reasons that related to doing things with objects and ideas.

(iii) Reasons that related to learning about objects and ideas.

Table 7.5 illustrates the distribution of the pupil responses in terms of each of these three broad categories.

Table 7.5 The distribution of the pupil responses in terms of three generic categories (N=96)

Generic category of response	**Pupils' reasons for claiming to like practical work**	**Number of pupils offering such a response**
Reasons that related to the affective value of practical work	Because it is less boring than writing Because it is fun Because it is better than listening to the teacher Because it is better than reading from a textbook Because it is better than theory Because it is exciting Because it is more believable Because it is better than work	73
Reasons relating to making, doing and seeing.	Because you get to make/do things Because you can see what happens Because you get to find things out Because you gain an experience	17
Reasons relating to learning, understanding and recollecting	Because you will remember it better Because you learn more Because it helps you understand better	6

As Table 7.5 shows, claims in the broad 'affective' category constitute the largest group of reasons given by pupils for liking practical work, accounting for 76% of all responses. It should, however, be pointed out that some of the reasons for liking practical work within this category, as the following quotation illustrates, are less of a positive endorsement of practical work than a desire to avoid having to write and/or do too much work:

Researcher: Do you like practical work?
SW1: Yeah it's better than doing other work.
Researcher: What other work?
SW1: Like writing.
Researcher: Do you think this is going to be an exciting experiment?

SW1: Well it's not exactly exciting but it's better than working all the time in the lesson.
Researcher: Do you think this particular practical helps you in any way?
SW1: No, it's just less boring.

Certainly this pupil's view, that practical work did not involve *working* all of the time, lends credence to the view expressed by one of the teachers (Mrs Ugthorpe) who, when asked why she thought practical work was popular amongst pupils, stated that "I think it's [practical work] just an easy option". Mr Normanby, a head of department, expressed a similar view when he claimed that the popularity of practical work amongst pupils was in part due to the fact that it avoided their "having to think". That pupils prefer the 'easy option' gains support from a comment made by another head of department (Mr Rainton) who suggested that subject choice appeared to have little to do with the amount of practical work offered, or its affective value, since "When you ask kids why they're doing these subjects [non-science 'A' levels] they just say it's easier, that's it, end of story". Such views support earlier findings that pupils' decisions not to pursue science are influenced by their perception of science as difficult (Hendley et al., 1996) and that perceived difficulty can be the main factor in dissuading pupils from deciding to study science at 'A' level (Harvard, 1996).

Of the remaining pupils, 18% cited, as their reason for liking practical work, issues relating to making, doing and seeing, whilst only 6% claimed that they liked it because it helped them to learn, understand and recollect ideas and concepts. What these findings suggest is that despite many of the pupils claiming to like practical work better than non-practical alternatives – in particular writing – very few pupils saw it as a better way of learning about, and understanding, scientific ideas and concepts.

There were some indications that practical activities were better liked than non-practical ones in other subjects, not just in science, and that although it has been reported (Bennett, 2003) that "writing, [is] a task which many pupils report as being something they particularly dislike about science lessons" (p. 86) it is in fact disliked quite generally:

> UE14: Yeah science is like English really. Well English is all right, but boring I don't mind reading in it but writing [shakes head in the negative].
> Researcher: But in English you don't have practical.
> UE15: You do sometimes.
> UE14: At the minute we're doing plays in English and we're acting out parts and that makes it...
> UE15: [Interrupting.] Fun.
> UE14: Yeah fun.
> Researcher: Would English without plays be boring then?
> UE14: Yeah.
> UE15: Yeah.

Exploring this further in the context of other subjects is beyond the scope of this study.

Having analysed pupils' views regarding the affective value of practical work I now want to consider the views of the teachers.

7.5 Teachers' views on the affective value of practical work

Whist some teachers initially used the term 'motivation' when talking about the value of practical work it emerged, during further discussions with these teachers, that in all but one case – that of Mr Ulleskelf – they were using the term 'motivate' to mean the generation of situational interest – or what some teachers referred to as 'short-term engagement'. The following examples are illustrative of this:

Researcher: If then, at one end of a scale, practical work was said to motivate pupils towards science in general and towards the pursuit of science post Key Stage 4 and at the other end to engage pupils in a particular lesson, where would you place practical work?
Mr Keld: I think it's the particular lesson.

Researcher: If motivation is a continuum where at one end practical work could be thought of as inspiring an interest towards science and at the other end we might talk about getting pupils involved or engaged in a particular lesson, where would you think that particular practical would fall?
Mrs Uckerby: It motivated them in that lesson, it got them involved in thinking about circuit diagrams, which they haven't done for a long time, which they couldn't remember. It wouldn't influence them into taking physics up as a career.

Mr Ulleskelf was the only teacher who indicated that his use of the term 'motivation' meant more than just the generation of non-enduring situational interest within a particular lesson.

Mr Ulleskelf: But it does have a motivating effect on most [academic ability] groups.
Researcher: Now when you say motivating do you mean encouraging pupils to go beyond the requirements of the syllabus, to enhance their curiosity and understanding about science or whether, by motivation, you mean it gets them engaged in that particular lesson and therefore it's important to have practical frequently otherwise they lose the sense of engagement?
Mr Ulleskelf: Both, but it's the latter one that's more important in terms of actually getting across a piece of information and getting the understanding, particularly with your lower [academic] ability sets.

Once it is recognised that the term 'motivating' was used by almost all of the teachers not to imply "an inner drive to action" (Bandura, 1986 p. 243) but rather what, in psychological terms, would be referred to as situational interest, the effect of which would be unlikely to endure beyond that particular lesson (Hidi and Harackiewicz, 2000; Murphy and Alexander, 2000), the need continually to re-stimulate the pupils', through the regular use of practical work, becomes more understandable. It might be argued here that the fact that pupils entered the laboratory at the start of lessons given by Mr Drax and Dr Kepwick requesting to do practical work exemplifies the motivational value of practical work and that its frequent use is designed to enhance the effect. However, the fact that it was reported by the teachers that the absence of practical work for even a few lessons, even amongst pupils who have been undertaking regular practical work for almost five years, made them behaviourally harder to manage suggests that its affective value is better understood in terms of its generating non-enduring situational interest than any form of enduring motivation towards science as a subject.

7.6 The value of situational interest

Having clarified the fact that what most of the teachers in this study referred to as motivation was, in fact, situational interest, I want now to examine the reasons given by teachers for wanting to generate what is essentially a non-enduring form of interest. What emerged from the comments made by the teachers was that they perceived practical work as having two, very distinct, affective purposes:

(i) To help in the behavioural management of the class - particularly with low to low/middle academic ability pupils.

(ii) To help off-set the image of science as difficult, dull and boring by presenting an alternative (arguably misleading) image of science in which the emphasis is primarily on 'doing' fun and enjoyable 'hands-on' work rather than on learning about ideas.

It is to a consideration of these two purposes that I now turn.

7.6.1 The role of practical work in behaviour management

Some of the comments made by the teachers in this study, as the following examples illustrate, show how pupils frequently arrive at science lessons with the expectation, or at least a hope, that they will be able to do practical work:

> Miss Sharow: I do find they expect practical. I think it builds on from years 7, 8 and 9, there's quite a lot of practical in all of them. It builds up from there and when they get to years 10 and 11, you know, lots of the practicals they've done before, you know, there's not the opportunity for it and, but I guess they've learnt to expect it. But they do come in the door and say 'Are we doing practical?' before they're even in the door, you know, 'Are we doing any practical?'.
>
> Mr Drax: You know as soon as they come through the door they're asking 'sir are we doing practical today?'

Although the researcher observed similar questions being asked by pupils as they entered the laboratory, it appeared that those keenest on doing practical work – as evidenced by the numbers asking and their repeatedly shouting out the same question – were often pupils of low academic ability who subsequently informed the researcher that they had no intention of pursuing science post compulsion. For many of these pupils the hope of doing practical work appeared to owe more to their desire to avoid writing (Table 7.1) than any genuine personal interest in doing practical work. This desire to avoid writing was recognised, and commented upon, by a number of the teachers. The following extracts are examples of these comments.

> Mrs Duggleby: I think all people have got this idea about science and practical work. Ok practical work and they [these other people], if you say 'practical work for kids' they will just go 'yes that's fantastic and engaging' but I think there's an element of 'well we [the pupils] don't like writing down and so we want to get on and do something like that'. I think there are so many other subjects in school where they're writing that anything that's practically orientated they'd prefer to do that.

> Dr Kepwick: It is a carrot with them [academically low ability pupils], it is more about making it bearable. For them it's just less writing. I think higher ability pupils could get by with fewer practicals but [non-practical science lessons would] still engage and interest them.

One teacher (Miss Sharow) saw the use of a laboratory, especially for non-practical science lessons, as problematic in the sense that laboratories, unlike classrooms, are essentially designed, with their uncomfortable stools, and benches containing sinks, power points and gas taps, for *doing* rather than sitting and writing (Donnelly, 1998).

> Miss Sharow: I think the whole thing generates an expectation for practical work [gestures around the laboratory], just the lab, you know, the gas taps, the water taps. So when they come in and it's not a normal classroom, you know, if they were sitting in a normal classroom, you know, they'd be thinking, you know, 'alright, we're not going to do practical because there's nothing to use.' Where as they come in here and see all the equipment out at the back [points to equipment at the back of the laboratory], gas taps and, you know, I think being in the lab raises expectations of practical work.

Whether the pupils' expectations and/or hopes to undertake practical work in science lessons are driven by a genuine personal interest in practical work, or merely by a desire to avoid having to write, what is clear is that these expectations and/or hopes are real. Therefore what is important, especially from a teacher's perspective, is the question of how pupils react to those lessons, or sequences of lessons, in which their expectations and/or hopes to do practical work are not fulfilled. Amongst the teachers in this study what emerges, as the following examples show, is a widespread perception that without interspersing practical work into a teaching sequence on a frequent and regular basis pupils become not only uninterested but also noticeably more difficult to manage, in terms of their behaviour, during non-practical lessons:

Researcher: And if you say no [to doing practical work]?
Miss Sharow: Murrrrr. [Pulls a face that appears to indicate something unpleasant.]
Researcher: So do you find it makes it harder for you as a teacher if you can't give them practical?
Miss Sharow: Yeah, that's what I'd say. [Nodding head vigorously in agreement.] It's certainly like that with some of the classes like that. [Year 11 - weakest academic ability class.]

Mr Normanby: The kids soon work out which teacher gives more practical work and certainly, for most classes, two lessons of theory on the trot is about the limit, after that they'll be very hard to teach. It's carrot and stick really.

Mr Saltmarsh: They come with the hope that they are going to do practical.
Researcher: If they don't get practical?
Mr Saltmarsh: It can be awkward.

Mr Drax: You know, as soon as they come through the door they're asking 'Sir are we doing practical today?' If I say 'no' I've lost them even before they sit down. If I say 'yes' I can keep their interest and, although they still might not learn anything, they will be easier to deal with.

Mr Rainton: At least they'll be engaged and it'll prevent them from any sort of disruption of any kind. It will allow the other kids, who are on the sidelines, to actually progress and do some work [without disruption].

This last point, made by Mr Rainton, was echoed by Mrs Ramsgill who, when interviewed after a lesson in which a number of academically low ability pupils had continuously misbehaved and disrupted the learning of others in the class, pointed out that:

Mrs Ramsgill: It's hard to get anything done when they [the disruptive pupils] don't feel like doing practical work.
Researcher: Would non-practical have been easier?
Mrs Ramsgill: No [screws up her eyes and shakes her head], that'd have been even worse.

Another teacher (Mr Keld) claimed that to cope with poor behaviour amongst Year 10 pupils, behaviour that he attributed to their not having undertaken practical work for a *few* lessons, that was disrupting a non-practical lesson, he had felt obliged to say to them " 'You haven't done any practical, I know you like doing it, and there's going to be two next week. So if you can just keep going with the theory this week'. So I don't try to sell it to them but I do let them know that there's a light at the end of the tunnel." Similarly Mrs Duggleby reported using the possibility of practical work later in the lesson "as a carrot, you know, 'can you be quite please because we're going to do some practical'. "

Taken together these claims suggest that for many of the teachers in this study, particularly those involved in teaching science to pupils of low academic ability who have little, if any, personal interest in science, there was a concern about the need to establish and maintain what Brown and McIntyre (1993) refer to as a "Normal Desirable State of Pupil Activity (NDS)" (p. 54) and a recognition that the frequent use of practical work, irrespective of how effective it was in terms of achieving the desired learning objectives, was an effective strategy for coping with poor behaviour. Certainly the view expressed by Richmond (1978) that "Most physics teachers would answer the question 'Who Needs Laboratories?' with the answer 'I do' " (p. 49) was echoed by Mrs Ramsgill who claimed "It [the use of practical work] can make my life easier".

If practical and non-practical work are equally effective (or ineffective) in terms of developing conceptual understanding then the very fact that, as Mr Drax suggests, the use of practical work means that "I can keep their interest and, although they still might not learn anything, they will be easier to deal with" provides a pragmatic justification for using practical work. Yet in order for practical work to be effective in getting pupils of all academic abilities to do, and see, what the teacher intended –

frequently without the need to engage at a meaningful conceptual level – the practical tasks were invariably of a closed 'recipe' style. The advantage of these, as Kirschner (1992) notes, is that "Years of effort have produced "foolproof" experiments where the right answer is certain to emerge for everyone in the class if the laboratory instructions are followed" (p. 278).

It should therefore come as no surprise to find academically low ability pupils exhibiting their displeasure, through poor behaviour, when required to write and/or think for themselves about scientific ideas rather than simply being allowed to *do* a cognitively undemanding 'recipe' style practical task.

Amongst some of the teachers there was, as the following extracts illustrate, a perception that for some low academic ability pupils practical work was essentially just 'something for them to *do*' in order to make both their time, and therefore hopefully the teachers' time, bearable. In such cases there appeared to be little, if any, expectation on the part of the teacher that any meaningful learning would occur:

> Miss Sharow: I mean some of the ones we've got are very weak and they're so weak they can't even do the calculations, you know, so they can't even plot the graph, you know, it's [practical work] just something to do with them.
>
> Mr Rainton: Because, if nothing else, it's [practical work] a relief, it's something different they're doing.
>
> Mrs Ramsgill: It [practical work] gives them something to do, especially the ones who get bored with too much writing

'Recipe' style practical tasks did appear to be a relatively effective means of keeping most of the pupils engaged during the lessons observed in this study. However, I would suggest that its use helps to generate a liking not for science *per se* but for a specific part of science – practical work – in which the emphasis is primarily on doing with objects, materials and phenomena rather than learning about ideas. Some teachers (Mrs Duggleby, Dr Kepwick, Mr Normanby and Mr Saltmarsh) actually referred to their use of practical work as a 'carrot' and it seems reasonable to assume that, in this context, it is non-practical 'theory' that constitutes the 'stick'. It is not surprising, given such a 'carrot' and 'stick' approach to practical, and non-practical, work that pupils appear reluctant to engage with the 'theory', or 'stick', side of the subject in a manner that would be necessary if science teaching and learning was to be "an interplay between experiment and theory" (Millar, 1991 p. 43).

7.6.2 The role of practical work in helping to foster a view of science as fun, exciting and enjoyable

One of the most disappointing findings to emerge from this study has been the fact that pupils, from as early as the end of Year 7, have moved from claiming to like practical work in an 'absolute' sense to merely preferring it to other non-practical teaching methods and approaches (Table 7.4). One factor that might help explain this change in pupils' perceptions emerged during discussions with teachers at Kyle school, where the lesson observations occurred during a period when the teachers were actively considering the arrangements for an impending Open Evening for prospective Year 6 pupils and their parents. What came out of these discussions was an acknowledgement that the image of secondary school science that these Year 6 pupils are encouraged by the teachers to 'see' (Ogborn et al., 1996) during these initial school visits is designed to inculcate an image of science as being primarily a fun, exciting and enjoyable *practical* activity:

Mr Keld: We'll do things that are the most interesting, so we try to sell it. The whole ethos behind Open Evening that is put down from the top of the school, from the SMT [Senior Management Team] through the head of department to us, is it wants to be interesting and good, and good fun.

Mrs Kettlesing: On Open Evening we always do whiz, bang, pops. The only physics thing we have out is the van de Graaff.
Researcher: What do you think then of this image of science as being all whiz, bang, pops?
Mrs Kettlesing: Maybe we're giving a false picture, I think we are probably. There aren't that many whiz bang, pops and most science is really about how does the world work and testing things out, why is this happening, why is that happening, rather than whiz bang, pops

When asked to explain the purpose of such an approach Mrs Kettlesing suggested that the reason was that "We're trying to make it appear more exciting, I suppose because it isn't exciting all of the time." It should also be noted that Mrs Uckerby, when questioned about the use of practical tasks on Open Days, expressed views that were very similar:

Researcher: Can I ask what you do on Open Days?
Mrs Uckerby: Do you mean how or what?
Researcher: What you actually do.
Mrs Uckerby: Each science puts on a selection of practicals and pupils, and their parents, wander around and try them out.
Researcher: What type of practicals do you use?
Mrs Uckerby: We try to use something eye catching and exciting and it's important, I think, that the kids find it fun.
Researcher: What would you do in physics?
Mrs Uckerby: I tend to have the van de Graaff out. The kids, and parents love it, although what with health and safety that will sadly probably have to go. But I also like imploding drinks cans and making plasticine boats to support as many coins as possible.
Researcher: Do you feel that is representative of practical work in general?
Mrs Uckerby: Definitely not [laughing] but I've got to compete with biology's dissection and, I mean, how often do they do dissections?

These quotations suggest that many teachers recognise that practical work is not, generally speaking, fun and exciting and that there are only a limited number of practical tasks – the 'whiz' 'bang' 'pops' – that can be used on Open Days, or the like.

when such an image needs (or is required) to be presented. The atypical nature of such tasks was also evident in a letter from the head of science at Ouse School, to head teachers of local primary feeder schools, regarding the itinerary for a Year 6 'Science (chemistry) in Action Day' in which it was stated that the pupils would spend the day "making Chemical Worms, Bouncing Custard, Chemical Gardens and the *usual* explosions" (Italics added). Whilst it would be possible for the pupils to learn something about the scientific ideas associated with these tasks it seems more likely, given that the event was only to last two hours, that these practical activities were chosen to present a particular image of science. It must be emphasised that I (as a physics teacher) am not suggesting that science is never fun, exciting and enjoyable (far from it) but that such an image does not truthfully reflect 'normal' school science. One teacher (Miss Kilburn) saw the main problem as being that 'normal' school science was simply not sufficiently exciting for enough of the time:

> Miss Kilburn: I think a main problem is that we don't do enough exciting stuff and lots of them have got bored by year 10 and 11 just when we'd ideally want them to be switched on to science because they're bored of dull experiments that look at how springs stretch as you add more weight, but that's what we've got to do, it's such a pity really.

Another teacher (Mr Fangfoss) suggested that it was the quantity rather than quality of practical work that was important particularly amongst low academic ability pupils who were not expected to pursue science post compulsion:

> Mr Fangfoss: We try to give them [academically low ability pupils] as much practical work as possible so that they will remember science as being enjoyable and interesting.

Although this view was expressed by only one teacher it suggests that when practical work is used with pupils of low academic ability the aim might not be to motivate them to study science beyond Key Stage 4 but rather to provide them with a positive recollection of the subject. The clear implication, if this view is taken to its logical conclusion, is that it becomes more important for the teacher to ensure that the pupils enjoy their lessons, irrespective of whether they learn or not, and that the best way to achieve this is to maximise the amount of time spent 'doing' practical work.

Some of the claims made by teachers within this study about the value of practical work appear, as the following examples serve to illustrate, to reflect the fact that their own positive recollections of school science involve specifically memorable *practical* episodes:

> Miss Kilburn: I was lucky really because when I was at school my science teacher ran a science club at lunch time and, even now, I can remember us all getting shocks from the van de Graaff. It made it so much fun.
>
> Mr Fangfoss: I still remember dissecting a rabbit and enjoying doing it.

Whilst such recollections suggest that these teachers' views as to the affective value of practical work have at least been influenced by their own experience as pupils, it must be remembered that these are the recollections of people who, from an academic perspective, did well in science and who chose to pursue it as a career. Using such recollections to inform their current beliefs about the affective value of practical work fails to take account of the fact that, in all likelihood, the vast majority of their peer group at school did not find the same practical tasks exciting, interesting and/or fun and probably chose not to pursue science post compulsion.

7.7 Review

This chapter has argued that what teachers have referred to as 'motivation' is, in a strict psychological sense, better understood as non-enduring situational interest. The fact that situational interest, unlike personal interest or motivation, is unlikely to persist beyond the end of a particular practical lesson (Hidi and Harackiewicz, 2000; Murphy and Alexander, 2000), helps to explain why pupils' need to be continuously re-stimulated by the frequent use of practical work. Once this fact is recognised the reason why many of those pupils who claim to like practical work also claim to have little, if any, personal interest in science, or any intention of pursuing it post compulsion, becomes clearer. For whilst these pupils *do* like practical work their reasons for doing so appear to be (Table 7.1) primarily that they see it as *preferable* to non-practical teaching techniques that they associate in particular with more writing (Edwards and Power, 1990; Gardner and Gould, 1990; Hodson, 1990; Denney and Chennell, 1986; Hofstein and Lunetta, 1982). However, what has also been shown (Table 7.4) is that the proportion of pupils, within each Year group, who claim to like practical work in its own right, as against simply preferring it to writing, decreases as the pupils progress through the school. One contributory factor to this, which has been suggested, is that pupils are, during visits to the school in Year 6, presented with an artificial image of school science, in which science and practical work are essentially one and the same and that practical work has, as its key features, 'fun', 'excitement' and 'enjoyment'. Yet, it would seem, from the pupils' comments, that within their first year at secondary school, during which time the novelty of being in a laboratory environment appears to wear off, they become disillusioned by the fact that the *reality* of school science is very different from the image that we, as teachers, initially seek to create in order to make our subject appear attractive.

Finally, this chapter has considered the affective value of practical work as a means of contributing towards effective behaviour management. In this respect teachers' comments have shown that when faced with having to teach science to pupils, and this is particularly so at Key Stage 4, who have little, if any, interest in science, or in some cases of even being in the lesson, practical work provides an effective 'coping' strategy. Whilst teachers felt that it was unlikely that these pupils would learn any more from practical, than non-practical, work it was thought that the use of practical work made them easier to deal with from a behavioural perspective. Whilst this might be considered as a 'lost' learning opportunity, it is arguable that amongst those pupils who have already 'switched off' the use of practical work might mean that their perception of science will be less negative than it might otherwise have been were they compelled to undertake more demanding, non-practical, work.

Chapter 8

Conclusion

8.1 Introduction

This chapter has five main sections. The first (section 8.2) provides a summary of the three previous chapters, each of which addressed one of the three research questions set out in section 3.10. Aspects of some of the teaching practice observed raised concerns about the rhetoric/reality divide, and section 8.3 will look at these and how they might be explained. The third (section 8.4) looks at the study with the benefit of hindsight and evaluates how some of the decisions and choices made may have affected the outcomes. In addition, section 8.4 suggests areas in which it might be advantageous, in terms of both educational policy and practice, to carry out further research. How the study has contributed towards educational knowledge and understanding is considered in section 8.5, whilst the fifth (section 8.6) suggests some implications of the findings for practice and research, and offers some tentative suggestions as to how practical work could be made more effective.

8.2 Research findings

In this thesis each of the three research questions has been addressed and answered in a separate chapter. It is therefore not the aim of this final chapter to merely re-present these findings in full. Instead I want to revisit each research question in turn and, in so doing, offer a reasonably brief answer to each, so as to highlight the main findings of this study.

8.2.1 To what extent was practical work observed to be effective in enabling pupils to *do* what the teacher intended?

Practical work was, generally speaking, relatively effective in enabling the great majority of the Key Stage 3 and 4 pupils observed, irrespective of their academic ability, successfully to do what the teacher intended them to do with objects and materials, and so produce the required phenomena. Whilst various factors contributed towards this effectiveness, two of the most evident were the use of 'recipe' style tasks, designed to reliably produce a particular phenomenon (Kirschner, 1992) if those undertaking it adhered to the 'recipe', and the allocation of a large amount of the total lesson time to presentation, and clarification, of procedural instructions. Because a particular piece of practical work was likely to be considered as having 'failed' if the pupils were unable to produce the desired phenomena, teachers tended to focus their attention on ensuring that pupils understood the procedure so as to maximise the likelihood that they would all successfully produce the desired phenomena. Time constraints, and the fact that 'doing something with ideas' was not a necessary pre-requisite for the successful production of phenomena, meant however that when using 'recipe' style tasks relatively little time was devoted specifically to getting the pupils to do what the teacher intended them to do with ideas, i.e. to think about the objects, materials and phenomena they were seeing in a particular way or, as Ogborn et al. (1996) have suggested, in getting the pupils to "See it my [the teacher's] way" (p. 130). Even when time was devoted to getting the pupils to 'do things with ideas', as for example in the practical lesson taught by Dr Starbeck, the ideas were kept relatively simple to ensure that there was sufficient time not only to get the pupils to think about the objects, materials and phenomena, using the intended ideas, but also to get them to produce the desired phenomena.

In answer to this research question the study found that, in general, practical work as currently practiced in a representative sample of schools is:

(i) Effective in getting pupils to *do* what the teacher intended with objects, materials and phenomena.

(ii) Only occasionally effective in getting pupils to *do* what the teacher intended with ideas.

8.2.2 To what extent are specific practical tasks effective in enabling pupils to *learn* what the teacher intended?

As regards learning, practical work was found to be more effective in getting pupils to *learn* what the teacher intended about objects, materials and phenomena than it was in getting them to learn about ideas. A plausible explanation for this is that to be effective in getting pupils to learn what the teacher intended about objects, materials and phenomena requires only that they be able later to describe qualitatively what they have seen and/or be able to formulate simple relationships about observables, such as 'more of x means more of y' (Stavy and Tirosh, 1996) where 'x' and 'y' are both directly observable quantities. Given the observed effectiveness of practical work in enabling pupils to produce the desired phenomena it seems reasonable to expect that most pupils will be able to achieve what are essentially intellectually undemanding learning objectives.

Yet whilst some pupils were able to describe their observations, and/or formulate simple relationships about the data, during, or immediately after, the practical lesson, most pupils were unable, without assistance, to recollect more than a few examples of the practical work that they had undertaken during their time at secondary school.

Indeed, even when pupils were able to recollect practical work it was found (Tables 6.2, 6.3 and 6.4) to relate primarily to practical tasks that were, in some sense, 'unusual', and that these recollections related almost exclusively to what had made that particular task – or something associated with it – unusual rather than what the teacher might have intended them to learn and recollect. For example pupil recollections about the Thermite reaction centred on the fact that it was visually spectacular, took place out of doors, and needed to be undertaken on a platform of bricks that they, the pupils, had been required to carry out for this purpose. There was also no evidence that 'memorable events' (White 1979), such as the Thermite reaction, were providing an anchor point, or 'trigger', for associated scientific ideas that might have been learnt within the teaching sequence in which the practical lesson was embedded, such as, in the case of the Thermite reaction, reactivity sequences or oxidation and reduction reactions.

In terms of getting pupils to learn about the ideas intended by the teacher, all of the observed practical lessons, other than in the atypical case of Dr Starbeck, were wholly, or to a large extent at least, ineffective. One way of helping to understand the reason for this is to think of the 'learning about ideas' as being the final step in a process that depends necessarily on the pupils having succeeded not only in *doing* and *learning* what the teacher intended about objects, materials and phenomena but also in *doing* what the teacher intended with ideas. A failure to wholly, or partially, achieve any one, or more, of these pre-requisites adversely affects the pupils' ability to *learn* about the ideas intended by the teacher within that particular practical lesson. Indeed the strong emphasis placed by the teachers on getting the pupils to 'produce the phenomena' resulted in teachers not including in their lesson plans the need to devote teaching time specifically to providing the conceptual 'scaffold' (Bruner, 1978; Wood, Bruner and Ross, 1976) that is required to help with the development of the pupils' conceptual understanding.

This study has found that, in general, practical work as currently practiced in a representative sample of schools is:

(i) Effective, at least in the short-term, in getting pupils to *learn* what the teacher intended about objects, materials and phenomena.

(ii) Generally ineffective in getting pupils to *learn* what the teacher intended about ideas and rarely designed in order to achieve this (or even in a way that takes account of its difficulty).

The findings on the effectiveness of practical work, both in terms of *doing* and *learning*, are summarised and presented in Figure 8.1 using a generic 2 x 2 effectiveness matrix.

Figure 8.1 A 2 x 2 matrix representation of the general effectiveness of practical work

Decreasing effectiveness

Intended outcomes	in the domain of observables (Domain o)	in the domain of ideas (Domain i)
at level 1 (what pupils do)	Generally very effective.	Only occasionally effective. However this effectiveness is limited to simple, and/or basic, ideas.
at level 2 (what pupils learn)	Generally effective in the short term. However this effectiveness is limited to descriptive accounts of procedure and phenomena and/or simple relationships between observables.	Generally *in*effective. There was some evidence to suggest that even when effective the pupils were unable to recollect the ideas over the long term.

What can be seen from Figure 8.1 is that the effectiveness of practical work differs between the two domains. This is not to say that there is no difference in the effectiveness of practical work in terms of 'doing' and 'learning', indeed it can also be seen in Figure 8.1 that practical work is more effective at getting pupils to 'do', across *both* domains, than it is in getting them to 'learn'. Yet it is the difference in effectiveness between domains that provides an explanation as to why, generally speaking, practical work was found to be relatively ineffective in providing the link between these two domains (Millar et al., 1999; Brodin, 1978), a link that is needed if learning of scientific ideas is to occur *within*, or as a direct result of, practical lessons.

8.2.3 Does practical work have affective outcomes?

A common claim is that practical work is valuable for affective, rather than purely cognitive, reasons. It was found that practical work had affective outcomes in the sense that it generated non-enduring situational interest or, what some teachers referred to as, 'short-term engagement'. There was little evidence that it produced or enhanced longer-term motivation to study science and some that it did not. From the pupils' perspective it was found (Table 7.1), with the exception of some Year 7 pupils, that their claims to like practical work were, in fact, statements of *relative* preference in which practical work was not liked in its own right, but merely preferred to other methods of teaching *within* science lessons. Indeed, the relative nature of their preference for practical work was also illustrated by the fact that many of those pupils who claimed to like practical work also claimed to have no intention of pursuing science post compulsion.

Even amongst the relatively small number of pupils who did claim to want to pursue science post compulsion, their reasons for doing so were, without exception, linked to career aspirations, or university entrance requirements, rather than to a personal interest in the subject or a liking for, or enjoyment of, practical work. Furthermore, practical work appeared to have little influence on the choice of which of the three sciences pupils intended to study, with biology the most popular choice, despite the claim by pupils, and some of their teachers, that as a subject biology contained the least amount of practical work, of any of the three sciences, throughout Key Stages 3 and 4.

It was also found that the pupils who expressed the strongest desire to *do* practical work, as evidenced by their repeated characteristic calls, from the moment they entered the laboratory, of 'Can we do a practical today sir?' or 'Are we doing a practical today miss?' were generally those in academically low ability classes in which the pupils were the most adamant about their dislike of science and their desire to drop it at the earliest possible opportunity.

In contrast to the claims made by pupils, most of the teachers, at least when initially questioned, used terms such as 'motivation', 'enjoyment' and 'interest' interchangeably, when expressing their views about the affective value of practical work. Yet, when these views were probed in greater depth, it became apparent that the use of these terms bore little, if any, relationship to their strict psychological meaning. Indeed, the affective value of practical work, for most of the teachers questioned, was principally a form of 'short-term engagement' or what, in the psychological literature (Hidi and Harackiewicz, 2000; Bergin, 1999; Krapp et al., 1992), is referred to as non-enduring situational interest. It also emerged that there was a recognition, especially amongst those teaching academically low ability pupils, that even if practical work was no more, or less, effective in the teaching of scientific ideas or concepts than other teaching tactics (Hofstein and Lunetta, 1982), the fact that these pupils preferred *doing* practical work made teaching them, particularly in terms of their behaviour, appreciably easier.

This study has found that practical work is:

(i) Generally affective, but only in the sense of providing short-term, engagement (non-enduring situational interest).

8.3 An overview of practical work

Having summarised each of the three research questions I now want to draw these findings together so as to provide an overview of practical work as currently practiced in a representative sample of schools. In order to provide an overview of practical work I want to start by suggesting that many teachers use practical work, despite the professional reasons that they might give, because they feel that doing so is an integral part of what it *means* to be 'a science teacher' (Donnelly, 1998). That is, part of the essence of being 'a science teacher' entails the use of practical work whenever possible in their teaching practice. This is not, of course, to claim that all science teachers who use practical work are necessarily *effective* teachers. From this perspective, claims made by teachers as to the effectiveness, and affective value, of practical work do not necessarily reflect firmly held personal beliefs, but represent what they believe to be appropriate professional responses that they provide when challenged to justify their use of practical work. Such a view shares a number of similarities to that suggested by McClelland (1984) who claims that this form of response "may be said to be part of the professional armoury of those like teachers and politicians who may be faced with unexpected questions in circumstances where an admission of ignorance might be damaging" (p. 4). Whilst I would suggest that 'ignorance' is too strong a claim, the findings of this study do suggest that teachers provide responses to questions about their professional practice that they believe science teachers (qua science teacher) are expected to give – and this might be country dependent – rather than what they might actually believe. This form of response has been referred to previously as 'role selection' (Anderson et al., 1975; Webb et al., 1966) and it is characterised by a respondent's "selection of responses perceived as "proper" or expected in the situation." (Anderson et al., 1975 p. 319). In this context I would suggest that the terms 'proper' or 'expected' can be seen as reflecting "taken-for-granted traditions of practice, articulated with the explicitly more normative (though not necessarily more powerful) canons of 'good practice' " (Donnelly, 1998 p. 594).

The fact that similar claims about the effectiveness, and affective value, of practical work have been made by teachers just completing their teacher training (Wellington 1998), as were made by experienced teachers in this study, suggests that these beliefs and/or claims are adopted, as part of a body of accepted professional wisdom, by many trainee teachers or perhaps even prior to starting their teaching career. Indeed, it is highly probable that some of the teachers within this study, who, for example, talked about the 'motivational' value of practical work, and/or its effectiveness in developing pupils' conceptual understanding, would, as mentors themselves, have made similar claims when discussing the use of practical work with trainee teachers.

Hodson (1996) has suggested that "because experiments are widely used in science. intending science teachers become socialized, during their own science education, into regarding them as essential to science education" (p. 756). It is the adoption, and use, of these beliefs and/or claims that, I suggest, indicates a teacher's membership of what might usefully be described as the 'teaching community'.

That teachers make such claims in the belief that they reflect the accepted wisdom of the educational community helps to explain why they felt justified in making them even though, in this study, only one teacher had knowledge of any educational research in the areas relating to their claims. Ratcliffe et al. (2004) have also found that, despite the claims that teachers make, "Few teachers gave examples of the influence of particular pieces of research, or research findings... More commonly research influences were referred to in *general* and *unspecified* terms... for example as supporting a teacher's preference for using practical work" (p. 72. Italics added). Yet the findings reported by Wellington (1998) also show that some trainee teachers, when questioned about why they would use practical work, offer a more 'pragmatic' set of reasons. The claims made by these trainee teachers appear, from their similarity to some of the claims made by pupils in this study, to reflect their *personal,* as opposed to *professional*, beliefs about practical work based, arguably, on their own experiences as pupils. For example, some of the claims as to why practical work should be used included: " 'to make a change from theory work'; 'something else to do apart from lessons'; 'keeps kids quiet'; 'makes lessons more interesting'; 'they break up lessons to keep the kids entertained'; 'fun – sometimes!'; 'nice change' " (Wellington, 1998 p. 6). Similar pragmatic responses were given by some of the more experienced teachers within this study, when they felt more relaxed, and less professionally challenged, in the presence of a researcher – for example over a coffee in the staff-room, rather than in the laboratory during the lesson observation. Many teachers appeared to operate a form of 'dualism' in which 'appropriate' professional responses were given when responding to questions in a professional capacity, whilst another set of pragmatic responses, such as those listed above, were given when responding to questions in an informal capacity. This is not to suggest that any particular set of responses – professional or pragmatic – is, in some sense, a better representation of the 'truth' about what teachers actually believe than another just that two distinctly different views are given. However, the issue of how and why practical work was used, as well as the findings relating to both its effectiveness and affective value that emerge from this study, are, I suggest, easier to understand if we see the pragmatic, rather than the 'appropriate' professional, reasons as the primary influence on how teachers use practical work. If pragmatic reasons, such as those listed above in which practical work is essentially perceived as an enjoyable *alternative* to 'theory', are seen as influencing teachers' practice, then it helps to explain why teachers place the emphasis on doing with objects, materials and phenomena rather than learning about ideas or 'theory' in what is essentially seen as a *practical* lesson - by which I mean a lesson devoted primarily to 'hands-on' rather than cerebral activity.

This is not to say that the teachers do not appear to *expect* pupils to learn as a result of getting them to successfully do with objects, materials and phenomena. That teachers' frequently included the learning of scientific ideas amongst their objectives for a practical lesson indicates, from the evident lack of planning as to *how* pupils will learn from doing and the fact that very little, if any, time was devoted to scaffolding the development of appropriate ideas, that many teachers still appear (consciously or unconsciously) to accept the validity of a 'discovery based' view of learning. These teachers consider themselves justified in expecting that the ideas that they intended the pupils to learn will 'emerge' from the phenomena and/or data of their own accord provided only that the pupils are able to produce them successfully (Solomon, 1994; Driver, 1983). And whilst the pupils *did* learn, by successfully producing the phenomena, what they learnt about was observable features of objects, materials and phenomena rather than about ideas. This is not to say that scientific knowledge cannot 'emerge' as a consequence of personal discovery but rather, as has been pointed out (Newman, 1982; Hirst and Peters, 1970), that:

> [The] natural home [for discovery based learning] would seem to be in contexts where the person is learning essentially on his own, where as a matter of fact there is no teacher, or where there could not possibly be a teacher, because what is to be learnt is as yet unknown... But, by contrast, the whole point of schooling is that there is a teacher whose function it is to bring about learning. (Hirst and Peters, 1970 p. 78)

Even if practical work were only *as effective as* alternative non-practical methods of teaching, in getting pupils to learn, I would suggest that, from a pragmatic perspective, its use still offers two distinct advantages over alternative, non-practical, 'theory' lessons. The first is that pupils claim to like it. Whilst such claims are, generally speaking, little more than statements of relative preference, they still illustrate that even amongst those pupils who claim to dislike science and to have no intention of pursuing it post compulsion, practical work is the preferred method of being taught science. In this context practical work is perceived, both by pupils *and* teachers, as the 'carrot' to the 'stick' of theory. Given that many pupils, especially those of low academic ability, find the cognitively demanding 'theory' part of science much more difficult than simply 'doing' practical work, they often exhibit their frustration and/or displeasure, at having to do 'theory' in which they are far more likely to be seen to fail, through poor behaviour during the lesson.

If, as seems likely, teachers recognise that academically low ability pupils will find learning about scientific ideas difficult, *whatever* teaching tactic they use, then the fact that pupils prefer practical work, and are likely to be better behaved if allowed to do it, means that one important advantage of the use of practical work is that, in terms of classroom management, it makes the *teaching* of science easier despite the added issue of safety in the laboratory.

The second advantage that the use of 'recipe' style practical work, with its emphasis on 'doing' rather than 'learning', offers is that it reduces the need for extended discussion and explanation, that make greater demands on teachers' subject knowledge, making it a particularly attractive option amongst teachers teaching outside of their subject specialism. For these teachers the use of 'recipe' style tasks provides a way of ensuring that, even if they themselves are less than fully secure with the associated concepts, they are still able to ensure that the pupils, by adhering rigorously to the 'recipe' (often part of a departmental scheme of work), are able to do with and, from a 'discovery based' view of learning, learn about objects, materials and phenomena.

Amongst the set of 'appropriate' professional beliefs that the teachers offered was that the use of practical work 'motivated' pupils towards science and/or that it generated personal interest in a subject or topic. Yet, in marked contrast to these 'appropriate' professional beliefs, the teachers' own personal, pragmatic, beliefs were that the affective value of practical work was essentially limited to providing short-term (i.e. non-enduring) situational interest, designed to keep pupils engaged during a specific lesson. Even allowing for the fact that some pupils might be prevented from pursuing science post compulsion, because of the selective nature of 'A' level choice in England, it appears difficult to reconcile the 'appropriate' professional claims, regarding the affective value of practical work, with the undeniable fact that a large number of pupils choose, despite having undertaken practical work regularly over a period of five years, not to pursue science post compulsion. The pragmatic view, amongst some teachers, is that practical work essentially provides a form of short-term engagement, which is viewed by pupils as the most enjoyable option within a compulsory subject. From this perspective pupils' enjoyment of practical work arises because it provides opportunities to 'mess around' and talk to friends, and, as Bennett (2003) notes, this talk is not always about the science task at hand, a view that helps to explain why many pupils claim both to enjoy practical work and yet are just as keen in their desire to drop science at the earliest possible opportunity. Indeed I would tentatively suggest that rather than motivating pupils towards science *per se* doing practical work frequently generates little more than a desire to do ever more practical work as a means of avoiding the need to engage with scientific ideas at a meaningful, if sometimes difficult, conceptual level.

In order to draw together, and make sense of, the findings of this study it is necessary to distinguish clearly between 'appropriate' professional claims - the rhetoric of practical work - and the pragmatic claims made by teachers in their personal capacity - the reality of practical work. What the findings of this study suggest is that it is the pragmatic claims, made by teachers in a personal, rather than professional, capacity that best account for how and why they use practical work. Similarly, by distinguishing between the rhetoric and the reality of the claims relating to the affective value of practical work it may be possible to explain not only why teachers use it, but also why those pupils who claim to like it so much still persist in dropping science in large numbers at the end of Key Stage 4.

8.4 An evaluation of the study and its findings

It is often valuable to look at a study with the benefit of hindsight in order to evaluate the extent to which choices and decisions – in particular, in this case, the use of multi-site case studies employing a condensed fieldwork strategy – have affected the findings. It will focus in particular on the reliability, and validity – both internal and external – of the findings as well as the effect of external constraints on the type and quantity of data collected.

8.4.1 The internal validity of the findings

The internal validity of qualitative research findings relates to the extent to which other researchers presented with the same data, or data collected in a comparable context, would be likely to arrive at the same set of conclusions. Internal validity does *not* necessarily require another researcher, placed in the same situation, to replicate identical findings. Indeed, not only would differences be expected but also their occurrence "would not generally raise serious questions related to validity or generalizability" (Schofield, 1993 p. 93). In qualitative research internal validity is essentially a measure of the extent to which the reader, having been presented with the data, agrees with the conclusions reached by the researcher on the basis of that same data.

In this study the decision to use the 2x2 matrix representation of practical work as an analytic framework was not an arbitrary choice, building as it did upon a two-level model of effectiveness developed by Millar et al. (1999) and Tiberghien's (2000) two-domain model of knowledge. These models, whilst not theories, created a framework for looking at practical work in which certain issues emerged as being worthy of investigation. Although this analytic framework did not predict what the outcomes of this study were likely to be, the framework imposes a way of viewing practical work that, because it differentiates between the two domains of knowledge, and between doing and learning, reduces the likelihood that another researcher, presented with the same data, would be able to arrive at conclusions that are inconsistent with the account provided here. Because of this I would argue that internal validity was achieved with regards to the findings on the effectiveness of practical work. The issue of internal validity, as it relates to the conclusions regarding the affective value of practical work, is more difficult to assess. What can be said is that the internal validity of these conclusions would depend upon the acceptance, by another researcher, of the strict psychological definitions of the various affective terms that have been provided in chapter 7. If these psychological definitions are accepted then there is little room to doubt the internal validity of the conclusions that have been presented.

8.4.2 The external validity of the findings

Campbell and Stanley (1963) wrote that "*External validity* asks the question of *generalizability*: To what populations, settings, treatment variables, and measurement variables can the effect be generalized?" (p. 175). Whilst some quantitative researchers, such as Smith (1975), claim "the goal of science is to be able to generalize" (p. 88), accounts of qualitative research methodology can be found, such as those by Kirk and Miller (1986) and Berg (1989) that make no mention of the issue of external validity. External validity has not only frequently been ignored but it has also been challenged by those within the qualitative methodological tradition, such as Denzin (1983), who argue that the "interpretivist rejects generalization as a goal and never aims to draw randomly selected samples of human experience. Every topic... must be seen as carrying its own logic, sense of order, structure and meaning" (pp. 133-134). Despite such claims Schofield (1993) argues that there is increased interest in the issue of generalisability amongst qualitative educational researchers and that this is reflected in some of the literature on the topic for example, Noblit and Hare (1988), Guba and Lincoln (1982, 1981) and Stake (1978).

One approach, that seeks to avoid what Firestone and Herriott (1984) have termed the 'radical particularism' of the traditional single, in-depth, case study is the multi-site case studies approach used in this study. Schofield (1993) has suggested "the possibility of studying numerous heterogeneous sites makes multisite studies one potentially useful approach to increasing the generalizability of qualitative work" (p. 101). This approach seeks to avoid the objection that "the traditional focus on single-case studies in qualitative research is obviously inconsistent with the requirements of statistical sampling procedures, which are usually seen as fundamental to generalizing from the data gathered in a study to some larger population" (Schofield, 1993 p. 92) by using a larger population sample size in order to increase the population validity of the study.

This study was not designed to meet the rigid requirements of external validity demanded by Krathwohl (1985) who, arguing from a strongly quantitative methodological tradition, claims that the "heart of external validity is replicability. Would the results be reproducible in those target instances to which one intends to generalize" (p. 123). In contrast the aim of this study has been to avoid talking about frequencies and instead paint a broad-brush picture that will enable what Stake (1978) refers to as 'naturalistic generalizations' from the findings obtained in this study to be taken and applied to similar (although not necessarily identical) situations. Whilst Guba and Lincoln (1982) reject the idea of generalisability, the possibility of 'naturalistic generalizations', or what Guba and Lincoln refer to as 'transferability' of hypotheses, appears a realistic aim:

> Generalizations are impossible since phenomena are neither time- nor context- free (although some transferability of these hypotheses may be possible from situation to situation, depending on the degree of temporal and contextual similarity." (p. 238).

Whether it be Goetz and LeCompte (1984) discussing 'translatability and comparability', Guba and Lincoln (1982, 1981) discussing 'transferability' or 'fittingness', or Stake (1978) with 'Naturalistic generalisations', the central criteria for each is ecological validity. Despite the contextual differences between the schools used within this study the fact that data saturation was achieved, in terms of the *types* of things the pupils and teachers did and said, suggests, in terms of ecological validity, that the sample could not have been "markedly dissimilar" (Spindler, 1982 p. 8). Given therefore the representative nature of the schools that comprised the sample it appears reasonable to assume that there will be sufficient contextual (environmental) similarities between the sample and the population from which it is drawn to enable what are essentially broad-brush findings to be transferred to that larger population.

8.4.3 The reliability of the findings

Before considering the reliability of the findings presented in this study it is useful to consider carefully what this term actually means within the context of a qualitative study. Anderson et al. (1975) suggest "A reliable measure is one that provides consistent and stable indications of the *characteristics* being investigated." (p. 325. Italics added). The difficulty in ascertaining the reliability of the findings from this study is that some, although not all, of the characteristics investigated were concepts that were themselves not directly measurable. This study did not, for example, directly measure motivation or interest – either situational or personal; instead it made inferences about these characteristics on the basis of observed pupil behaviour and/or comments. Similarly whilst it was possible to observe directly what pupils did with objects and materials what pupils learnt could only be inferred indirectly from what they were able to recollect when questioned. All studies that are designed to investigate concepts or variables that are not directly observable will necessarily depend upon an indirect form of measurement.

As a means of assessing the extent to which the data obtained from different observations provided a consistent and stable indication of the characteristics being investigated, this study used a combination of lesson observations and interviews with pupils and teachers as a means of triangulation (Yin, 2003; Hakin, 1997; Patton, 1987; Cohen and Manion, 1982). There are of course limitations in a study of this size. In particular the type of access that schools were willing to provide meant that it was not possible to assess the pupils' recollections over the medium, or long, term with regard to the specific practical tasks that they were observed undertaking. However, by questioning pupils about (unobserved) practical work that they had previously undertaken, it proved possible to assess not only the type of practical work that they were able to recollect over the medium, and long, term but also the nature of their recollections (Tables 6.2, 6.3 and 6.4). It cannot be claimed that the recollections of pupils observed undertaking a particular practical task will, in the medium term, or indeed the long term, *necessarily* be the same as those of older pupils who undertook the same, or at least a very similar, practical task when they were of a similar age. However, there appears to be little, if any, reason not to believe that this will be the case.

Yet even if schools had been willing to accede to requests for multiple access visits to facilitate the pre and post-testing of pupils, as another means of indirectly measuring what they had learnt, such tests would necessarily have needed to be specific to a particular class and topic and, as such, would have been extremely time consuming to construct and hard to generalise from. Furthermore the results of such testing would only reveal what pupils learnt from a *sequence* of lessons which might have included practical and non-practical elements rather than from any specific practical lesson embedded within that sequence. Whilst providing an insight into how teachers integrate practical work into their teaching of science topics (Bery et al., 1999), as well as why they chose to use it at a particular point within a sequence of lessons (an area of possible future research) it would be extremely difficult, if not impossible, to ascertain the contribution to any changes in pupil understanding brought about by a particular lesson within such a sequence. It should also be borne in mind that the fact that pupils are sometimes only able to recollect a practical task, within a sequence of non-practical lessons, does not necessarily mean that the non-practical lessons did not contribute towards their overall understanding. It might, for example, be the case that if learning is an incremental process, which occurs throughout a sequence of lessons, the pupils associate their knowledge and understanding of that topic with the only lesson within that sequence that they can recollect on an individual basis – the memorable episode (White, 1979) – which in many cases is the practical lesson.

Given the consistency of the data obtained within this study I would suggest that the findings provide a reliable measure of the effectiveness and affective value of practical work as observed in a representative sample of schools.

8.4.4 External constraints on the design of the study

A number of external constraints influenced the design of the study and, to a limited extent, the reliability of its findings. It is an undeniable fact that teachers perceive themselves to be under increasing pressure, not only from the introduction of 'league tables' that compare school performance in terms of GCSE and 'A' level examination results, but also from other factors such as the amount of coursework and its assessment that they are required to undertake. In real terms this means that teachers are becoming more cautious about agreeing to any request that might possibly impact in a negative way on pupil examination results and so access to lessons had to be negotiated with an awareness of these growing concerns amongst both teachers and schools. It quickly became apparent that whilst most schools were happy to allow 'one-off' opportunities to observe one, two or, in some cases, three different practical lessons, each taught by a different teacher, they were less likely to agree to extended and/or multiple visit access even when it was suggested that this would only be for the purpose of non-participant observation. Access considerations also played a part in the decision not to include practical work associated with 'Science enquiry', Attainment

Target 1 in the national curriculum (DfEE/QCA, 1999), in the study on the grounds that such investigations often extend over a number of lessons and that access to all of these lessons would be difficult if not impossible to negotiate. It was also felt, given that such investigations are almost always carried out in connection with a formal 'high stake' assessment process, in which the teachers' primary concern is not the teaching of science content (and access was always requested to lessons in which practical work was to be used to teach science content) but the achievement of good marks, that the way teachers see and use these 'investigations' would be very different to 'normal' practical work, a view endorsed by Ofsted (2002). As one teacher (Dr Starbeck) made clear:

> When we do investigations [Sc1] I'm perfectly honest with the kids. I'll say to them that, as a piece of science, I think this is garbage, in terms of getting coursework marks it's superb. So we'll just play the game, we'll spend two or three weeks playing the game, getting some good marks, and then we can move on and do some science again. That's intellectual honesty.

8.4.5 Changes to the study design

A change to the initial design of the study became necessary when it emerged from the data collected in the first twenty-four case studies that, despite having apparently achieved data saturation, there was very little convincing evidence that teachers were using practical work to scaffold the development of appropriate ideas. In order to assess whether such scaffolding could be found, it was decided to use the data collected from the first twenty-four case studies to ascertain where it would be envisaged to be most likely to occur and to arrange to observe such a lesson – in effect to seek out a critical case study. This data suggested that the likelihood of observing this would be maximised if the teacher:

- Was teaching within their subject specialism.
- Had very good subject knowledge with regard to the topic that they were teaching.
- Was recognised, by their peers, as a skilled practitioner.
- Was aware of, and their teaching was informed by, educational research.

The teacher selected, Dr Starbeck, is therefore atypical – both in comparison to the other teachers involved in this study and to teachers nationally. He has been teaching for more than twenty years and has held the posts of head of physics and head of science. He has a research degree (in the subject he was to be observed teaching), has achieved Advanced Skills Teacher status, and has also been awarded a national prize in recognition of his teaching. Furthermore he has been involved in various science education initiatives, originating at university level, and is familiar with a wide range of educational research literature that has, he claims, not only informed his practice but caused him to challenge some of the widely accepted beliefs about the teaching of science and, in particular, the use and role of practical work. Whilst access constraints made it impossible to assess what the pupils he was observed teaching were able to recollect, as the lowest level indicator of learning, either in the medium, or long, term, his lesson did provide a clear example as to how practical work can be designed to help pupils to do with and learn about ideas, as well as about objects, materials and phenomena. So whilst this lesson 'proves' that this is possible – and does actually occur – the evidence from this study is that it is rare.

8.5 Understanding practical work

Having evaluated the study, and the reliability and validity of its findings, it might be useful at this point to stand back and consider how the study has contributed to educational knowledge and understanding. Whilst some of the results are not in themselves surprising - the effectiveness of practical work as a means of teaching scientific knowledge has already been questioned (Gott and Duggan, 1996; Clackson and Wright, 1992; Hodson, 1990) - this study has, through the use of a relatively large number of case studies and the systematic collection and analysis of data, provided a considerable amount of evidence that might otherwise have been anecdotal. Furthermore, because of the fact that data saturation was achieved (the critical case of Dr Starbeck was highly unusual and had to be specifically sought) the findings of this study provide a much needed insight into the typical use of practical work in secondary school science. A second contribution made by this study is that it has linked the two-level model of effectiveness, designed by Millar et al. (1999) for use in the study practical work at upper secondary school and university level, with the two-domain model of knowledge, designed by Tiberghien (2000) specifically for the teaching of energy transfer, to form the 2 x 2 matrix representation of practical work. This theoretical structure has then been tested in the context of lower secondary school science practical work and shown to be capable of accommodating a wide range of practical work in a way that provides a useful, and illuminating, framework for analysing the effectiveness of practical work. This suggests that this combined structure – the 2 x 2 matrix representation of practical work – could be useful in further research in this area as well as in continuing professional development (CPD) as a means of helping teachers identify practical tasks which require pupils to make links between observables and ideas. The study has also highlighted the fact that there is little evidence to show that teachers design, or use, practical tasks with the specific intention of developing conceptual understanding or see the need to do so. Indeed it has shown that much practical work takes place within the framework of what appears to be a tacitly accepted 'discovery' based approach to teaching and learning, in which teachers appear to assume that pupils will 'discover' the relevant scientific ideas for themselves simply by generating and observing the appropriate phenomena and/or data. It has also made a new and distinctive contribution to the understanding of the effectiveness of practical work in the affective domain. It has in this respect illustrated that, despite the frequent and widespread claims regarding the motivational value of practical work, what teachers actually mean when they talk about 'motivation', and in fact what practical work has been shown to be effective in generating, is referred to, in psychological terminology, as short-term (non-enduring) situational interest. Moreover, it has drawn attention to the fact that, with the exception of some Year 7 pupils, many of the claims made by pupils to like practical work are, in fact, expressions of relative preference that do not necessarily indicate a liking of science *per se* or reflect a desire to pursue its study beyond Key Stage 4.

8.6 Implications for practice

Science education is, as Millar (1991) has suggested, "irreducibly an interplay between experiment and theory, and so a total separation of theory and experiment is neither desirable nor possible" (p. 43). What this study found was that although teachers used both practical lessons and non–practical 'theory' lessons (the latter, whilst reported by teachers, were not observed as part of this study), there was little, if any, evidence of an interplay between experiment and theory within the context of a practical lesson – the planned and deliberate construction of a bridge that would be necessary to link the domain of observables with the domain of ideas, required if effective learning is to occur. This is not to say that such a linkage might not have been developed in lessons following the practical work observed, but that it did not occur during the overwhelming majority of the practical lessons observed nor did any of the teachers state or imply that it would be developed in subsequent lessons.

Two principal implications for practice arise from this study. Firstly there is a need for greater clarity amongst teachers about what pupils can realistically be expected to achieve, *both* in terms of 'doing' and 'learning', in practical lessons that seldom last more than sixty minutes and, with arrival and registration at the beginning of the lesson and the need to pack away at the end, are, in reality, unlikely to exceed fifty minutes. Secondly there is a need, as Millar (2004) has pointed out, for teachers to recognise that "Ideas and explanations do not simply 'emerge' from data" (p. 3). If pupils are to *learn* from, rather than merely produce, phenomena, the 'discovery based' view of learning that was clearly evident within this study, despite its rejection by most philosophers of science (Millar 2004), needs to be replaced by a hypothetico-deductive view of learning in which teachers recognise that 'doing' with objects, materials and phenomena is unlikely to lead to the pupils 'learning' about scientific ideas and concepts unless they are also provided with what Wood, Bruner and Ross (1976) term a "scaffold" (p. 90). The process of scaffolding provides the initial means by which pupils are helped to 'see' the phenomena in the same 'scientific way' that the teacher 'sees' it (Ogborn et al., 1996). Indeed, as Lunetta (1998) has argued, "laboratory inquiry alone is not sufficient to enable students to construct the complex conceptual understandings of the contemporary scientific community. If students' understandings are to be changed towards those of accepted science, then intervention and negotiation with an authority, usually a teacher, is essential" (p. 252). The issue then is the form that this intervention and negotiation with the teacher takes and the extent to which the need for it is acknowledged and built into the practical task by the teacher.

An example of a strategy designed to get pupils thinking about a particular practical task, as opposed to merely 'doing' it in a mechanical, often unthinking, manner, is the Predict-Observe-Explain (POE) task structure designed by White and Gunstone (1992). In these (POE) tasks the pupils are required to predict, and write down, what they expect to observe *before* they carry out the task and then, having carried out the task, they have to explain what they observed, which might not necessarily be the same as what they predicted. Although this strategy was used in a number of the observed practical lessons there was little evidence to suggest that teachers (or pupils) saw it as anything other than something that had to be done at the start of a sequence of procedural instructions that were essentially designed to get the pupils to produce the desired phenomenon. In one case, when Mr Overton used this strategy, the pupils were required to predict, by writing either 'yes' or 'no' on a pre-printed table, whether a magnetic field would pass through a particular named material. As Mr Overton focused his introduction almost exclusively on what they were to do with objects, materials and phenomena (Table 5.9) the pupils appeared to see the unexplained *requirement*, that they make a prediction, as something that had to be done before they could move on to the 'real' part of the practical that involved 'doing' with objects and materials. Many of these pupils were observed rushing to complete the prediction table often inserting 'yes' and 'no' responses in what was subsequently found to be an unthinking and essentially random manner. This is not to say that the

POE strategy cannot be effective, indeed both Millar (2004) and Lunetta (1998) have reported that it has been found to be "strikingly successful" (Millar, 2004 p. 10). However, it suggests that if it is to be successful teachers must be helped to appreciate that the Predict-Explain components of the POE are as, if not more, important than the need to generate, and subsequently observe, the phenomena. Another strategy that might be incorporated into a wide range of practical work in order to encourage pupils to 'think', as well as merely to 'do', is that developed by Tiberghien (1996) to help in the introduction of ideas about energy transfer amongst secondary school pupils. This strategy involves presenting the pupils with a prototypical approach, referred to as the 'seed' of a model, for representing simple processes in energy terms and exemplifying its use in one specific example. The pupils are then presented with other examples of energy transfer (electric motors raising weights, weights turning dynamos and the like) and are helped to think about, and represent, these new energy transfer process using the same 'seed' model.

Given the perceived need for, and apparent success of, 'recipe' style tasks as a means of helping to get a large majority of pupils, irrespective of their academic ability, to do what the teacher intended with objects and/or phenomena in the limited time available, it would be both counter-productive, and unrealistic, to expect teachers to abandon their use in practical lessons. However, by recognising the importance of developing a pupil's conceptual understanding of the phenomena, as well as merely getting them to produce them, teachers might be encouraged to divide the time available within practical lesson more equitably between 'doing' and 'learning'. This is not to say that 'doing' and 'learning' need to be rigidly separated, but that teachers should try to devote a greater proportion of the lesson time to helping the pupils to use the ideas associated with the phenomena that they have produced, rather than seeing the successful production of the phenomena as an end in itself. Clearly, given the time constraints under which teachers operate, devoting a greater proportion of time to 'learning' is achievable only if less time is devoted to 'doing'. Yet what was observed in the practical lesson taught by Dr Starbeck was that these two objectives are not mutually exclusive. Indeed, by using a closed, 'recipe' style, task to enable the pupils to quickly, and successfully, complete relatively *short* practical tasks, Dr Starbeck was able to devote an approximately equal amount of time to the development of a teaching model that served as a scaffold between the pupils' observations and the scientific ideas that he intended them to learn about.

One possible suggestion that might help in achieving this more equitable division of lesson time, between the domains of 'observables' and 'ideas', would be for teachers to make use of the 2 x 2 effectiveness matrix to audit the practical tasks they use. By suggesting that teachers fill in such a matrix for each task it would help them to consider and address the specific issue of what they intended pupils to 'do' and 'learn', not only in the domain of observables, but also in the domain of ideas. By breaking their objectives up into 'doing' and 'learning' in both domains, teachers may be better able to plan how to allocate time to each objective and, because the completed matrix provides evidence as to what would be required of the pupils *if* the practical lesson was effective, they can focus their attention on how best to achieve these aims. It is therefore tentatively suggested, given the potential value that the use of such a matrix offers, that teachers might be introduced to its use either during initial teacher training (ITT) or within the framework of a continuing professional development (CPD) programme.

In conclusion it must be recognised that although science deals with the natural world, practical work cannot be used to make science into something it is not – a *solely* 'hands-on' activity. We use novel and exciting practical tasks to arouse pupils' interest in our subject from the moment they visit our secondary schools on Open Day in Year 6. However, if we are successful it is often as a result of having presented an image of science that, whilst exciting, fun and enjoyable, is false and ultimately unsustainable. In effect what we have sold the pupils is not a science that involves meaningful cognitive engagement with difficult ideas, but a science that is quintessentially a simple, conceptually undemanding, 'hands-on' type activity that anyone can do, with little need for much thought, provided that they follow the 'recipe'. As long as the façade holds then we, and our subject, remain popular. However, we cannot put off indefinitely the need to teach the pupils about what are, relatively speaking, conceptually challenging scientific ideas and, as a consequence, it becomes ever more difficult to maintain the façade that we have created. Indeed this study has found that the façade has already begun to crumble from as early as the end of Year 7. Likewise because we use practical work to present a particular image of science, an image designed to appeal to pupils of all academic abilities, it should come as little surprise to us that pupils come to see practical work as being the 'nice', conceptually undemanding, part of science and arrive at science lessons hoping to do it. Indeed we, as teachers, help to create this image of practical work by removing anything that we perceive as being detrimental to the effective 'doing' of the practical task, such as the need to write which, for example, we minimise with the use of work sheets. We reduce or remove the need for independent thought, and the possibility that such thought presents for error, by using highly structured 'recipe' style tasks to ensure that all our pupils, irrespective of whether they think about the task or not, are able to produce the phenomenon that we want them to see. Many pupils like this because doing without thinking is an 'easy' option. What the findings of this study suggest is that, for most of the teachers observed, the focus of their attention was on getting the pupils to 'do' with, and 'learn' about, objects, materials and phenomena rather than the cognitively more demanding 'doing' with, and 'learning' about, ideas relating to those phenomena. Furthermore, their use of a method of teaching that is preferred by the pupils, and is arguably no less effective in getting the pupils to learn about ideas than a method of teaching that they do not like, often makes the issue of class management easier. Whilst there might be situations when health and safety considerations preclude allowing pupils who are behaviourally difficult to manage, and who have little interest in science, to undertake practical work, these will arguably constitute only a fraction of the practical tasks that could be used safely with such pupils.

I would like to end by suggesting that the overall effectiveness of practical work can be improved but that if this is to happen it is essential that teachers be helped, both in pre- and in-service training, to appreciate the role of practical work as a bridge between the two domains of knowledge. If this is to occur it will also require teachers to relinquish the 'discovery based' view of learning, in which 'doing' and 'learning' about ideas are seen to emerge of their own accord from the successful production of a phenomenon, and embrace a hypothetico-deductive approach in which practical work needs to be designed with the explicit aim of helping to 'scaffold' (Wood, Bruner and Ross, 1976) pupils' efforts to form links between the domain of objects, materials and phenomena and the domain of ideas.

APPENDICES

Appendix A.1

Practical task: Profile form
(From Millar et al., 1999)

A1 Intended learning outcome (learning objective)

To help pupils identify objects and phenomena and become familiar with them	a
To help pupils learn a fact (or facts)	b
To help pupils learn a concept	c
To help pupils learn a relationship	d
To help pupils learn a theory/model	e
To help pupils learn how to use a standard laboratory instrument, or set up and use a standard piece of equipment	f
To help pupils learn how to carry our a standard procedure	g
To help pupils learn how to plan an investigation to address a specific question or problem	h
To help pupils learn how to process data	i
To help pupils learn how to use data to support a conclusion	j
To help pupils learn how to communicate the results of their work	k

B1.1 What pupils are intended to do with objects and observables

Use	an observation or measuring instrument	a
	a laboratory device or arrangement	b
	a laboratory procedure	c
Present or display	an object	d
Make	an object	e
	a material	f
	an event occur	g
Observe	an object	h
	a material	i
	an event	j
	a quantity	k

B1.2 What pupils are intended to do with ideas

Report observation (s)		a
Identify a pattern		b
Explore relation between	objects	c
	physical quantities (variables)	d
	objects and physical quantities	e
Invent or ('discover') a new concept (physical quantity or entity)		f
Determine the value of a quantity which is not measured directly		g
Test a prediction	from a guess	h
	from a law	i
	from a theory (or model based theoretical framework)	j
Account for observation	in terms of a given explanation	k
	by choosing between two (or more) given explanations	l
	by proposing an explanation	m

B1.3 Objects or Ideas driven

What the pupils are intended to do with ideas arises from what they are intended to do with objects	a
What the pupils are intended to do with objects arises from what they are intended to do with ideas	b
There is no clear relationship between what the pupils are intended to do with objects and with ideas	c

B1.4 Degree of openness/closeness

Question to be addressed	specified by teacher	a
Equipment to be used	specified by teacher	b
Procedure to be followed	specified by teacher	c
Method of handling data collected	specified by teacher	d
Interpretation of results	specified by teacher	e
Question to be addressed	decided by teacher-pupil discussion	f
Equipment to be used	decided by teacher-pupil discussion	g
Procedure to be followed	decided by teacher-pupil discussion	h
Method of handling data collected	decided by teacher-pupil discussion	i
Interpretation of results	decided by teacher-pupil discussion	j
Question to be addressed	chosen by pupils	k
Equipment to be used	chosen by pupils	l
Procedure to be followed	chosen by pupils	m
Method of handling data collected	chosen by pupils	n
Interpretation of results	chosen by pupils	o

B1.5 Nature of pupil involvement

Demonstrated by teacher; pupils observe	a
Demonstrated by teacher; pupils observe and assist as directed	b
Demonstrated by teacher; then carried out by individual pupils	c
Demonstrated by teacher; then carried out by pupils in small groups	d
Carried out by individual pupils	e
Carried out by pupils in small groups	f

B2.1 Duration

Very short (less than 20 minutes)	a	
Short (one science lesson, say, up to 80 minutes)	b	
Medium (2-3 science lessons)	c	
Long (4 or more science lessons)	d	

B2.2 People with whom the pupil interacts

Other pupils carrying out the same practical task	a	
Other pupils who have already completed the task	b	
Teacher	c	
Others (teaching assistants, technicians)	d	

B2.3 Information given to pupils on the task

Oral instruction	a	
Instructions on blackboard / whiteboard/OHP	b	
Guiding worksheet	c	
Textbook (s)	d	
Other (e.g. data book, data base, instruction manual, etc.)	e	

B2.4 Type of apparatus involved

Standard laboratory equipment	a	
Standard laboratory equipment + interface to computer	b	
Everyday equipment (kitchen scales, domestic material…)	c	

B3.1 Nature of pupil's record of work on task

No written record	a
Notes	b
Completion of printed worksheet(s)	c
Written account (using given structure and format)	d
Written account (free format)	e

B3.2 Purpose of record

To assist pupils in learning science content or process	a
To provide evidence that the task has been carried out	b
As a basis for assessing the pupil's performance	c
As a record which the pupil can use to revise for tests or examinations	d
To help pupils learn how to write a scientific report	e

B3.3 Audience for record

The pupil	a
The teacher	b
Other pupil	c
Other	d

Appendix A. 2

Coding categories for sub-dimension B1.1 with examples of each (From Millar et al., 1999)

What pupils are expected to do with objects and observable things	Examples
Use an observation or measuring object	Use a microscope to look at onion skin cells Use an ammeter to measure electric current Use a burette to deliver measured volumes of a liquid
Use a laboratory device or arrangement	Set up distillation apparatus to separate two miscible liquids Use a dissecting kit/scalpel to remove a muscle from a chicken wing Set up a filter funnel to separate a solid from a liquid
Use a laboratory procedure	Carry out a titration to neutralise a given sample Set up a control for a biological investigation
Present or display an object	Carry out a dissection of a heart to display the main features of interest Display a collection of geological specimens to illustrate a particular feature
Make an object	Make a microscope slide to display the cell of a given specimen Make an electric circuit from a given circuit diagram
Make a material	Synthesise a particular chemical substance
Make an event occur	Remove the air from a tin can so that it implodes Carry out physical exercise to increase pulse rate
Observe an object	Note and record the pattern of iron filings sprinkled around a bar magnet Look at some fossil specimens Inspect some rock samples with a hand lens for evidence of volcanic origins
Observe a material	Note and record the shape of crystals of copper sulphate Note and record the physical properties of a sample magnesium oxide
Observe an event	Record the manner in which an animal (an invertebrate, a fish) moves Note what happens when a piece of sodium is placed in water Pass a ray of white light through a prism and note the spectrum produced Make observations of the germination and growth of a broad bean Note whether an object floats or sinks when placed in water
Observe a quantity	Measure the resistance of a piece of wire Measure the melting point of a substance Measure the length of a spring with different loads hanging from it Measure the density of a sample of a solid material

Appendix A. 3

Coding categories for sub-dimension B1.2 with examples of each (From Millar et al., 1999)

What are pupils expected to do with ideas	Examples
Report observation(s)	Describe in detail how a fish moves Describe the shape of crystals of a given substance
Identify a pattern	Note the regular changes in appearance of the moon over a 29 day cycle
Explore relations between objects	Note that a pinhole camera produces an inverted image on the screen
Explore relations between physical objects	Find out how the (extension-increase in length) of a spring depends upon the (load-mass) attached to it
Explore relations between objects and physical quantities	Compare rates of reaction of a selection of metals with dilute acid Investigate the effect of different drinks (tea, coffee, cocoa, etc.) on rate of heartbeat
'Invent' (or 'discover') a new concept (physical quantity, or entity)	Identify the need for (or the usefulness of) the quantity defined as energy/time (power) in accounting for a set of observations
Determine the value of a quantity which is not measured directly	Determine the power of a pupil from measurements of the work done and time taken
Test a prediction based on a guess	Test the prediction that rubber-soled shoes provide better 'grip' on a wooden floor
Test a prediction from a law	Test whether the current through a given conductor is proportional to the applied p.d. (as predicted by Ohm's Law)
Test a prediction from a theory (or model based on a theoretical framework)	Predict the period of a simple pendulum using the relationship $T = 2\pi\sqrt{l/g}$ and then test this by measurement
Account for observations in terms of a given explanation	Explain similarities and differences between related species of birds in terms of a given account of their evolution
Account for observations by choosing between two (or more) given explanations	Is the behaviour observed when the temperature of a sample of air is raised better explained by saying that 'hot air rises' or 'air expands when heated'.
Account for observations by proposing an explanation	Measure the temperature of a sample of water in a calorimeter over a period of minutes as it is heated by an immersion heater. Explain the shape of the temperature-time graph produced

Appendix A. 4

A Practical task profile summary form for Case Study 5 (From Millar et al., 1999)

A1 Intended learning outcome (learning objective)	To help pupils identify objects and phenomena and become familiar with them	a
	To help pupils learn how to carry our a standard procedure	g

B1.1 What pupils are intended to do with objects and observables	Make an event occur	g
	Observe an event	j

B1.2 What pupils are intended to do with ideas	Report observation (s)	a
	Explore relation between objects and physical quantities	e

B1.3 Objects or Ideas driven	What the pupils are intended to do with ideas arises from what they are intended to do with objects	a

B1.4 Degree of openness/ closeness	Question to be addressed	specified by teacher	a
	Equipment to be used	specified by teacher	b
	Procedure to be followed	specified by teacher	c
	Method of handling data collected	specified by teacher	d
	Interpretation of results	specified by teacher	e

B1.5 Nature of pupil involvement	Demonstrated by teacher; then carried out by pupils in small groups	d

B2.1 Duration	Short (one science lesson, say, up to 80 minutes)	b

B2.2 People with whom the pupil interacts	Other pupils carrying out the same practical task	a
	Teacher	c

B2.3 Information given to pupils on the task	Oral instruction	a
	Instructions on blackboard/whiteboard/OHP	b

B2.4 Type of apparatus involved	Standard laboratory equipment	a

B3.1 Nature of pupil's record of work on task	Written account (using given structure and format)	d

B3.2 Purpose of record	To assist pupils in learning science content or process	a
	As a record which the pupil can use to revise for tests or examinations	d
	To help pupils learn how to write a scientific report	e

B3.3 Audience for record	The pupil	a

Appendix A.5

A Practical task profile summary form for Case Study 10 (From Millar et al., 1999)

A1 Intended learning outcome (learning objective)	To help pupils learn a fact (or facts)	b

B1.1 What pupils are intended to do with objects and observables	Observe a quantity	k

B1.2 What pupils are intended to do with ideas	Identify a pattern	b

B1.3 Objects or Ideas driven	What the pupils are intended to do with ideas arises from what they are intended to do with objects	a

B1.4 Degree of openness/ closeness	Question to be addressed	specified by teacher	a
	Equipment to be used	specified by teacher	b
	Procedure to be followed	specified by teacher	c
	Method of handling data collected	specified by teacher	d
	Interpretation of results	specified by teacher	e

B1.5 Nature of pupil involvement	Demonstrated by teacher; then carried out by pupils in small groups	d

B2.1 Duration	Short (one science lesson, say, up to 80 minutes)	b

B2.2 People with whom the pupil interacts	Other pupils carrying out the same practical task	a
	Teacher	c

B2.3 Information given to pupils on the task	Oral instruction	a
	Guiding worksheet	c

B2.4 Type of apparatus involved	Standard laboratory equipment	a

B3.1 Nature of pupil's record of work on task	Completion of printed worksheet(s)	c

B3.2 Purpose of record	To assist pupils in learning science content or process	a
	As a record which the pupil can use to revise for tests or examinations	d

B3.3 Audience for record	The pupil	a

Appendix 6

A Practical task profile summary form for Case Study 12 (From Millar et al., 1999)

A1 Intended learning outcome (learning objective)	To help pupils learn a relationship	d

B1.1 What pupils are intended to do with objects and observables	Make an object	e
	Observe a quantity	k

B1.2 What pupils are intended to do with ideas	Report observation (s)	a
	Identify a pattern	b
	Explore relation between objects and physical quantities	e

B1.3 Objects or Ideas driven	What the pupils are intended to do with ideas arises from what they are intended to do with objects	a

B1.4 Degree of openness/ closeness	Question to be addressed	specified by teacher	a
	Equipment to be used	specified by teacher	b
	Procedure to be followed	specified by teacher	c
	Method of handling data collected	specified by teacher	d
	Interpretation of results	specified by teacher	e

B1.5 Nature of pupil involvement	Demonstrated by teacher; then carried out by pupils in small groups	d

B2.1 Duration	Short (one science lesson, say, up to 80 minutes)	b

B2.2 People with whom the pupil interacts	Other pupils carrying out the same practical task	a
	Teacher	c

B2.3 Information given to pupils on the task	Oral instruction	a
	Instructions on blackboard/whiteboard/OHP	b

B2.4 Type of apparatus involved	Standard laboratory equipment	a

B3.1 Nature of pupil's record of work on task	Written account (using given structure and format)	d

B3.2 Purpose of record	To assist pupils in learning science content or process	a
	As a record which the pupil can use to revise for tests or examinations	d

B3.3 Audience for record	The pupil	a

Appendix 7

Table A.1 Teacher details

School	Teacher	Teaching Experience t (years)	Subject Specialism	Lesson Observed
Derwent	Mr Dacre	$25 \leq t \leq 29$	Physics	Chemistry
Derwent	Mr Drax	$25 \leq t \leq 29$	Biology	Chemistry
Derwent	Mr Drax	$25 \leq t \leq 29$	Biology	Physics
Derwent	Mrs Duggleby	$0 \leq t \leq 4$	Physics	Physics
Foss	Mr Fangfoss	$30 \leq t \leq 34$	Biology	Chemistry
Foss	Ms Ferrensby	$5 \leq t \leq 9$	Biology	Physics
Kyle	Mr Keld	$5 \leq t \leq 9$	Biology	Chemistry
Kyle	Miss Kilburn	$10 \leq t \leq 14$	Chemistry	CASE
Kyle	Dr Kepwick	$0 \leq t \leq 4$	Biology	Physics
Kyle	Mrs Kettlesing	$15 \leq t \leq 19$	Physics	Physics
Nidd	Mr Normanby	$10 \leq t \leq 14$	Chemistry	Physics
Nidd	Mr Normanby	$10 \leq t \leq 14$	Chemistry	Physics
Nidd	Miss Nunwick	$25 \leq t \leq 29$	Psychology	Chemistry
Ouse	Mr Oldstead	$10 \leq t \leq 14$	Biology	Chemistry
Ouse	Mr Overton	$10 \leq t \leq 14$	Biology	Physics
Rye	Mr Rainton	$30 \leq t \leq 34$	Chemistry	Chemistry
Rye	Mrs Ramsgill	$25 \leq t \leq 29$	Chemistry	Physics
Rye	Mrs Risplith	$5 \leq t \leq 9$	Biology	Biology
Swale	Mr Saltmarsh	$25 \leq t \leq 29$	Biology	Chemistry
Swale	Mr Sewerby	$30 \leq t \leq 34$	Biology	Biology
Swale	Miss Sharow	$0 \leq t \leq 4$	Physics	Physics
Swale	Dr Starbeck	$15 \leq t \leq 19$	Physics	Physics
Ure	Mrs Uckerby	$20 \leq t \leq 24$	Physics	Physics
Ure	Mrs Ugthorpe	$0 \leq t \leq 4$	Chemistry	Biology
Ure	Mr Ulleskelf	$15 \leq t \leq 19$	Chemistry	Chemistry

Appendix 8

Table A.2 Class details

School	Teacher	Year Group	Set X of Y (X = 1 is highest academic ability)	Boys	Girls
Derwent	Mr Dacre	Year 8	1 of 3	12	20
Derwent	Mr Drax	Year 10	2 of 6	19	10
Derwent	Mr Drax	Year 7	Mixed	12	12
Derwent	Mrs Duggleby	Year 7	Mixed	17	11
Foss	Mr Fangfoss	Year 7	Mixed	9	14
Foss	Ms Ferrensby	Year 7	Mixed	11	12
Kyle	Mr Keld	Year 9	1 of 9	11	13
Kyle	Miss Kilburn	Year 7	Mixed	16	13
Kyle	Dr Kepwick	Year 8	2 of 11	11	15
Kyle	Mrs Kettlesing	Year 7	Mixed	12	10
Nidd	Mr Normanby	Year 11	1 of 3	7	17
Nidd	Mr Normanby	Year 11	2 of 3	7	16
Nidd	Miss Nunwick	Year 8	1 of 6	13	18
Ouse	Mr Oldstead	Year 8	1 of 5	12	11
Ouse	Mr Overton	Year 8	1 of 5	12	11
Rye	Mr Rainton	Year 10	3 of 4	14	8
Rye	Mrs Ramsgill	Year 10	3 of 4	14	8
Rye	Mrs Risplith	Year 9	4 of 4	10	16
Swale	Mr Saltmarsh	Year 8	3 of 6	12	16
Swale	Mr Sewerby	Year 10	1 of 6	10	7
Swale	Miss Sharow	Year 11	1 of 6	12	14
Swale	Dr Starbeck	Year 10	2 of 5	14	12
Ure	Mrs Uckerby	Year 11	1 of 8	5	4
Ure	Mrs Ugthorpe	Year 8	8 of 8	13	14
Ure	Mr Ulleskelf	Year 10	1 of 8	22	9

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