INVESTIGATIVE PRACTICAL WORK IN YEAR 12 BIOLOGY PROGRAMMES

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Abstract

The most recent New Zealand national curriculum development in Science occurred between 1991 and 1993. This Science curriculum placed value on students developing scientific investigative skills. The senior Biology curriculum for students in Years 11 - 13, developed to link with the Science curriculum, restated the Science curriculum's investigative emphasis.

With this new emphasis on the investigative approaches to learning school Science by national curriculum policy, it became important to identify how teachers may help their students to achieve the investigative objectives; to determine ways to support Biology teachers when they are introducing openness into their programmes; and to identify perceived benefits and constraints related to the introduction of investigative activities.

This study explores the nature and role of practical work, including investigative approaches, in school science. It reviews the purported functions of, and degree of intersection between, problem solving and investigative approaches to learning in science. After an exploration of competing views of learning, scientific investigative problem solving practical work is placed within a framework of a co-constructivist pedagogy.

There were three main phases in the data gathering for this study. The first two phases of this research project were conducted within a large, urban, co-educational, state secondary school. All of the school's Biology teachers participated in the initial introduction of investigative practical work and one of these teachers worked with additionally developed material for a second year. A teaching package relating to the introduction of partially open investigative practical work was developed during 1994. Teachers from other secondary schools from around New Zealand participated in the third phase trial of this material.

The research findings present challenges to a growing rhetoric regarding the value of open investigative practical work in school science. The introduction of partially open investigative practical work into a Year 12 Biology programme was found to be exacting of the teachers and students. The students required deliberate and focussed teaching if they were to progress their scientific inquiry skills. The students valued the opportunity to have more control over the direction of their practical work. They found investigative work motivating and claimed that it increased their learning. Some students accepted the opportunity for personal involvement, self-direction and responsibility very quickly, whilst others needed ongoing support and encouragement. The teachers acknowledged a cognitive and affective value for investigative practical work in a Biology programme but reported considerable difficulties with the introduction and assessment of such a programme.

Implications for both classroom practice and teacher development emerge from this study. Suggestions of ways to help students to carry out investigations, to better hypothesise, and to plan and gather data are given, as are strategies to help students critique their work. It is suggested that teacher development programmes include opportunities for teachers to develop their own understandings and skills in relation to investigative science There could also be an emphasis on pedagogical practices which may enhance students' learning in this regard. Time, personnel, equipment and materials resource implications may need to be addressed.

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Dedication

I dedicate this thesis to:

- the memory of my parents, Alfred and Olive West, who taught me the importance of life-long education and the satisfaction of accomplishment;
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Chapter 1: Introduction

1.1 Introduction

Changes to the New Zealand curricula in Science and Biology in the last decade have reflected an international trend towards the introduction of open investigative approaches to learning in school Science. This thesis explores student learning and teacher development in the context of such an introduction to senior Biology practical work. Practical work is here defined as any activity which provides students with the opportunity to have direct personal experience of the subject being studied and which requires both cognitive and psychomotor participation of students. Practical work does not necessarily mean laboratory bench 'wet work' (Hodson, 1993a) though the investigations that were carried out as part of this research study frequently did involve such activity. An investigative approach to practical work requires students to use previous knowledge, new observations and carry out carefully designed experiments to find answers to a specific problem or set of problems (Duveen, Scott and Solomon, 1993). For the purposes of the research a decision was made to restrict the introduction to partially open investigative practical work (Simon, Jones, Fairbrother, Watson, and Black, 1992). It was partially open in that the researcher and teachers defined the problem whilst the students had control over the method(s) by which they solved the problem. In addition, the outcomes/solutions were often unpredictable.

My interest in the cognitive and affective value of practical work in secondary school Science and Biology stemmed from many years as a teacher helping students as they struggled with practical work. Whilst many students appeared to welcome the opportunities to "do practicals", far too often their joy with this experience was dampened when "it didn't work!". Throughout the years I had, along with many other teachers, attempted to remove some of the unknown variables which contributed to the "it didn't work" syndrome by presenting students with practical work which had a carefully trialed and pre-determined method. Thus, although the New Zealand Biology curriculum of the 1970's and 1980's had been based on the inquiry oriented Biological Sciences Curriculum Studies approach developed by Schwab (1962) in the

United States, by the late nineteen-eighties much of the practical work commonly carried out in senior Biology classes required students to follow procedures which had been set for them by others.

Thus it was that in the 1980s "recipe following" practical work had become pervasive in a majority of New Zealand schools' senior Biology courses. This was particularly the case for Year 12 Biology courses where curriculum linked Biology practical guides had been developed and were freely available. Students were given detailed guidelines to follow as they carried out their practical work, whether it was experimental, theory reinforcing or explorative in nature. After following detailed instructions and gathering a set of data, students were often also provided with precise instructions as to how to analyse and report on this data. Frequently they were presented with a set of questions aimed at directing their thinking as they reached conclusions about the data they had gathered. Students were given very little freedom of thought, nor were they required to make decisions as to methodology, validity or reliability of gathered data or the implications of their findings.

One of the outcomes of such recipe following for most students was that they carried out their practical work unthinkingly. If I asked students to explain what they were doing they often responded, after a quick scanning read of the text or worksheet, in terms such as "Number 2". That is, they were indicating that they had reached the second of the pre-set stages of the exercise. Frequently they were unable to articulate why they were doing "Number 2" in that particular way, nor why the writer of the exercise may have chosen to set out the directions in that particular order. The students were not engaging in any depth with the task in hand and were not, I felt, learning much about the nature of scientific enquiry. When asked to explain what science meant to her one fifteen year old wrote

> *(Science is) pretending that you've done things and found out things that you haven't.*
> Personal communication, 1991

Increasingly I had found this type of response disappointing and perplexing. I had become frustrated by my students' inability to think creatively when meeting new and challenging situations. I had therefore experimented with introducing an enquiry approach into my own teaching of Biology and Science and had found that my students responded very enthusiastically to practical work which allowed them to make decisions for themselves.

At the same time as teaching in regular school-based Science and Biology programmes, I was working with students who were engaged in doing 'research' for Science Fair projects. Such activity was often extra to classroom science learning, taking place in lunch breaks, after school and at home. Here, some students were able to successfully engage in what Jungck (1985) has called the three Ps of science - problem posing, problem solving and peer persuasion. These students were often highly motivated, posing questions which they could attempt to answer through research of the literature and/or personal investigation, collecting data, analysing and interpreting this data and presenting their findings in an appropriate manner. All of the students were personally broadening their own knowledge base and some were engaged in the construction of new scientific knowledge. Not all students found these Science Fair investigations easy to complete and it has to be acknowledged that in many instances the students had very little overt preparation for their involvement in this process. However, a few students were highly motivated and involved, spending many hours grappling with their own particular research question. The question arose: could practical work in the regular Science classroom become more openly investigative in nature?

1.2 Curriculum change in Science and Biology

By the nineteen-eighties and nineties science education writers were also critically questioning both the value of the then current approaches to practical work in school science and the frequent misrepresentation of the nature of science in science curricula. Hodson, for example, in a series of papers written between 1988 and 1996, offered a strong critique of the very structured practicals which represented most of school science practical work through the seventies and eighties and into the nineties (for example, Hodson, 1990, 1993a, 1996). After analysing many studies regarding the efficacy of practical work as a way of learning scientific knowledge and the development of laboratory skills, Hodson (1993a) concluded that practical work as was frequently practiced in the 1980s and early 1990s was not particularly efficient as either a means of learning scientific knowledge or learning about the nature of science. He also claimed that, rather than being motivating, much school practical work lacked challenge for students and that claims regarding practical work's efficacy for attitudinal development were often exaggerated (Hodson, 1990).

In response to this growing unease regarding the nature, and learning outcomes, of practical work in school Science programmes there was a re-introduction of problem-solving, with its focus on novelty of encounter and paucity of instruction, to Science and Biology programmes. In Biology education this was seen as a natural successor of the United States Biological Sciences Curriculum Studies approaches of the mid-sixties (Hurd, Bybee, Kahle and Yager, 1980). This re-emphasis of the work of Schwab (1962) and his BSCS team also led to the formation of institutions such as BioQUEST (Jungck, 1985) with their emphasis on the use of information technology to help students solve complex problems in biological areas such as genetics that are otherwise difficult to access with the time and equipment restraints common in schools (Stewart, 1988). Science educators in the United Kingdom (Garrett, 1986; Heaney and Watts, 1988) were also promoting problem-solving in a variety of forms, ranging from 'egg races' to the solution of useful and relevant scientific problems. A problem-solving approach was thus, by the early nineteen-nineties being valued for its ability to encourage creativity and cognitive flexibility in students (Spiro, Feltovich, Jacobsen and Coulson, 1991). It was also recognised that the processes of problem solving have close links with the investigative processes of science, a matter which will be addressed in depth in Chapter 3. Additionally, it was also frequently stated that, while science has its own philosophical base, its methods are part of everyday life and that learning in Science can help students to learn life skills. Whilst such statements may be based on questionable assumptions, such assertions have been made in curriculum documents, for example:

> Learning in science is fundamental to understanding the world in which we live and work. It helps people to clarify ideas, to ask questions, to test explanations through measurement and observation, and to use their findings to establish the worth of an idea.
> *Science in the New Zealand Curriculum*, Ministry of Education, 1993b, p 7

The inclusion of investigative practical work in Science and senior Biology courses was thus supported by groups such as employers and curriculum developers. Over the last decade employer groups and curriculum developers had emphasised the importance of students being able to solve problems, for example:

> Workers at all levels should have a capacity for cooperative action, **decision making and problem-solving**. These cognitive, creative and interpersonal skill have traditionally been seen as among the desirable outcomes of schooling.
> Australian Manufacturing Council 1988 (as quoted by K Richardson, SCICON 1990)

> [There are] the cross-curricular categories of essential skills and qualities to be developed by all learners. These are ......
> Communication skills
> Numeracy skills
> Information skills
> **Problem-solving and decision making skills**
> Self-management skills
> Work and study skills
> Social skills
> The National Curriculum of New Zealand: A Discussion Document, Ministry of Education, 1991, p 16

This list in the draft curriculum framework document was modified in the final document to become eight essential skills (communication, numeracy, information, problem solving, self-management and competitive, social and co-operative, physical, and work and study). Although problem solving was no longer linked with decision making it was still considered to be an important part of the learning to 'be developed by all students across the whole curriculum throughout the years of schooling' (Ministry of Education, 1993a, p 17). The Essential Learning Area of Science (Ministry of Education, 1993a) was seen by curriculum developers in New Zealand to be well placed to develop the Essential Learning Skill of problem solving with statements such as 'Problem solving is an essential part of scientific investigation' occurring in the New Zealand Science curriculum document (Ministry of Education, 1993b, p 43).

The emphasis on investigation in *Science in the New Zealand Curriculum* (Ministry of Education, 1993b) is such that students in Science, as well as being introduced to the 'scientific culture' and learning well-established scientific "facts", are also expected to learn about the nature of the scientific process - about how scientific knowledge is constructed. It is also expected that the students might grasp an understanding of the status of this knowledge. Not only should they learn how investigations may be done, but also why they are done. Students, according to the curriculum documents, should encounter a science education whose purpose is to develop their understanding of science as having explanatory and instrumental goals as well as helping them to understand scientific information and the enterprise in which scientific theory is grounded.

Whilst the value of problem solving and investigative approaches was acknowledged, science educators were also realising that students needed help if they were to become successful scientific problem solvers and investigators. Some, for example, Bentley and Watts, (1989), Lock (1991) and Simon *et al* (1992) were analysing teacher and student roles during problem solving and scientific investigation and were attempting to identify ways by which teachers could help their students to solve scientific problems or carry out scientific investigations. Others were engaged in searching for a generalised non context-specific, problem solving approach which could be taught to students (for example, Gayford, 1989 and Instone, 1988). A few educators, however, sounded a note of caution regarding the notion of a generalised problem solving process and the transferability of such generalised skills (Brown, Collins and Duguid, 1989; Hennessy, 1993). The belief that generally useful problem solving skills can be developed and subsequently applied to different kinds of activities in different school subject areas, or to outside of school activities, can be strongly criticised on the grounds that most forms of everyday problem solving require context specific capability (Hennessy, McCormick and Murphy, 1993).

1.3 Research questions

This research project was carried out in this climate of change with respect to school Science practical work. My personal reasons for selecting this area of research were three-fold and were situated in (i) my own felt dissatisfaction of the then current practice of practical work in school Science, (ii) the changing community expectations of school leavers and (iii) the directions of curriculum change in New Zealand and elsewhere.

Prior to this research I had carried out an Auckland wide survey relating to science teachers' understandings of the role of problem-solving in school Science. The science teachers in the greater Auckland region had indicated benefits accruing from introducing a problem-solving approach to science education programmes but had also identified some constraints which restricted its use and learning outcomes. The findings from this survey had been published in the Auckland Science Teachers' Newsletter (Haigh, 1992) and formed the basis of some of the directions of the early data gathering related to this research project.

The research project sought to elucidate the cognitive and affective responses of students and teachers in senior Biology classrooms during the introduction of open investigative work to senior Biology programmes. The questions guiding this research were:

1. In what ways can the students' abilities at carrying out open investigative practical work be enhanced?

2. In what ways can Biology teachers be supported to introduce openness into Year 12 Biology practical programmes?

3. What are the perceived benefits accruing from introducing investigative activities into classroom programmes in Science/Biology?

4. What are the perceived constraints regarding the introduction of investigative activities into school Science/Biology?

1.4 Background information about the researcher

The knowledge assertions made in this thesis are based on data gathered from either the researcher's personal observations or from both verbal and written information submitted to the researcher in response to the researcher's questioning. The observations and question foci were influenced by the previous experience of the researcher, either first hand or from reference to other's work. It is, therefore, important that the reader is aware of the background of the researcher.

When I prepared my proposal for my doctoral research I was lecturing in pre-service teacher education, within the School of Secondary Teacher Education at the Auckland College of Education. I was educating beginning teachers in Science and Biology and considerably involved with ongoing in-service teacher education. I was also lecturing in the Secondary Professional Education programme with particular interests in the psychology of learning, co-operative learning and assessment. My own academic studies covered Zoology, Chemistry, Education, Sociology and Psychology.

Prior to my appointment at the Auckland College of Education I had spent more than twenty years teaching Science, Chemistry and Biology in secondary and tertiary institutions, with all of my secondary teaching in large New Zealand co-educational state schools. Within the secondary school system I had been especially interested in the role of practical work in science learning and had played an active part in promoting Science Fair activities, being continuously involved in the organisation of Science Fairs at the school, regional and national levels from 1980. I have been a judge at local and regional levels and still judge at the national level.

From 1986 until 1995 I was an examiner in Biology and Science for, sequentially, the University Entrance Board, the South Pacific Board for Educational Assessment and the New Zealand Qualifications Authority.

In July 1991 I was appointed to co-ordinate the writing of the New Zealand Science Curriculum statement, *Science in the New Zealand Curriculum* (Ministry of Education, 1993b). As the Co-ordinating Writer I had considerable input, with others, into the structure of the curriculum statement and the inclusion of its two integrating strands relating to the nature of the scientific endeavour and development of scientific investigative skills.

Thus I brought a background of secondary school Science teacher, university Biology lecturer, college of education lecturer (with interests in both pre-service and in-service teacher education), Science Fair advocate, curriculum developer and examiner to this research project.

1.5 Overviews of the research and the thesis structure

1.5.1 Overview of the research

A broad overview of the time-lines of the research project is shown in Table 1.1.

Year	Phase of research
1992	Negotiation of research direction with teachers at City High
1993	First intervention at City High. Three open investigations trialed by four teachers and their students.
1994	Second intervention at City High. One of the four teachers and her students trial an extended series of open investigations.
1995	Trialing of units on open investigations by Biology teachers and students at other schools throughout New Zealand.
1996	Completion of data gathering. Validation of data analysis and interpretation by participating teachers.

Table 1.1 Overview of thesis time-lines

There were three main phases in the data gathering for this thesis. The first two data gathering phases of this research project were conducted within a large, urban, New Zealand co-educational state secondary school called, for the purpose of this study, City High (not its actual name). All four members of the senior Biology department in this school agreed to participate in the research. Classroom based field work and related studies of these teachers and their students were principally carried out over the years 1993 and 1994. In 1993 I spent at least one period per week with all four of the teachers in the Biology department, monitoring the classroom as these teachers and their students engaged in the teaching and learning of Biology at Year 12. Additional time was spent interviewing the teachers and their students. In 1994, in order to gather more in-depth and focussed information following on from the 1993 observations I carried out more frequent monitoring of one teacher with one of the Year 12 Biology classes in City High School. The class was observed for a minimum of two periods per week and the teacher and students provided considerable additional written and verbal information. During 1995 I kept in regular contact with the 1994 teacher with a final interview in December of 1995.

A teaching package relating to the introduction of partially open investigative practical work was developed during 1994. A sample of this material was presented by the researcher at a New Zealand Science Teachers Conference, SCICON 94, and teachers were asked to express interest in a wider trial of the material. Teachers from twenty-two other secondary schools from around New Zealand agreed to participate in this wider trial. Each was sent a package containing student task sheets and worksheets for open investigations, teacher guide material and research response sheets (Haigh, 1995 - see Appendix A for details of contents). The 1995 teachers sent information back to the researcher at the end of the 1995 school year. A small number of these teachers and their students were also personally contacted during 1995 and 1996.

1.5.2 Structure of the thesis

The thesis is divided into three major sections. In the first section the thesis explores the nature and role of practical work in school science (Chapter 2), the relationship between problem solving and investigation (Chapter 3), and presents a co-constructivist view of learning as a theoretical framework for investigating in school Science in Chapter 4. Chapter 5 describes the research methodology and design.

The second major section of the thesis covers the research findings. Chapters 6 and 7 trace the activities and abilities of the participating students as they carried out investigations, and their attitudes to investigating. Chapters 8 - 10 of this section focuses on the teachers. It describes the teachers' response to the three phases of the intervention with particular emphasis on the professional development of one of the participating teachers (Kaye) in Chapter 9.

The final chapter presents general findings from this study. It also answers the research questions, assesses curriculum expectations against demonstrated classroom practice and presents a model to indicate the complexity of the investigative process. Implications for classroom practice and teacher development from the findings of this research project and proposals for future research are also discussed.

Chapter 2: The Nature And Function Of Practical Work In School Science

2.1 Introduction

There is an expectation by curriculum developers (see *Science in the New Zealand Curriculum*, Ministry of Education, 1993b) and teachers that student involvement in investigative practical work will help the students to achieve some of the expected learning outcomes of a science course. However, before we can determine the degree to which engagement in investigative practical work helps students to learn Biology we need to consider the nature of practical work in school Science and Biology programmes and the reasons given for its inclusion. The characteristics of investigative practical work will also need to be clarified as will the links between investigative approaches and other teaching-learning approaches such as problem solving.

In this chapter I will trace an historical view of practical work in school science (Section 2.2). Discovery learning approaches (2.2.1) and process science approaches (2.2.2) will be presented and critiqued. An investigative approach is presented as a means of presenting a balance of process and content to practical work (2.2.3). Reasons given for the inclusion of practical work in school Science programmes will be addressed in this chapter (Section 2.3) as will general criticisms of the role of practical work in school Science (Section 2.4). The nature of investigation and its relationship to problem solving will be considered in Chapter 3.

2.2 An historical view of practical work in school Science

As formal teaching in science developed in Britain during the nineteenth century, practical work became an essential part of the school science curriculum (Gee and Clackson, 1992). Since the New Zealand secondary education system reflected the English secondary education model (McKinnon, Nolan, Openshaw and Soler, 1991) practical work also became an integral part of the New Zealand science curriculum in the nineteenth century.

Early practical work developed under the influence of educators such as Armstrong (1896) who encouraged an heuristic approach to practical science where the students were trained to find out, or discover, things for themselves (see van Praagh, 1973 for an historical overview). According to Nott (1997), students following Armstrong's heuristic approach were trained in particular skills and required to use these to solve problems. Challenges to the heuristic approach came as science educators began to dispute whether scientific concepts could be discovered by common sense, whether transfer of scientific method skills occurred, and whether development of atomised process skills of observing, hypothesising and the like was a worthwhile aim (see the historical reviews of Wellington, 1989 and Hodson and Reid, 1988). In part as a response to this debate, but also because of difficulties with the adequate provision of equipment for increasing numbers of students (Gee and Clackson, 1992), an emphasis on teaching the content of science developed during the first half of this century, with practical work serving largely illustrative purposes. This attention to teaching the content of science was compounded by widespread written theoretical examinations rather than practical examinations. Consequently, concerns arose regarding the widespread presentation of science as received fact. What was taught in New Zealand largely reflected the 'teaching of science content' approaches of Britain, with science as a school subject not compulsory in New Zealand until after the Thomas report of 1945 (Department of Education, 1959). Here, too, an emphasis on written examinations led to a lesser emphasis on practical work in science except for that which illustrated scientific principles.

2.2.1 Discovery Learning Approaches

By the late 1950s and early 1960s concerns, in the United Kingdom and the United States, that science was being taught largely as received fact led to the influential Nuffield and Biological Sciences Curriculum Study (BSCS) projects. Practical exercises in the laboratory were central to both Nuffield and BSCS curricula. The emphasis in the Nuffield Science courses was on 'learning rather than being taught, on understanding rather than amassing information, on finding out rather than being told' (Nuffield Advanced

Science, 1970, p vii). The first teachers' guide to the physics series (Nuffield Foundation, 1966) says of practical work:

> A very strong influence in young people's understanding of science and scientific work is their own experimental work. Professional scientists devise their own experiments, meeting difficulties as well as successes, trying things out with a watchful eye and a critical mind, ... Our pupils can do the same, with both understanding and delight, if we give them opportunity and plenty of time.
> *ibid* p 3

Linked to information processing models of learning, these discovery learning approaches encouraged students to collect data from which it was expected that generalisations would emerge and with subsequent discussion would lead to concept formation and understanding (Hodson, 1993a). Such ideals were difficult to effect in the classroom and the Nuffield project produced very detailed teachers' guides to overcome the dilemma of steering a course between the two extremes of simply indicating areas for investigation or providing detailed lesson-by-lesson outlines (van Praagh, 1991). Alexander (1974) quotes the Nuffield project organiser as indicating that:

> Since there are dangers of frustration if the work is 'open ended', much of the experimental work is structured so that the pupils do obtain an answer to a real problem and we want them to experience the excitement of a discovery which is a genuine one for them.
> *ibid* p 1

The underlying philosophy of the BSCS projects was 'the production of creative and imaginative programs at the cutting edge of the discipline' (Klinckmann, 1970, vii). The developers were aiming not just to make materials from recent scientific journals available to school students, but to 'develop and present those materials so as to contribute to the development of attitudes and skills as well as of knowledge' (*ibid*, p 7). The materials were 'to reflect the principles and emphases of science as a whole' (*ibid*, p 8) with their focus on enquiry science (Schwab, 1962). Students were to be *shown* how knowledge arises from an interpretation of data, that interpretation of data is made on the basis of concepts and assumptions that may change as knowledge grows, and that knowledge may change. The emphasis was on *showing* not *telling*. The primary aim of the BSCS materials was for the students to understand enquiry and for this the students were to be actively participating. In so doing the student might find that science is not 'merely learning' what others already know but 'an activity of the mind, a challenge to the imagination and a place where thought and invention are rewarded' (Klinckmann, 1970, p 132). The students were also expected to develop their skills of interpretation and their understanding of scientific knowledge.

To explain their rationale the BSCS team developed a definition of inquiry which they published as a position paper (cited in Anderson and Koutnik, 1972). In it the substantive body of biological knowledge was defined as including both the knowledge of inquiry processes and the findings of these inquiries. They stressed that both knowledge of inquiry processes and the findings of these inquiries, were equally important but that, historically, one (content) had been emphasised more heavily than the other, and that a greater attention to inquiry processes was needed. However, such attention should not 'exclude or foreshadow the importance of teaching the findings of scientific inquiries. As a matter of fact, teaching inquiry processes demands the teaching of content inseparable from process' (*ibid*, p 4). For them, inquiry was a set of directed activities engaged with for the purpose of increasing understanding and possible application of that understanding. They also emphasised the complexity and personal dimension of inquiry and that solution of a problem was not necessarily 'essential for inquiry to be deemed successful' (*ibid*, p 4).

New Zealand curriculum development followed the lead of Nuffield and BSCS. The yellow version of the Biological Sciences Curriculum Studies was first trialed at Heretaunga College in 1963 and trials of the blue and green versions followed. Nuffield science was introduced into New Zealand by Rae Munro at Avondale College in 1965 (R. Munro and C. Percy, interview notes, 6/9/94). Such trials required a rethink of teacher and student behaviours and the classroom culture. Munro commented that 'enquiry science is a high risk endeavour' and that 'more important than anything else it required that I have the confidence to eyeball my colleagues and convince them that ... all the noise that came out of my lab was in fact worthwhile'. In New Zealand, text writing followed these trials with the junior science text series "Science Makes Sense" (Buckley, Lubeck, Percy, Roberts and Tarrant, 1968) and the senior biology text "Biological Science" (Curriculum Development Unit, 1969) being strongly influenced by the Nuffield and BSCS approaches. These widely used New Zealand texts displayed a concern to induct children into the spirit, and ways of working, of science as practised by scientists.

Criticisms of Discovery Learning Approaches

The emphases and underpinning pedagogical assumptions of the Nuffield and BSCS approaches have been challenged. The major criticism about the Nuffield approach was its re-introduction of a "discovery" learning approach, an approach which had been criticised earlier when promoted by Armstrong (1896).

Stevens (1978) addressed the underlying philosophy of practical programmes such as the Nuffield schemes and declared that he had 'exposed errors in an imputed philosophy of science subscribed to by the Nuffield Foundation' (p 99). To support this claim he critiqued heuristic methods, the relationship of hypotheses to discovery approaches, the concept of discovery itself, and the difficulty of establishing theory-neutral observation. He claimed that underpinning much of the discovery approach to science was the understanding that there would be one right answer, that at least one student would come up with an answer near to the received answer. He felt that this was at best pretence and at worst dishonest since the science that students do is comparatively crude. It also portrayed a false account of 'doing' of science in a manner not recognised by scientists. Stevens therefore asserted that 'learning science by doing science is thus emotionally impossible and is likely to generate logical absurdities' (*ibid* p 109). Stevens accordingly contended that a different balance between discovery methods and more traditional demonstration methods was required.

Other writers (Claxton 1984; Hodson, 1996) have claimed that the discovery methods proposed by programmes such as Nuffield had, over time, become 'guided discovery'. Teachers were leading students to a pre-determined concept by providing them with a series of planned exercises, thus allowing the students very little personal decision making. Thus the contrived nature of the Nuffield "discovery" approach left little opportunity for students to design and carry out their own investigations and the strength of the Nuffield based science curricula was seen to be more in aspects of illustrating or refining concepts rather than 'finding out' (Gott and Duggan 1995).

Many teachers in New Zealand schools in the late seventies used guided discovery learning as a vehicle for understanding science content (Osborne, Freyberg and Tasker, 1979). Osborne *et al* noted that teachers were concerned about the ideas to be discovered requiring such complicated instructions or experimental design, that students could not cope with the demand. The ideas to be discovered frequently did not follow on from the experimental evidence which the students obtained, forcing the teachers to make 'broad generalisations to support theory based on trivial evidence from experimental results' (*ibid,* p 8). Students and teachers became apprehensive about obtaining 'the right answer' (*ibid,* p 6). Their findings from this initial survey led Osborne *et al* to suggest that students might carry out investigations or projects 'where children might find out for themselves without the threat of not getting the right answer hanging over their head' (*ibid,* p 14) and that students need to be involved with their teacher in discussing how they might design experiments rather than being given instructions to follow.

As a result of perceiving these philosophical misgivings of teachers, and noting some learning difficulties for students being taught within a framework of the Nuffield approach, writers such as Stevens (1978) were claiming, that there 'is a logical conflict between learning and discovery which can produce some very undesirable results.' (p 9), and, questioning the underlying philosophy:

> It seems then that the Nuffield philosophy's discovery method cannot imitate science by allowing real discoveries, but can only encourage guesses at what scientists have done in the past, since, presumably, we want children to rediscover our science.
> *ibid,* p 103

Also concerned about the required pedagogical approaches, Stevens highlighted the stage management required to obtain received answers:

> The discovery method requires the teacher to assess the evidence with the class to try to show how the received answer is in fact the best explanation.
> *ibid*, p 107

Thus, whilst the Nuffield projects were developed with the intention of increasing student participation in experimental work and imaginative discussion, in reality their main purpose had increasingly become the teaching of basic declarative concepts (as defined by Bereiter, 1992; Husen and Postlethwaite, 1994). In New Zealand the reality of poorly designed classrooms, restricted access to equipment, and a strong theoretical emphasis in senior school examinations also operated against a high level of student participation in practical work.

The inquiry approaches of BSCS have also been analysed and critiqued (Hurd *et al*, 1980; Lott,1983; Shymansky, 1984; Costenson and Lawson, 1986; Yager, Engen and Snider, 1969; Sydney-Smith and Treagust, 1992). Lott (1983) and Shymansky (1984) both carried out meta-analyses of research reports comparing the learning results of traditional practical work (that is, where a designed activity is performed by close following of a set of instructions) versus practical work which takes an inquiry approach. Both meta-analyses reported superiority of laboratory based inquiry teaching methods for the learning of declarative concepts, particularly in the biological sciences. These findings have been supported by a more recent study as reported by Hall and McCurdy (1990) which indicated that students using the Biological Sciences Curriculum Study inquiry approach scored significantly higher than students in the comparison group for biology content achievement. However, data from follow-up investigations have indicated that only a small percentage of teachers have used such methods in their teaching of biology in the United States and usually for less than twenty-five percent of the time (Hurd *et al*, 1980). In an attempt to uncover the reason(s) for this Costenson and Lawson (1986) interviewed experienced teachers and found teachers suggested ten reasons for their non-use of inquiry methods. These were: time and energy required by teachers; time taken to complete, thus making covering the curriculum difficult; reading level of inquiry texts too difficult; risk of uncertain outcomes being too high; tracking (streaming) was cutting out formal thinkers from biology classes, therefore most of the students could not cope with the intellectual demands of this approach; student immaturity; difficulty of changing established teaching habits; the need to follow sequential material very carefully; discomfort regarding lack of control, and expensive materials needed. Costenson and Lawson (1986) concluded that all ten of the reasons were not sufficient of themselves to prevent an inquiry approach in the classroom but that teacher education (both pre-service and in-service) needed to address teacher preparation for teaching science in an inquiry mode. Sydney-Smith and Treagust (1992) also came to this conclusion after carrying out a study into whether or not inquiry based biology courses meet the needs of today's more varied student population.

Criticisms of Nuffield and BSCS programmes (for example, Hodson, 1996) have also arisen from perceptions that both programmes appear to support an naive inductivist Baconian view of science where scientific knowledge is derived from the facts of experience acquired by observation and experience (Chalmers, 1982). Since such a simple Baconian view of science is no longer widely supported but has largely been replaced by a hypothetico-deductive perspective, Nuffield and BSCS have been criticised for presenting a view of science at variance with what it actually is. However, it can be questioned if all of 'real' science is necessarily driven from an hypothetico-deductive perspective and, if this is not so, the programmes should not be so severely censured. That they should not be so criticised is supported by philosophers such as Nickles (1989) who claimed that in practice an inductivist approach, compared with hypothetico-deductive methods, remains an important aspect of science. Thus, Nickles supported Coulter (1966) who argued that an inductivist approach is superior to a deductive approach for learning, in school, about the method of science inquiry. He claimed that, while traditionally practical work in school science was used in a deductive manner to demonstrate, or verify, some principle, practical work in the majority of secondary school laboratories was more akin to an inductivist approach with students designing and developing their own experiments to solve problems suggested by observation. Analysis of his own research data led Coulter to support the latter as a means of introducing students to scientific enquiry as he concluded that inductive approaches tended to impart a better appreciation of the aspects of scientific enquiry than did traditional deductive approaches where the aim was to verify some principle.

In addition, others were concerned that programmes such as Nuffield and BSCS did not take into account the reality of the classroom environment. Blumenfeld, Soloway, Marx, Krajcik, Guzdial and Palincsar (1991) considered that the programmes were developed and distributed without sufficient appreciation of the complex nature of student motivation, without considering the questions from a student's point of view and without paying enough attention to the 'nature and extent of teacher knowledge and commitment and the complexity of classroom organisation' (*ibid*, p 373).

2.2.2 Process Science Approaches

The Nuffield Foundation and BSCS programmes were not the only science curriculum developments arising out of a felt need for there to be a greater emphasis on inquiry and scientific methodology. Schemes such as 'Science - A Process Approach" were developed in America in 1967 (American Association for the Advancement of Science, 1967), and 'Warwick Process Science' (Screen, 1986, 1988) in the United Kingdom. Whilst discovery learning approaches focussed on student learning of scientific concepts the underlying premise of both of these process approach schemes was that education in science should place more emphasis on the methods of science rather than focussing primarily on its products. It was felt that specific teaching of how to do the processes was necessary, and there was a belief that the process skills so learned could be transferred to other situations. Screen developed Warwick Process Science on the basis of his 'belief and experience' (Screen, 1988, p 146) that whilst the content of science is important it is not the facts themselves but how they are arrived at which constitutes an education in science. He claimed that the Warwick Process Science scheme enabled students to learn transferable process skills which the students could use to practise science and also to question the practice of others' scientific work - a skill he identified as being required by many decision makers who use or allow the use of scientific knowledge. Concurrently process science assessment schemes such as TAPS (Bryce, 1991a, 1991b; Bryce, McCall, Macgregor, Robertson, and Weston, 1991) and GASP (Davis, 1989) were being developed. Similarly the work of the Assessment Performance Unit in the United Kingdom, with its emphases on the monitoring of processes and skills of science also gave impetus to a change in direction in science education (Black, 1990, 1993, 1994).

Criticism of process approaches

Such 'process science' approaches were also not without their critics. These schemes have been censured for unsound philosophical and epistemological assumptions (Hodson, 1993a, 1993b; Millar and Driver, 1987). They were also criticised for their emphasis of the importance of process. Screen (1986) himself had claimed that 'important though the content of science might be it is not the facts themselves but how they are arrived at which constitutes an education in science' (p 146) and Swatton (1990) believed that by so claiming, Screen had shifted from a descriptive analysis of the characteristics of science to claiming a process approach as a prescription for the practice of science education. In so doing Screen had failed to acknowledge that the process of science is not necessarily equivalent to the process of learning science (Kirschner, 1992). Similarly, contributors in Wellington (1989) suggested that, if we believe that science activity has explanatory aims, what passes as models for scientific processes in process oriented curricula are defective, untenable and of questionable validity since the intended outcome of such curricula is not scientific explanation, but rather new individual knowledge.

The notion that there is a scientific method which is a discrete, context-independent, generalisable and transferable process is strongly attacked (Hodson, 1993b). Such a belief is said to deny the theory ladeness of all processes and to ignore the *scientific* concepts which underpin, for example, *scientific* observation or *scientific* hypothesis making (see also Bell, 1986; Driver, 1993; Osborne and Wittrock, 1985). That an observation or interpretation is made from an implied theoretical viewpoint, that is, is not theory neutral, must therefore be acknowledged:

> It is clear that the processes of science are theory-laden. We observe not what is there but what our theoretical perception tell us is significant, and our success in applying these understandings is content-dependent.
> Woolnough, 1991, p 6

This view was also argued by Millar and Driver (1987) who stated that 'there is no empirical evidence to support the view that a clearly describable method of science, consisting of a set of identifiable processes, exists' (*ibid*, p 36). They also questioned whether it is possible to teach content independent processes.

Other writers have noted that highly structured school science practical activities are not closely related to science as it is generally practiced. Schon (1983) pointed out that faithful following of a prescribed method is not essential for the learning of scientific processes in school and practising scientists are quick to note that their research may not strictly follow the sequence suggested by the 'scientific method'. Close following of a scientific methodology hierarchy can also lead to naive inductivism (Chalmers, 1982; Hodson, 1992a).

Additionally, Millar and Driver (1987) suggested that the 'process perspective reflects ... an inappropriate view of learning' (*ibid*, p 36). They were concerned that the underlying pedagogy of the process approach did not take into sufficient account the influence of the learners' prior knowledge on learning activities. They were also concerned with the presumed hierarchy of process which is implied in initiatives such as Warwick Process Science, [observing, inferring, classifying, predicting, controlling variables and hypothesising] and, in particular, with the suggestion that such an hierarchy represents an hierarchy in intellectual activity. They did, however, acknowledge the commitment to the high levels of student engagement which underpins process oriented schemes, and suggested that, rather than being seen as goals of instruction in science, having students engaged in science processes should rather be seen as a means of encouraging children's 'thoughtful participation' (*ibid*, p 56) in their science learning.

Many programmes of practical science which have an emphasis on skill development have also been questioned regarding their notion of the transferability of such skills, the development of practical skills as a 'means' or an 'end' and the relationship between skills and processes (Denny and Chennell, 1986; Hodson, 1992b; Hennessy *et al*, 1993). These criticisms have arisen from a view of learning which maintains that all learning is contextualised and thus it is difficult to conceive of the learning of skills in a de-contextualised situation. Some writers (Gott and Duggan, 1995) are careful to define scientific processes as separate from scientific skills, others are not and discuss the development of process skills (Roth and Roychoudhury, 1993). This leads to confusion of understanding and difficulty in equating statements from different sources. Millar (1991) divided practical skills into three categories - general cognitive processes, which included observation skills, practical techniques and inquiry tactics - claiming that the first of these categories can not be taught but that the other two can. Millar's view of the unteachability of general cognitive processes is not universally accepted. Adey and Shayer (1990), for example, have argued that it is possible to accelerate students' formal thinking and have developed teaching programmes in this regard which they have called "Cognitive Acceleration in Science Education" programmes. Gunstone (1991) has also made a differentiation between 'doing' and 'understanding' with regard to observation, stating that students can be taught to understand the nature of observation which may lead to a higher level of 'doing' observation.

In addition, process approaches have been criticised because, with their tendency to focus primarily on process, they may permit inattention to the manner in which engagement in process stimulates scientific conceptual development (Hodson, 1993b). As well, through their emphasis on the practice of scientific process there is often a perceived lack of continuity in concept development and teachers consequently have difficulty fleshing out a process approach into a coherent scheme of work (Gott and Duggan, 1995). However, Screen (1986) himself argued that the process versus content debate should not arise because 'in reality such a conflict does not exist' since:

> No one would surely put forward a case for an education in science completely devoid of process, for without process the memorising of facts is neither science nor education. Equally, a process course devoid of content or scientific context is merely organised common sense.
> *ibid*, p 148

It has also been pointed out that 'process skills are not separated from science content when problems are encountered in real life situations' but that when problems are encountered in classrooms, teachers have arranged them in such a way that processes are isolated in order to give student intensive practice on skills (Tobin, 1984). It is the artificiality of the classroom which may cause the disjunction of process and content.

2.2.3 Investigations

This perceived artificial disjunction of process and content has, in recent years led to a call for a return to a more balanced approach to science education with an emphasis on scientific processes **and** content aligned with a consideration of views of learning (Hodson, 1992b). Such views of learning would need to take into account the learning of content and process. What is needed is the introduction of an approach which better reflects both our 'understanding of the learning process and of science as a human activity' (Millar and Driver, 1987, p 57) and the interaction of these within a given context. Millar and Driver proposed that we should view the learner as an 'intelligent adaptive problem solver' (p 57) and thus develop a curriculum which employs a pedagogy where students are actively engaged in doing science and where students are enabled to develop personal knowledge in the scientific domain which will empower them to work in their everyday lives and live in a participatory democracy. The essence of such a curriculum is the students' thinking of concepts and processes as they are engaged in the practical work.

Engagement of students' minds as well as hands in investigative problem solving science has been promoted as a means of enhancing, and utilising, linkages between conceptual and procedural learning (Gott and Mashiter, 1994). Such an approach is also considered to address both concerns regarding discovery and process approaches to learning in school science and a reluctance to return to a situation where didactic demonstrations become the norm for practical work.

Similarly, Swatton (1990, 1993) and Tytler and Swatton (1992) have argued that, since both the process and content dimensions of science education are important in children's learning in science we can not afford to emphasise one at the expense of the other. Instead, students should be engaged in complex investigations since procedural and content understanding are both essential components of such practical investigations.

That students' prior knowledge (tacit and acknowledged) should be developed through the experience of a whole series of complete investigations has been similarly argued by Hodson (1993b). As Woolnough and Allsop (1985) have indicated, the role of tacit knowledge as students carry out investigations is critical:

> We often pretend that focal, articulated knowledge is the highest aspiration and that having acquired this we use it to solve problems. In reality most problem solving is done directly through tacit knowledge, acquired through personal experience.
> p 72

Other writers such as Gott and Duggan (1995) have also emphasised the value, and essentially holistic nature, of investigations:

> Investigations aim to allow pupils to use and apply both concepts and cognitive processes, as well as practical skills.
> p 20

The relationships between engaging in investigative practical work and learning outcomes from this engagement are not seen as simple. Hodson (1992a) re-introduced Oakeshott's (1962) notion of connoisseurship to knowing how, and when, to apply principles and rules. Hodson also re-presented Gage's (1978) concepts of the art and craft of the scientist which acknowledge tacit knowledge and the role of intuition and inspiration to gifted scientists and suggested that students likewise may act on hunches when they are carrying out investigations even if they are not be able to articulate these. Teaching process and content as separate chunks of a science programme may not provide opportunity for students to use their hunches in an authentic situation.

However, the opportunity to link conceptual and procedural understanding was not the only reason given by science educators when they promoted the role of investigation in science education. Another reason was that of the linkage of process with an understanding of the nature of the scientific pursuit (Peterson and Jungck, 1988). In their argument for the introduction of a problem-solving based investigative approach in biology they argued that such an approach helped students to understand how scientific knowledge is constructed, but they also continued to acknowledge the theory-laden nature of such investigations:

> Textbooks are dry and static, labs are cookbook, lectures push information to students who have become junkies for mythical 'scientific facts' In reality there is no such thing as a fact unsullied by theory (or prejudice or hunch). The store of information in biology is doubling several times a decade and the theories that shape our knowledge are constantly changing. ... What could endure longest from an introductory course is an understanding of, and some practice with the way biologists pursue their craft. Our courses must help students understand how biologists: perceive the world; pose questions; pursue the problems from these questions; and, ultimately, persuade others of the value of their solutions.
> p 14

There is also a claimed social advantage which accrues when students are investigating. The complex task of engaging simultaneously with both scientific concepts and process is most fruitfully carried out within a social discourse. We should acknowledge and appreciate the social collective nature of scientific endeavour and recognise that students carrying out investigations are working in ways more closely corresponding to the way in which scientists work as a team (Gil-Perez and Martinez-Torregrosa, 1983).

In summary investigative science is seen as significant as it presents students with the opportunity to engage with scientific concepts and processes at the same time. An investigative pedagogy is seen as taking into account views of learning as well as views of science. Students are perceived as being encouraged to engage their minds as well as their hands. An investigative approach is perceived as allowing for and encouraging the use of both tacit and acknowledged prior knowledge. It is seen as enabling students to gain a better understanding of the nature of the scientific pursuit and as supporting the social collective nature of scientific endeavour. Thus, whilst investigative science is not seen as the only form of practical work in which students can be valuably engaged it is perceived to be one of significance.

But investigations are not the only form of practical work promoted in science curricula today. Woolnough and Allsop (1985), for example, categorised three types of practical work. There are *experiences*, where students get a feel for phenomena; *exercises*, where students practise skills and techniques and *investigation*, where students carry-out tasks which may be open-ended. Others have presented a more complex model. Gott, Welford and Foulds (1988) developed a five fold classification of practical work with each type of practical work serving a different function. Their categories included *skills* (with the aim to provide opportunities for pupils to acquire a particular skill); *observation* (to provide opportunities for pupils to use their conceptual framework in relating real objects and events to scientific ideas); *enquiry* (to discover or acquire a concept, law or principle); *illustration* (to 'prove' or verify a particular concept, law or principle); and *investigation* (to provide opportunities for pupils to use concepts, cognitive processes and skills to solve a problem). They noted that the boundaries between these types of practical work are not watertight and that practical activities can clearly include more than one aspect.

Whilst some science educators note that it is important to include opportunities for students in school Science classrooms to do science, to learn science and to learn about science (Hodson, 1993a), others restrict the doing of science to that activity which establishes new scientific knowledge (Kirschner, 1992). Still others claim that in the learning of science, practical work is only one strategy of the many available to a teacher (Osborne, 1997) and that there may be any number of other active learning strategies which are not practically based which can be used to help students learn science.

As already discussed in Chapter 1, changes to New Zealand curricula in Science and Biology in the last decade have reflected the international trend towards a more balanced approach to science education with an emphasis on scientific process **and** content and on students gaining a better understanding of the nature of science. There has been an emphasis on the inclusion of investigative approaches in practical work. However investigative approaches are seen to be only part of a student's practical programme. The New Zealand curriculum documents include the suggestion that students should experience a variety of different kinds of practical work. The introductory statement to the practically focused integrating strand in *Science in the New Zealand Curriculum* (Ministry of Education, 1993b), for example, made a similar division to that of Woolnough and Allsop (1985):

> Practical work in science can include experiencing phenomena, developing practical skills or techniques, and carrying out investigations.
> Ministry of Education, 1993b, p 42

In summary, Section 2.2 has presented an historical overview of the nature of practical work in school Science programmes. Just as practical work has long been seen as a powerful resource for 'persuasion and conviction' with regard to increasing scientific knowledge within the scientific community (Gooding, Pinch and Schaffer, 1989), it can be argued that this is no less so for school students' understanding of science. In fact, practical work has long been a important part of school Science programmes with different approaches being emphasised at different times. What reasons are given for this widespread inclusion of practical work in school Science programmes?

2.3 Reasons for the inclusion of practical work in school Science

Practical work in school Science is 'taken for granted' such that explicit justifications for it are not generally required of curriculum documents and teaching materials. Intended goals for practical work are also frequently implied rather than directly stated.

Science educators concerned with the objectives of the school Science curriculum have reported, either directly or by implication, many, ostensibly positive, outcomes of practical work. It should be noted that various of these stated outcomes could also be arguments for science education in general, rather than specifically for practical work in school Science. Suggested reasons for the inclusion of practical work in school Science can be grouped according to their links with the development of conceptual understanding, both declarative, (content understanding, sometimes also called substantive concepts) and procedural (the understanding of scientific processes and procedures); attitudinal outcomes; and skills development. In addition, practical work is sometimes presented as a means of helping students to achieve generic educational outcomes such as logical thinking.

Using these five broad categories, a list of outcomes have been identified from curriculum documents, teaching materials, conference presentations and research reports. Some of these outcomes statements are rhetorical, others research based. In some instances the proposed outcomes have been explicitly stated; in others they have been identified from implied statements. The citation beside each simply means that it has been mentioned by the writer as a possible outcome - it does not necessarily imply the writer's support for that notion, nor a belief that engagement in practical work automatically bestows that learning outcome. A presentation and critique of these reasons for the inclusion of practical work in school Science programmes follows.

Practical work is included in school Science programmes to enhance the learning of declarative (substantive) concepts; to enhance students' understandings of scientific procedures and cognitive processes; to enhance students' learning of scientific skills; to enhance students' learning of scientific attitudes; and to help students achieve generic educational objectives.

2.3.1 The learning of declarative (substantive) concepts

Practical work may be a vehicle for knowledge learning (Fensham, 1990). Engagement in practical work is perceived to reinforce and develop students' understandings of scientific concepts, such as 'photosynthesis', 'respiration' and 'growth'. (Kerr 1964; Shulman and Tamir, 1973; Osborne *et al*, 1979; Ivins, 1983; Bell, 1986; Bond, Dunn and Hegarty-Hazel, 1986; Denny and Chennell, 1986; Kahn, 1990; Woolnough, 1991; Scott, 1993; Millar, 1994; Parkinson, 1994).

A second declarative objective for practical work mentioned in the literature is that engagement in practical work allows students to get a feel for phenomena such as, for example, the cellular nature of living material (Woolnough and Allsop, 1985). Doing practical work is also perceived to help students discern the links between science and technology, such as that between the development of lenses and our understanding of the structure of cells (Fensham, 1990; Saunders, 1990; Ramsden, 1994).

In addition, practical work can act to confirm scientific laws in the 'neutral' atmosphere of the laboratory, such as the 'proof' in ecological systems of Leibig's Law of the Minimum, or Shelford's Law of Tolerance (Kahn, 1990). There may also be an aspect of community value in that practical work may serve to help students learn scientific knowledge of public worth through the application of scientific knowledge in everyday contexts such as the disposal of biological waste materials or the slowing of decay in fruit and vegetables (Fensham, 1990; Hobson, 1992).

However, not all research has produced evidence to support the value of practical work for conceptual development (Johnston and Wham, 1982). Woolnough and Allsop (1985) have argued that there can be a detrimental effect from a 'tight coupling' of practical and theory with the quality of both practical work and conceptual understanding suffering. Similarly, Osborne (1993) claimed that there was too often an illusion of active and purposeful learning when in actuality practical work did not really aid conceptual understanding. There has also been concern expressed regarding the discrepancies which can occur between teacher intent and actual learner perceptions or outcomes when students are engaged in teacher-guided activity based lessons (Tasker and Freyberg, 1985). Three general areas where discrepancies could arise are defined by Tasker and Freyberg as discrepancies of intent, actions and views of the world. Discrepancies in intent arise from teachers' and students' different perceptions of scientific context, purpose and design; discrepancies in actions may cause students to simply follow instructions or try to get the results that they think their teacher wants and to not consider their findings in any critical way; and discrepancies in the teachers' and students' views of the world may mean that the students may have quite a different perspective on an activity from that of their teacher. It may also give rise to a situation where a teacher may indicate that a practical activity has provided information on which to base a pre-determined conclusion but from the students' point of view the given conclusion may not be supported by the data.

2.3.2 Enhancing students' understandings of scientific procedures and cognitive processes

The second main group of objectives for the inclusion of practical work in school Science programmes relate to procedure and process. Engagement in practical work is perceived to give students insight into the 'scientific method' (Kerr 1964; Stevens, 1978; Woolnough and Allsop, 1985). It also fosters understanding of the nature of scientific enquiry (Dewey, 1910/1995; Klinckmann, 1970; Shulman and Tamir, 1973; Denny and Chennell, 1986; Hegarty-Hazel, 1990; Kahn, 1990; Klopfer, 1990). Another claimed procedural/process reason for doing practical work is that it offers the opportunity for teachers to train students in general science enquiry skills such as thinking scientifically or solving problems (Shulman and Tamir, 1973; Osborne *et al*, 1979; Ivins, 1983; Denny and Chennell, 1986; Byrne, 1990; Kahn, 1990; Roth and Roychoudhury, 1993; Swatton, 1993; Millar, 1994).

In addition, the inclusion of practical work in school Science programmes enables practice of scientific cognitive processes such as scientific classification, scientific hypothesising (Fensham, 1990; Klopfer, 1990; Skinner, 1992), the empirical testing of ideas (Denny and Chennell, 1986; Ramsden, 1994), the ability to recognise the role of laboratory experiments and observations in the formulation of scientific theories (Gooding *et al*, 1989), and the ability to organise, communicate and interpret appropriate data (Kerr, 1964; Klopfer, 1990).

2.3.3 Enhancing students' learning of scientific skills

The third main group of objectives proposed for practical work relate to the opportunity for students to develop manipulative (psychomotor) skills required by science such as the precise use of measuring instruments and careful assembly of equipment (Kerr 1964; Ivins, 1983; Denny and Chennell, 1986; Bell, 1986; Swain, 1988; Byrne, 1990; Fensham, 1990; Kahn, 1990; Klopfer, 1990; Clackson and Wright, 1992; Fairbrother, 1993; Parkinson, 1994). Practical work is also claimed to provide students with opportunities to develop communication skills and learn through group discussion (Parkinson, 1994).

2.3.4 Enhancing students' learning of scientific attitudes

The fourth main group of objectives proposed for practical work relate to attitudinal development. Practical work is said to motivate students by providing interesting and enjoyable activities (Kerr, 1964; Bell, 1986; Denny and Chennell, 1986; Hegarty-Hazel, 1990; Kahn, 1990; Parkinson, 1994). It is said to give students the experience of being "scientists for a day" by being an integral part of the process of finding facts by investigation and arriving at principles (Kerr, 1964; Woolnough and Allsop, 1985; Kahn, 1990).

Practical work is deemed to be useful for inculcation of desirable science attitudes and habits (Osborne *et al*, 1979; Hegarty-Hazel, 1990; Hodson, 1993b) such as critical thinking (Jungwirth and Pottenger, 1992), creativity and curiosity (Bell, 1986) and social co-operation (Denny and Chennell, 1986; Pugh and Lock, 1989). Practical work may also offer teachers the opportunity to induct learners into science so that they may share in the 'wonder and excitement which have made the development of science such a great human and cultural achievement' (Fensham, 1990, p 300). In addition, practical work may be included in a school Science programme simply because many students have indicated that doing practical work is their favourite part of Science (Bentley and Drobinski, 1995).

Not all science education writers support the value of practical work as necessarily helping students to develop scientifically useful attitudes. The given structure of much school practical work may lead to a lack of challenge for students rather than being motivating (Hodson, 1990). A practical work scheme based entirely around "discovery learning" could lead to a lack of motivation on the part of students, particularly when students consistently do not discover that which is expected (Stevens, 1978). Too often students are passively watching a teacher carry out all of an activity without being cognitively challenged (Penick, 1991). Hodson (1993a) contended that, when we are considering attitudinal development, we often make exaggerated claims for the outcomes of practical work. He referred to the claim that engagement in practical work in school science will inculcate scientific attitudes and questioned our stereotypical representation of these. He questioned whether scientists really do manifest detached objectivity and whether the kind of practical work we do in schools is likely to promote these attitudes if that is required. He asserted that with so much striving for correct answers and massaging of data, students are unlikely to adopt a 'value-free and theoretically-unprejudiced objectivity, open-mindedness and a willingness to suspend judgement' approach in their science studies (*ibid*, p 95). Thus it is the quality of work in which the students are engaged which is of crucial importance in the development of scientific attitudes.

2.3.5 Enhancing students' achievement of generic educational objectives

A fifth group of objectives for practical work relates to practical work in Science being used to promote generic educational objectives which are not necessarily linked only to learning in Science. Such objectives could be to promote logical thinking (Parkinson, 1994); to assist students to learn to ask more appropriate questions (Klopfer, 1990); to enable provision for individual difference in student ability, both cognitive and motor (Hegarty-Hazel, 1990) and to compensate for the lack of industrial technology in the school's locality, particularly in developing countries (Kahn, 1990).

2.4 Critique of the role of practical work in school Science

In addition to the specific criticisms of the specified goals of practical work covered so far there are also some more general criticisms of the role of practical work in school Science. Increasingly, the validity of school Science practical work with regard to goals such as those given above is being questioned. Hodson (1990) argued that a lack of distinction between 'learning science', 'doing science' and 'learning about science' has led to a confusion of expected outcomes for practical science. Failure to make these distinctions when planning practical work has led to inadequacies of conventional practical work. Students should be given opportunities for doing science in such a manner that they begin to appreciate that science is an "untidy, unpredictable activity" (Hodson, 1995, p 8). Doing science can lead to enhanced conceptual understanding, procedural knowledge and investigative expertise but practical work of itself is not sufficient for these to occur (Hodson, 1995). Similarly, Zoller (1987) also questioned the assumed coherence between problem solving educational objectives and conceptual objectives (assumed by the researcher as declarative, since the distinction is not made), stating that achieving one does not automatically imply achieving the other.

Other writers, such as Osborne (1993, 1997), have also agreed with Hodson's (1995) concerns regarding the exaggerated claims made for the role of practical work in Science. Osborne's list of problems associated with practical work included that it was too often seen as a vehicle for exemplifying and confirming theory and that, frequently, there was a mismatch between intentions and outcomes. He listed alternative activities for students which focus on the reserved language of science and scientific thinking.

Another critique is that the psychological loads placed on students by laboratory manuals are considered to be too high (Johnstone and Letton, 1990; Byrne, 1990). Considering three different kinds of load placed on students when they are engaged in practical work - theoretical, experimental and reporting - Johnstone and Letton felt that such high levels of demand on students in these three areas make the attainment of the goals of practical work difficult to attain. Likewise, Byrne (1990) claimed that an aspect of school Science practical work which needs to be considered more carefully is the intensity of information 'noise' associated with much practical instruction such that students very easily move into information overload.

In summary, Sections 2.3 and 2.4 have considered learning outcomes which are suggested in support of the inclusion of practical work in school Science and critiqued these proposals. The objectives included enhanced learning of declarative concepts; enhanced student meta-understanding of scientific procedures and cognitive processes; enhanced learning of scientific skills; enhanced learning of scientific attitudes; and achievement of generic educational objectives such as logical thinking and learning to ask questions.

The critiques addressed aspects such as a lack of cognitive challenge in much carefully structured practical work; lack of motivating power for teacher and student; the passive nature of much of school Science practical work; the structured nature of practical exercises at secondary school level; the questionable notion of transferability of skills; whether skills development is a means or an end; the difficulty of ascertaining if practical work is an efficient way of learning science knowledge; exaggerated claims for outcomes of practical work; the high level of information "noise" associated with practical work; a lack of distinction between learning science, doing science and learning about science; the lack of similarity between school Science and science as it is practised; the philosophy underpinning much school Science practical work; the complex interaction between concept and process learning; and the mismatch between student and teacher expectations.

2.5 The efficacy of practical work in school Science

The value of practical work for achieving its stated outcomes has been the focus of numerous research studies. Hodson (1993a) analysed many studies regarding both the efficacy of practical work as a way of learning scientific knowledge and the development of laboratory skills. He concluded that, allowing for the difficulty of interpretation, 'on balance it cannot be argued that practical work is superior to other methods and, on occasions it seems to be less successful' (p 94) as a means of learning scientific knowledge and that it is only 'with respect to the development of laboratory skills that practical work has an advantage over other learning methods' (p 94).

Hodson (1993a) also highlighted difficulties involved when carrying out research into the efficacy of practical work for learning science. There is the difficulty of assessment and evaluation of learning outcomes of practical work for individuals, and individuals working within groups. Moreover, he believed that the tendency for researchers to lump different kinds of practical work (experiencing phenomena, developing skills and investigations) together as 'practical work' makes it difficult for informed conclusions from research findings to be made. He also pointed out the difficulty of relying on teacher comment given the mismatch between espoused and actual practice which can occur and also the influence of the teacher's personal style on learning outcomes. Student factors may also be a complication given that different students with different learning styles may respond differently to different styles of laboratory work (Mulopo and Fowler, 1987). Hodson (1993a) summarised these complications as:

> ... different kinds of practical activities, presented by teachers with different overall teaching styles to different students have profoundly different influences on learning outcomes.
> p 99

He listed three additional complicating factors. These are teachers' tendencies to change their style with gender of student, teachers' tendencies to change curriculum materials and interactive patterns to accommodate perceived abilities of students, and thirdly, the tendency of a relatively small proportion of students in the class to monopolise a teacher's time.

Given the difficulties in the interpretation and application of research findings, Hodson (1993a) asserted that it is important to consider science as a coherence of *learning* science, *learning about* science and *doing* science such that the students' experience in science is conceived of as three different orientations of the same 'constructivist, reflexive and interactive activity' (p 124). He claimed that it is the:

> ... very idiosyncrasy and personalisation of scientific investigation (doing science) that provides students with the stimulus for recognising and understanding the inter-relatedness of the three activities. First, enhanced conceptual understanding of whatever is being studied or investigated. Second, enhanced procedural knowledge - learning more about the relationships between observation, experiment and theory, provided of course there is adequate time for reflection. Third, enhanced investigative expertise - which might eventually develop into connoisseurship.
> p 125

It can thus be argued that 'acquisition of procedural knowledge is neither an end in itself nor the means of developing conceptual understanding ... but the means by which real world problems are tackled' (Hodson, 1993a p 126). Teachers, according to Hodson (1993a) may find Lock's (1990a, 1991) framework - considering practical work along the dimensions of teacher student involvement and openness - helpful when moving towards this ideal. However, Hodson also sounded two notes of caution for those working within an overall constructivist epistemology. The first regarded the necessity to avoid the trap of relativism and the second referred to ensuring that practical activities move students towards currently accepted knowledge without imparting the feeling that such knowledge is 'out there, waiting to be discovered' (Hodson, 1993a, p 126).

There has also been a concern regarding communication between teachers and students in the science laboratory - all is not straightforward, or seemingly transparent. Tasker and Freyberg (in Osborne and Freyberg, 1985; Tasker, 1981, 1992) reporting on findings from a study focusing on the mismatch of students' and teachers' expectations in the practical laboratory, listed discrepancies in intent, action and in views of the world. They noted that there are implications here for teachers and warned that teachers should not view student investigative tasks from their own scientific perspective.

2.6 Summary

In this chapter I have considered some of the historical influences on the nature of practical work in science education in New Zealand schools. An overview and critique of the function of practical work in formal school

Science education has also been presented. There are problems associated with promoting practical work as being able to enhance students' achievement of wide-ranging learning outcomes. When considering possible learning outcomes, it is important to identify the particular nature of the practical work that students are engaged in, whether it involves experiencing phenomena, offers the opportunities to practise skills or techniques, or whether it is investigative. Investigative practical work is seen to offer many opportunities to enhance student learning in that is presented as a means by which students can do science, learn science and learn about the nature of scientific enterprise.

An integrative investigative strand is an important component of current New Zealand Science and Biology curriculum documents. In these curriculum documents there is strong encouragement for investigative practical work to be a significant part of Science and Biology programmes. Questions remain however. Is this curriculum emphasis actioned in schools? What reasons do teachers and students give to support the inclusion of investigative practical work in school Biology programmes? What do they value about this approach? What do they find difficult? How can teachers be supported in this approach? What learning outcomes result from student involvement in investigative practical work? How can we enhance the learning of students who are carrying out investigations?

To help find answers to these questions it is important to consider in more detail the nature of investigating within practical work in science education. What is it? How is it linked to problem-solving in science education? The literature addressing these questions will be explored in the next chapter.

Chapter 3: Investigation in school Science

3.1 Introduction

In the previous chapter the history of the influences on practical work in New Zealand schools was briefly traced and questions regarding the nature, role and efficacy of practical work were presented. Investigative approaches to science education in general and to practical work in particular have been advocated to address some of the perceived shortcomings of either didactic approaches coupled with very structured practical activities, or process-skills approaches. This global trend towards investigative approaches to practical work in school Science is reflected in New Zealand science curriculum documents.

In *Science in the New Zealand Curriculum* (Ministry of Education, 1993b) there is an expectation that students, as well as being introduced to well-established scientific knowledge, will also learn about how scientific knowledge is constructed and in such a way that they gain an understanding of the status of this knowledge. It is expected that they will develop an understanding that observation is not theory neutral, that social and peer group beliefs influence both the management of an investigation and the interpretation of data, and that scientific theory cannot be derived solely by a set of inductive rules. Not only are students expected to learn *how* investigations may be done but also *why* they are done.

However, although there is a curriculum driven emphasis on the inclusion of investigative work in school science programmes, there is a lack of consensus about what is meant by investigative work (Gott, 1987). This chapter looks in more detail at the nature of scientific investigation and the related process of problem solving (Section 3.2). It considers possible relationships between investigation and problem solving (Section 3.3) and explores reasons given for the inclusion of investigations in school Science (Section 3.4). A summary of research directions related to investigative work in school Science is presented in Section 3.5 and the reasons for the research directions of this study are outlined in Section 3.6.

3.2 The nature of investigation and problem solving

Science education writers have provided wide ranging definitions for investigation. Additionally, this range of given definitions for investigative work from some writers is compounded by an absence of clear definitions on the part of other writers. Many writers define the term 'investigation' as it relates to problem solving, and vice versa, and they frequently use the same, or similar, process diagrams for each (Johnsey, 1986; Murphy, 1988). The relationship of investigation with problem solving will be addressed in section 3.3 of this chapter. First though it is important to consider the range of activities encompassed by 'investigation' and 'problem solving'.

3.2.1 Investigation

An investigation has been defined as a situation in which a scientific problem is set (Woolnough, 1991). In this framework, pupils are expected to plan their course of action, carry out an appropriate experiment (in the general sense of the term), record and interpret the data and communicate the results. On the other hand, Gott and Murphy (1987) indicated that they viewed a practical investigation as one type of problem and described a problem as a task for which the student has to do more than recall a well tried solution to be successful. By 1995 Gott, with Duggan, was defining investigation more specifically as 'a task for which a pupil cannot immediately see an answer or recall a routine method for finding it' (p 14). They also defined problem solving as 'any activity that requires pupils to apply their understanding in a new situation' and stated that 'investigations are one type of problem solving' (p 14). A similar definition was provided by Gil-Perez and Martinez-Torregrosa (1983). Although concerned primarily with the 'end-of-chapter' pen and paper problem solving tasks rather than practical work they perceived problem solving to be an investigative process and they defined an investigation as 'something for which there does not exist an obvious solution at the beginning' (p 447).

A broader, more encompassing definition for scientific investigation was presented by Duveen *et al* in 1993. They defined scientific investigation as:

> an enterprise which searches for explanations about why phenomena happen in the way they do, using previous knowledge, new observations, imaginative analogies and carefully designed experiments.
> Duveen *et al*, p 19

Writing and presenting materials for teachers, Twiss (1994) extended the definition to include decision making. He saw investigation as a process of testing existing beliefs about cause and effect relationships or as a means of exploring further one's relatively firm ideas about an existing relationship. He emphasised that this did not imply learning by discovery, nor did he perceive investigation to be a mainly practical activity. He listed the understanding required for successful completion of investigations as procedural, conceptual and contextual. Students were therefore expected to have an understanding of the procedures that were required, to have knowledge of the declarative concepts inherent in the investigation and to understand the context in which the investigation was set. Decision making in science has also been linked with investigating in the work of the OPENS project (Jones, Simon, Black, Fairbrother and Watson, 1992) which defined an investigation as an activity where students 'use their existing knowledge and ideas to devise a suitable exploratory procedure' (*ibid* p 7).

The notion of research is incorporated in some definitions of investigation. Woolnough (1994), for example, used the term 'student research activities' to cover a range of investigative activities in science. The key factor in these student research activities was that they should be focused on a problem of genuine concern to the students and that the students should take personal responsibility for the progress and outcome of the project.

For other writers there was a focus on the process in which students are engaged rather than on the problem area. Parkinson (1994), for example, defined investigation as one where students will be 'finding things out by enquiry'. They will be experimenting and searching for information in other ways. For him such work was characterised as investigative because it:

> gives pupils the opportunity to test their own understanding of scientific phenomena; encourages pupils to make statements that they can test; allows pupils to plan their own investigation; presents pupils with the opportunity for discussing their ideas with other pupils; encourages pupils to think in a scientific way, considering the variables and carry out a fair test; makes pupils think about the type of apparatus and measuring

equipment they will need; allows pupils to make decisions on what observations to make; gives pupils the opportunity to decide on the most appropriate way of recording their results; places pupils in a position where they have to interpret their own results and can initiate further discussion and /or further investigative work.
Parkinson, 1994, p 15

Other definitions of investigation focus on what the students will be doing. Investigating may mean students being engaged in 'hands on' conducting of experiments, or gathering information from a wide range of resources using a variety of information technologies or, more likely, an integration of these, for example:

Carrying out an investigation in science involves an interaction of many complex skills. These include focusing, planning, information gathering, processing, interpreting, and reporting. Students may be investigating by carrying out a practical investigation of the 'real world', by carrying out an investigation of appropriate reference material, or by integrating these approaches.
Ministry of Education, 1993b, p 43

Some writers define investigations obliquely by focusing on the opportunities which first hand investigations give students to use both creative and critical thought, 'together with practical and observational skills to solve a problem or find and answer to a question' (Wenham, 1993, p 231). Another example of this indirect defining is given by Driver (1981) who, when reviewing the case for 'the pupil as a scientist', claimed that providing opportunities for pupils to undertake their own investigations is 'not in order to establish an important principle, but to gain some experience of planning an experiment using their own initiative' (p 81).

For the purpose of this research, I have defined an investigation as practical work which requires students to use previous knowledge and new observations as they carry out carefully designed experiments to find answers to a specific problem or a set of problems. This definition emphasises the personal involvement of the students in the investigative work. In order to design and carry out experiments to find answers to specific problems the students will be required to construct links between their prior understandings of declarative and procedural concepts and their new observations. The definition is thus consistent with a generative learning model as proposed by Osborne and Wittrock (1985). Problem solving, which is frequently linked with investigating in the literature will now be considered.

3.2.2 Problem solving

In the next part of this section the range of activities included in problem solving will be defined and the nature of its links with investigation will be considered in Section 3.3.

Problem solving as an educational activity is not new. It has been the concern of science educators for more than 85 years. In 1910 John Dewey (Dewey, 1910/1995) was saying that problem solving, through reflective thinking - the method of science, as he defined it - should be both the method and valued outcome of science instruction in America's schools. Fifty years later Gagne (1965) perceived problem solving as a process by which the learner discovers a combination of previously learned rules which can be applied to a achieve a solution for a novel problem situation. By the late eighties Heaney and Watts claimed (1988, p 1) that 'engaging youngsters in solving useful and relevant problems in science is clearly an important part of science education [because it is common in science curricula].'

It has been argued that we all engage in problem solving every day of our life. Proponents of this view claim that we constantly gather information about a situation, evaluate the usefulness of this information and then make decisions based on this information. This ability to solve problems is deemed to be very important, as is the ability of students to transfer this problem solving ability to situations outside of the classroom. The importance of this activity is often emphasised in educational policy statements, such as New Zealand's curriculum framework document which indicated that a school curriculum should provide learning opportunities for all students to apply learned ways of investigating, describing and understanding to solve problems beyond the context of the classroom (Ministry of Education, 1993a).

This comment from the National Curriculum Framework implies both a generalisable problem solving ability and the transfer of this ability from the school classroom into wider world experiences. The search for this generalised non subject-specific, problem solving approach has occupied many science education authors, for example Instone (1988), who have tried to identify stages in the problem solving process which could apply to all problems. However, others have expressed concerns regarding the notion of a generalised problem solving process and transferability of such generalised skills, proposing instead that much problem solving capability is situationally embedded. That is, the problem is so closely linked to the context in which it is framed that it is impossible to solve it without addressing the framing context (Hennessy, 1993). Another problematic aspect is highlighted by Brown *et al* (1989) who argue that what is learned as part of the school culture and classroom procedures 'thereafter remains hermetically sealed within the self-confirming culture of the school' (p 34).

There is also a complexity of meanings for the term 'problem solving' with a wide ranging use of the term to cover aspects of learning such as the solution of problems in end of chapter revision sessions presented for the purpose of exercising mental skills, to simple 'egg race' situations, and contextual applications demanding high intellectual performance. It is therefore important to seek to understand the features of problem solving and unpack the reasons for the inclusion of problem solving strategies and approaches in school science.

Another difficulty for reviewers of the literature on problem solving is that a definition of problem solving is often not precisely stated in many of the papers which address this strategy, thus making it unclear which concept of problem solving the writers are following. However, the working concept of problem-solving that the writers were operating within can often be deduced both from classification systems which they use and from their stated claims as to its value.

Most writers would appear to agree with Ross and Maynes (1983) who developed a definition of problem-solving which focused on novelty of encounter and paucity of instruction. They defined problem solving as:

> a situation in which an individual is called upon to perform a task not previously encountered and for which externally provided instructions do not specify completely the mode of solution.
> *ibid*, p 155

Alternatively the focus may be on the complexity of the route required to reach solution, such as:

> when (s)he has a goal which cannot be achieved directly.
> Watts and West, 1992, p 58

Zoller (1987) likewise emphasised the complexity of the route to solution, claiming that it is this complexity which helps differentiate between a problem and an exercise. If problem solving is 'what you do when you don't know what to do', then, if one knows what to do when one reads a question it isn't a problem but an exercise.

For some writers the concept is often interpreted in a restricted sense as the carrying out of 'end-of-chapter' exercises requiring the application of mechanical, algorithmic procedures in order to arrive at one correct answer (Reif and Heller, 1982; Gil-Perez and Martinez-Torregrosa, 1983; Gorodetsky, Hoz and Vinner, 1986; Hadfield, 1987). For others, there is a clear link between a complex process of problem solving, active learning and higher order cognition (Bellamy, 1983; Bentley and Watts, 1989; Tennyson, 1989; Abell, 1990; Jungwirth and Pottenger, 1992). Thus there is a complexity of tasks and activities that are classified under the collective label of problem solving with varying factors relating to problem situations, and the intentions and technical skills of the problem solvers involved, for example:

> Problem-solving can be regarded as an element of thinking but is probably more properly considered as a complex learning activity that involves thinking. Problem-solving is the last act in a series of cognitive procedures, and included in this chain of events is a process of at least equal importance, namely problem-recognition. The whole range of activities from recognition to solution is often called problem-solving.
> Garrett, 1987, p 133

In addition, Garrett (1987) suggests calling the whole process *problem-encountering* rather than problem solving as this de-emphasises the final solution and recognises the complexity and importance of the procedure. The nature of the problem and the process of problem solving have both been used as attributes for definition purposes (see Figure 3.1 for a summary of the continua of these defining systems). A number of these classifications systems employed by science philosophers and educators to define problem solving will be described under the headings below. These include empirical v. conceptual; puzzles v. problems; authenticity; structure; ownership; degrees of openness; purpose of engagement; demand on student; and process descriptions.

Empirical v. conceptual

The first classification system is that of empirical versus conceptual. Laudan (1977), theorising that science fundamentally aims at the solution of problems, defined two types of problems. These are empirical and conceptual problems. Empirical problems are first order problems where scientists are looking for explanations in a particular context and where solved problems count in favour of a theory. Conceptual problems however are characterised by inconsistencies in the theory, either internally where the theory may be vague or unclear or logically inconsistent, or externally if the theory is in conflict with another theory considered rationally sound.

Form of problem situation: puzzles v. problems

A second classification system is that of puzzles versus problems. For Garrett and Sanchez-Jiminez (1992) the concept of problem was itself 'very catholic, embracing what might be termed closed, fixed answer puzzles to open-ended situations in which no final answer can be guaranteed' (p 271 - 272). Garrett (1986, 1987) (also Baker and Baker, 1986 and Tinnesand and Chan, 1987) described two forms of problem situations: puzzles and problems. Puzzles were defined as activities where a successful completion is possible, the means by which the successful completion can be reached is known and the answer is usually recognised as correct by the solver (Garrett, 1987).

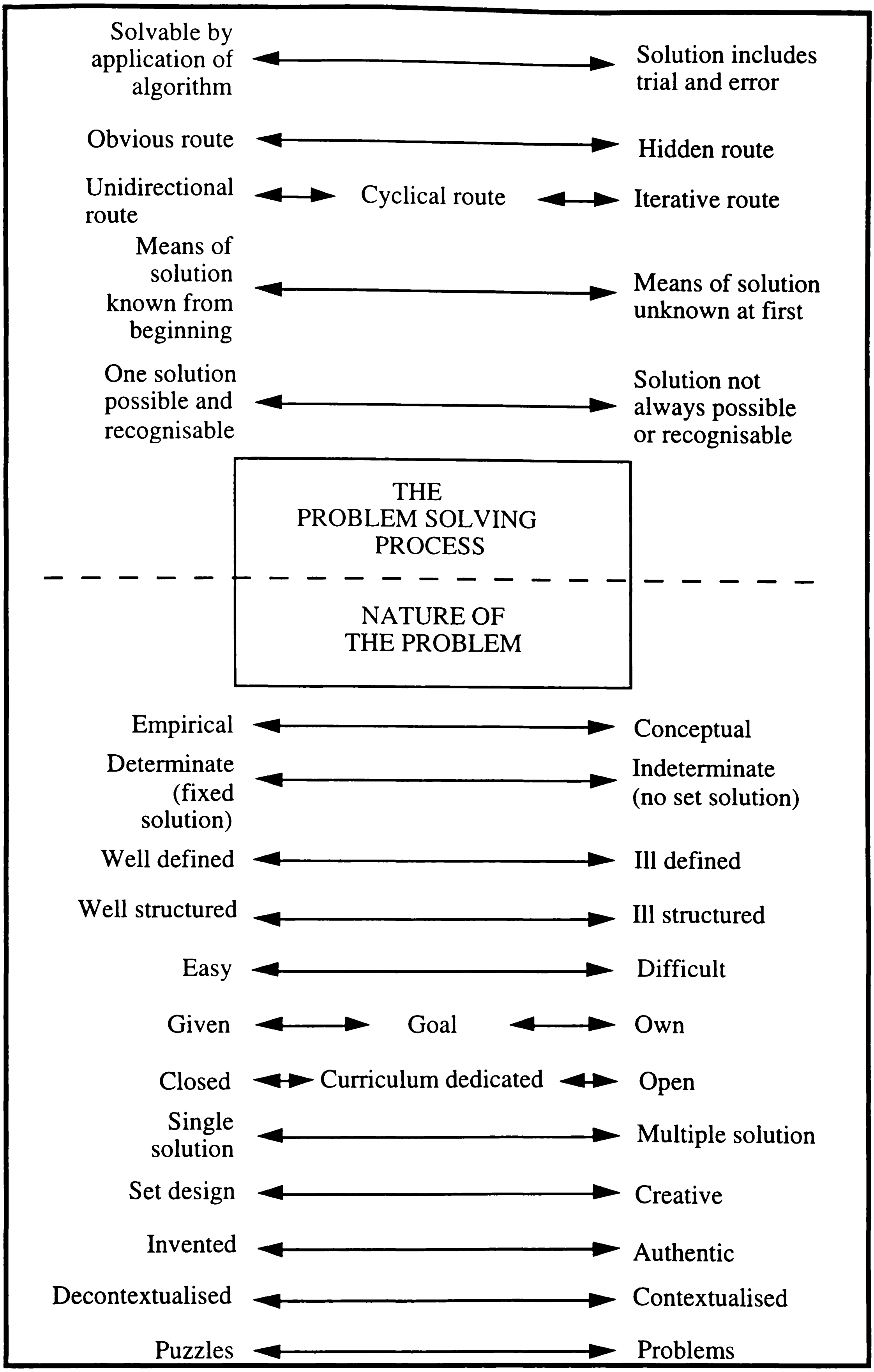

Figure 3.1: Summary of continua of terms and phrases used in the literature to classify problems and the problem solving process.

Problems on the other hand were activities where the means to the solution is not quickly identified, there may be more than one solution and the answer may not be necessarily 'correct' but rather simply 'acceptable' by most people involved. Thus the degree of difficulty, the route to the solution and the complexity of the solution are attributes which contribute to the definition of 'problem'. Situations may be deemed to be puzzles or problems by the problem encounterer, depending upon factors such as context, and prior knowledge and age of the encounterer. Garrett (1987) proposed that both puzzle and problem-solving activities are important to provide in school Science but that too little attention is paid to real problem solving 'with the result that the specific skills required are not practised' (p 125). Garrett quoted Ziman (1981) to demonstrate a possible relationship between puzzle and problem - 'as puzzle after puzzle is solved, within some orthodox framework of theory and method, we begin to perceive new problems - questions that can be easily formulated but which have no obvious answer' (Garrett, 1987, p 132). It must not, therefore be assumed that:

> ... all puzzles are necessarily of a lower order of intellectual activity than problems. However, if all science teaching revolves around puzzles and no genuine problems are ever attempted, then the attributes and skills required to solve even puzzles may go into decline. The originality of problem solvers and the utility of puzzlers are both attributes to be nurtured.
> Garrett, 1987, p 132

Authenticity

Another classification system used to define problem-solving includes the notion of authenticity. Here contextually authentic problems are compared with problems which have been created or invented for the purpose of solving them. Heaney and Watts (1988) claimed that we must be careful to acknowledge that puzzles such as those of an 'egg race' type are not problems existing out of real need but simply designed for competition. According to them, genuine problem solving is a technological procedure as it arises out of the need to either explain a phenomenon or to satisfy a need to produce an artefact, a more efficient technique or procedure.

Dunlap & Grabinger (1994) suggested that students will be more able to transfer their skills to new situations and will be able to 'attack' problems constructively if they have been in a classroom that encourages problem solving in realistic, authentic situations where they are actively involved in seeking meaning during the process. Science education researchers working at BioQUEST (1989) have also emphasised the value of authenticity of problem situation as do Reif and Heller (1982), Lave (1988), Bransford and Vye (1989), and Preston (1990). The BioQUEST (1989) team used the terms 'realistic' and 'unrealistic' when they were defining problem solving:

> We call problem solving in science education 'realistic' when it captures the open-ended aspect of science as it is practiced: problems must be both posed and solved by the problem-solver. In practice most general biology courses are taught with 'unrealistic' problems that; come pre-posed; have unique answers arrived at unambiguously; and are checked for correctness by an authority.
> *ibid*, p 3

This distinction between 'real' and 'unreal' problems was similarly addressed by Gil-Perez and Martinez-Torregrosa (1983) and Garrett, Satterly, Gil-Perez and Martinez-Torregrosa (1990). For them, 'real', or 'authentic' problems often necessitate a much more qualitative approach which requires students to articulate the underpinning conceptual understandings rather than using rote, algorithmic approaches when solving the problem.

Structure

A fourth classification system focuses on the structure of the problem. The terms 'ill-structured' as compared to 'well structured' have also been used to define problems (Kuhn and Angelev, 1976; Gallagher, Stepian and Rosenthal, 1992; Main and Rowe, 1993). 'Ill structured' problems have the following characteristics: more information than that initially given is needed to understand the problem; the problem-definition changes as new information is added to the situation; many perspectives can be used to interpret information and there are no absolutely right answers. They maintained that many of the problems with which school students are faced are "well structured' problems which do not require problem-finding and require different skills to solve them. Ill-structured problems, on the other hand, require:

a reiterative process of problem definition and redefinition, the generation of several problem solving approaches and the analysis of many equally viable solutions. Gallagher *et al*, 1992,p 195

Ownership

Ownership of the problem is another system of classification of problem solving. Writers have suggested a distinction between 'given' problems where the solver is given both goal and solving strategies; 'goal' problems where the solver is given the goal but has to provide strategies and 'own' problems where the solver decides both goal and strategies (Bentley and Watts, 1989; Watts and West, 1992).

Degrees of openness

Problem solving activities can also be characterised by their degree of openness. British science educators frequently use the terms 'open' and 'closed' when referring to problem solving situations (Bentley and Watts, 1989; Garrett, 1989b; Gayford, 1989; Lock, 1989, 1990a, 1990b, 1991; Simon *et al*, 1992). This classification has also been adopted by New Zealand writers of documents such as *Investigating in Science* (Ministry of Education, 1995, p15 - 16). Simon *et al* (1992) defined three possible continua of openness. These are associated with defining the 'problem'; choosing a method for solution and arriving at solutions. If students have the opportunity to select and define the 'problem' (that is, the problem is their 'own' rather than 'given' to them); free choice with regard to the method of probing the problem; and there may be more than one acceptable solution then that problem solving situation is deemed to be 'open'. The removal of freedom from any one of the continua results in a more closed situation, with a given teacher problem, a set procedure and only one possible solution representing a 'closed' problem solving situation. The term 'curriculum dedicated' has also been used to indicate problems that are at points between the extremes of the open-closed continuum (Bentley and Watts, 1989). Such curriculum dedicated problems are embedded in usual classroom/text activities and are more closely connected with traditional disciplines.

Watts (1994) stating a close link between science and technology education, called his mixture of problem solving and technology 'open-ended task-oriented problem solving', claiming that participation in such activities enables students to (i) appreciate that science can be a passport to employment, (ii) actively participate in democratic decision making, and (iii) understand physical phenomena in everyday life. Watts (*ibid*) proposed such an approach believing that scientific knowledge should be useful and lead to practical action - which he referred to as 'cognition in practice' and the construction of 'situated knowledge', terms used before Watts by Brown *et al* (1989) and Hennessy, *et al* (1993). Open work as Watts defined it required the learners to use a planned approach to tackle a new problem based on their prior knowledge and learning to produce a discernible outcome:

> It becomes their responsibility to delineate the problem, decide on what an appropriate solution might be, derive and test possible solutions and choose the point at which they think the problem has been solved.
> Watts, 1994, p 42

Purpose for engagement

A further classification system used to define problem solving is that employed by Howlett (1988) who divided problem solving into two distinct categories - 'problem testing' and 'problem learning'. The first is 'problem testing' where pupils learn skills and concepts in lessons and are then asked to solve a problem as a means of evaluating the topic or assessing the level of skills/concepts learnt. The second is 'problem learning' where pupils encounter a problem, for which they have no earlier experience in school, that is constructed to draw them into research and experimentation along required curriculum lines. In finding a solution to the problem they will of necessity encounter and acquire the desired skills and concepts. Howlett claimed that his second category can be likened to open-ended problem solving.

Demands on student

Problem solving situations can also be classified according to the demands they place on a student - a system used by Ross and Maynes (1983). These science educators identified four problem types which frequently occur in science curriculum, which have real life applications, and which students have difficulty mastering. These are *decision-making problems* in which a student must select the best course of action in a complex situation; *correlational problems* in which a student tries to find an association between two or more variables in circumstances in which the values of the variables cannot be physically manipulated; *experimental problems* in which a student seeks to establish a causal relationship between two or more variables by physically manipulating the variables; and fourthly, *comparative problems* where a student establishes similarities and differences between two or more entities.

Defining through a description of process

The final classification approach to be discussed in detail defines problem solving through a description of process, often in a diagrammatic form. An incentive to define a model for the problem solving process lies first in attempts to simplify the process for novices. The simplest representation of the process of problem solving is characterised by a statement from Middleton (1991) who claimed that 'problem solving involves a series of steps which allow a person to come to a solution and make a decision' (p 45). Gayford (1989) also outlined a simplified step like process for problem solving in order to help students to learn to better solve a problem.

However the tendency for some science educators to attempt to simplify what is a complex process sufficiently for it to be understood by novice problem solvers is of concern to other writers. Their concerns are differently based. Firstly, some of those concerned question the portrayal of problem solving as a simplified model because such a simple process model may deny any content or context for the problem solving:

> Many teachers and educators believe that problem solving can be characterised as an idealised process independent of content and involving the sub processes of 'recognising a problem', 'generating and implementing a solution' and 'evaluating the results'.
> Hennessy *et al*, 1993 p 73

Hennessey *et al* (1993) claimed that such idealised problem solving approaches derive from models of how expert practitioners operate and were concerned by this focus. They noted the many different models, and cautioned by asking who is interpreting and developing the models, and if it is appropriate for school students to use models derived from watching experts solve problems.

Secondly, there is concern about the variously different ways in which the different models are presented (Hennessy *et al*, 1993). These may be linear or circular sequences, interacting sub processes, or a generalised process of exploring and defining problem and solution together. It has also been noted that there is disagreement about the degree of iteration (*ibid*). However, generally the process is regarded as complex and difficult to represent as a model especially if it is to be simple enough for teaching to school children.

Some writers have questioned the assumed existence of universal cognitive skills of problem solving and thinking, maintaining that there are limitations of transfer and that the situated nature of cognition should be recognised (Hennessey *et al* , 1993). Referring to Lave (1988), Hennessey *et al* said:

> According to Lave (1988) attempts to represent authentic problem solving activity and dilemma resolution as a systematic sequence of recognising a problem, representing it, implementing a resolution and evaluating the results, ignores the multitude of ways of tackling a problem and the fact that some activities take place simultaneously or structure each other differently on different occasions.
> Hennessy *et al*, 1993, p 83

Since research on problem solving in knowledge-rich fields has shown that subject matter knowledge and reasoning processes are intimately connected, Hennessy *et al* (1993) believed that there is useful debate regarding the use of the term "situated cognition" and the application of scientific knowledge with regard to problem solving:

> [This] converges on the conclusion that the thinking of experts and lay people alike is goal directed, intricately interwoven with the specific problem-solving context and sensibly adjusted to meet the situation's changing demands.
> *ibid*, p 75

Others who criticised the presentation of problem solving as an idealised and generalised process which can be represented by a model were Gil-Perez and Martinez-Torregrosa (1983) but they criticised this presentation from an epistemological viewpoint. They claimed that extreme positivism 'underlies the proposal that there are recognisable stages which form part of the strategy for solving a given problem' (*ibid*, p 448).

The incentive to define a model for the process of problem solving also appears within the context of assessment. Heaney and Watts (1988), for example, defined problem solving by explaining the process in the stages outlined by the Assessment of Performance Unit (1984) and then referred to the diagram presented by Gott and Murphy in APU material in 1987 - see Figure 3.2.

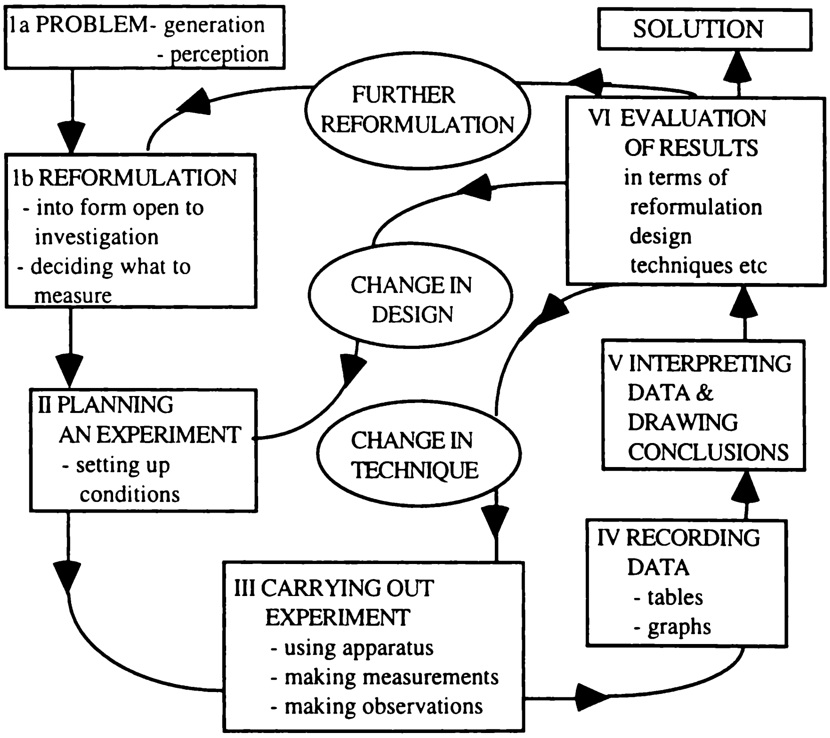

Figure 3.2 The Problem Solving Process (Gott and Murphy, 1987)

This same diagram has been utilised by other British science education researchers and writers (Henderson and Lally, 1988; Skinner, 1992; Parkinson, 1994) as they focussed on the feedback/iterative nature of the holistic process and emphasised the crucial nature of the evaluative phase. Non-British writers have also developed diagrams to help them define problem solving (Zoller, 1987; Simmons, 1988). The adoption of schema developed for assessment purposes as curriculum goals is problematic since aspects of investigating which are significant, yet not readily assessed, may be overlooked.

Other terminology

There have been many other classification systems used to define problem solving. In some instances the adjectives used in relation to problem solving give an indication of an author's concept of problem solving even if there is no direct attempt at defining the concept. Garrett (1987) cited Dewey (1910/1995) as considering degree of difficulty as an important attribute of a problem; Thorndike (1903) who was concerned with route to the solution - was it 'obvious' or not; Marx (1958) who described 'determinate' (fixed solution problems) and 'indeterminate' (different solution problems); and Lindsay and Norman (1977) who used the terms 'well defined' and 'ill defined'. Other authors have used terms such as 'formal' or 'informal' (Bentley and Watts, 1989); 'everyday/local' and 'global' (Hennessy, 1993); 'general' or 'specific' (Glaser, 1984); 'co-operative' (Lapp, Flood and Thrope, 1989); and 'prediction' (Lavoie, 1989).

Figure 3.1 (page 47) summarised the terms used by science education writers when they refer to the nature of problems and the problem solving process. Representations of both the problem solving process and means of defining the nature of the problem were included in the diagram. It demonstrated the complexity of the notion of problem solving and the range of activity which is lumped together under the collective title of problem solving. It is therefore clear that the generic label 'problem solving' has insufficient clearly defined, and commonly held, meaning to make comparisons and applications of research findings and writings directed at teachers easy.

For the purposes of this study a working definition of problem solving included the notions of problem encountering, problem recognition, problem solution and authenticity. Problems are activities where the means to the solution is not easily identified. There may be more than one solution and the answer may not be necessarily 'correct' but rather simply 'acceptable' by most people involved. The process of problem solving does do not necessarily involve traditional 'wet' practical work at a laboratory bench.

In addition to the many ways of classifying and defining problems and problem solving, the relationship between investigation and problem solving is also complex and frequently not obvious in science education literature. The nature of this relationship will be explored in the next section of this chapter.

3.3 Developing a model of the relationship between problem solving and investigation

Problem solving is often linked with one particular aspect of science classroom work - that of carrying out investigations. Problem solving and investigation are thus linked closely by science educators but the nature and overlap of their relationship is variously defined, in that they may be considered to be equivalent or subsets of each other.

Given the lack of direct definition from many writers, the confusion of generic and specific usage of the terms problem solving and investigating, and the universal nature of problem solving classification of these activities is difficult. There appears to be support for one (or more) of the three relationship models shown in Figure 3.3.

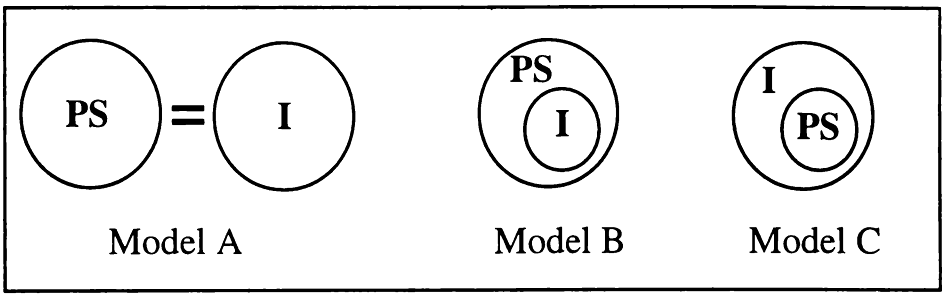

Figure 3.3: Models of the possible relationship between problem solving and investigation (PS = problem solving, I = investigation).

The three diagrams in Figure 3.3 represent possible models of a relationship between problem solving and investigating. In Model A problem solving is equivalent to investigating. This is the model which appears to be supported by Kuhn and Angelev (1976); Bentley and Watts (1989); Abell (1990); Gil-Perez and Martinez-Torregrosa (1983) and Woolnough (1994). In Model B investigating is a sub-set of the process of problem solving. This model appears to be supported by Bellamy (1983); Garrett (1986); Gott and Murphy (1987); Heaney and Watts (1988); Murphy (1988); Gallagher *et al* (1992); Wenham (1993); Parkinson (1994) and Gott and Duggan (1995). In Model C problem solving is a sub-set of the process of investigating. The relationship described in Model C appears to be supported by Ivins (1983); Keeves (1986); BioQUEST writers (1989); Gayford (1989); Lock (1990); Woolnough (1991) and Watts and West (1992).

The confusion which exists regarding the relationship between problem solving and investigating, such that different reports from one writer (Watts) suggest support for all three of the models given above, may be better resolved with the development of another model (D) as shown in Figure 3.4. This model has been developed by the researcher after reflection on the literature.

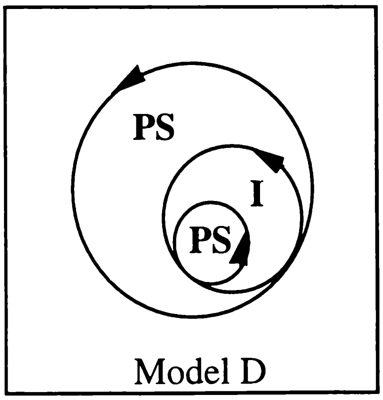

Figure 3.4: A further model of the relationship between problem solving and investigating

In Model D problem solving and investigating are portrayed as a closely linked spiral of sub-setting activities. Here, carrying out an investigation may be one of a number of alternative or complementary ways of solving a problem and whilst carrying out this investigation the investigator may have to solve a problem and so on ...

The relationship between problem solving and investigation is thus complex and difficult to define. The two processes inter-relate at a number of different levels. This complex inter-relationship, and the positioning of problem-solving and investigation with respect to practical work will be further developed to produce a model which will be used during this thesis.

3.3.1 The model for the relationship between practical work, problem solving and investigation used in this thesis

In order to develop the model of the relationship between practical work, problem solving and investigation used in this thesis it is necessary to define the domain of practical work. For the purposes of this thesis, practical work is defined widely as any activity which provides students with the opportunity to have direct personal experience of the subject being studied and which requires both cognitive and psychomotor participation of students. It is the broadest and more inclusive of the three terms (practical work, problem solving and investigation). If practical work does not necessarily mean laboratory bench 'wet work' then any learning activity which is structured to actively engage students may be considered to be practical work. If this is so then problem solving may be seen to be a subset of practical work. This is in contrast to the situation which would apply if practical work was defined more narrowly as laboratory bench 'wet work'. Then, practical work would be considered to be a subset of problem solving.

A development of Model D (Figure 3.4) describes the model of the relationship between practical work, problem solving and investigation which will be used in this thesis (Model E, Figure 3.5). This model portrays investigation as tightly interwoven with problem solving and practical work. Practical work is defined widely and inclusively. Problems may have a large canvas or be of decreasing dimension as students refine or focus the current investigation.

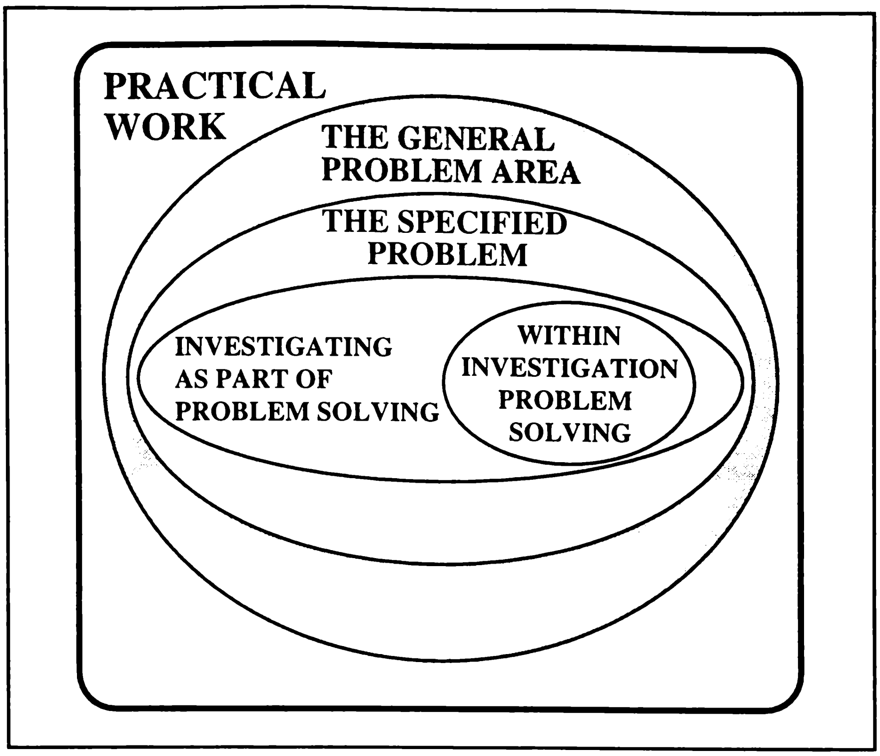

Figure 3.5: Model E: The proposed relationship between investigating, problem solving and practical work.

A general problem area which students might encounter could be that of raising healthy tank fish in the school laboratory. An investigation may help the students to solve a specific problem associated with the maintenance of a fish tank, for example students may wish to solve the problem of a fish tank where the water turns green very quickly after it has been cleaned. If the students propose a link between time for the water to turn green and the amount of fish food introduced into the tank, they could design and carry out an investigation to test this hypothesis. In turn, problem solving may be part of the investigation, for example students may need to solve a problem regarding the development of specialised equipment, or a particular chemical test, to help them complete the investigation. The students would have been engaged in investigative problem solving practical work.

The interwoven complexity of possible relationships between practical work, problem solving and investigation serves to underline the centrality of these activities in school Science programmes. Science education writers have long argued for the inclusion of investigative problem solving practical work in school Science. Some of these arguments are listed below.

3.4 Arguments for the inclusion of investigative problem solving in science education

Why is an investigative problem solving approach to school Science so strongly presented in school Science curricula? Arguments for the inclusion of investigative problem solving approaches can be found in the literature. These arguments can be classified as from educational, scientific, vocational, social and social action, ideological and epistemological perspectives. These aims of science education are often supposition or rhetorical since the claims are not always able to be supported by research data. The arguments given by each of the perspectives will be considered in turn.

3.4.1 General educational arguments

Many researchers (Gagne, 1977; Ivins, 1983; Peterson and Jungck, 1988; Slack and Stewart, 1989; Garrett *et al*, 1990; Preston, 1990; Simon *et al*, 1992; Main and Rowe, 1993) claim positive and long-lasting general educational outcomes for students engaged in investigative problem solving. These general educational outcomes are greater mental dexterity and an increase in the ease by which subsequent problems are tackled, for example:

> What emerges from problem-solving is higher order rule, which becomes part of the individual's repertory. The same class of situation, when encountered again, may be responded to with greater facility by means of recall, and is no longer looked on as a 'problem'. . Problem solving then, must definitely be considered a form of learning.
> Gagne, 1977, p 157

Problem solving is asserted to be an effective method of learning with its efficacy based on assumptions about learning during problem solving such as the involvement of students in the selection and formulation of relevant, motivating problems where students can be challenged to find things out for themselves (Bentley and Watts, 1989). The resultant motivation is claimed to enhance learning (Heaney and Watts, 1988; Garrett, 1989b). Other writers (Garrett and Sanchez-Jiminez, 1992; Wilson, 1995) have emphasised the metacognitive value of problem solving with students being encouraged to consciously evaluate their progress and solutions.

Frequently, problem solving occurs in small group situations and the academic achievement of students encountering problems in such situations has been studied. Ross and Maynes (1983) considered the links between student communication and achievement in problem-solving settings where the frequency of communication was increased by the establishment of small groups. Whilst students in tightly structured groups did not achieve as highly as students working more freely, they noted that students who encountered problems in small groups achieved better learning than students working as individuals.

3.4.2 Scientific arguments

A second argument for the inclusion of investigative problem solving is that this is seen as an important process that scientists engage in and students should therefore experience it if they are to attain a scientific perspective (Stewart, 1988; BioQUEST, 1989; Garrett, 1989b; Garrett *et al*, 1990; Garrett and Sanchez-Jiminez, 1992; Watts and West, 1992). The BioQUEST writers claimed that problem-solving was one of three essential 'P's of scientific practice - problem-posing, problem solving and peer persuasion (BioQUEST notes, February 1989). Such writers support the proposition that science education should imitate science, an argument debated in the previous chapter. Henderson and Lally (1988) endorsed the move away from wholly fact-oriented teaching towards an approach which recognised the educational value of scientific processes as did Flannery (1991, 1993) and Preston (1990), for example:

> It is one thing for a student to read about such problem probing and quite another to actually experience it, to feel the frustration and helplessness of error and the elation of shedding light on a problem.
> Flannery in BioQUEST, 1993 p 4

It may be claimed that what can be remembered the longest from an introductory course in biology is an understanding of, and some practice with, the way biologists pursue their craft, for example:

> Our courses must help students understand how biologists: perceive the world; pose questions; pursue the problems from these questions; and, ultimately, persuade others of the value of their solutions.
> Peterson and Jungck, 1988, p 14

A second scientific argument is that investigative problem solving is seen as an appropriate vehicle for the learning of the declarative knowledge of science (Garrett and Roberts 1982; Reif, 1986; Stewart, 1988; BioQUEST, 1989), for example:

> ...we feel that domain specific problem-solving can be a powerful vehicle for teaching the content of the domain along with its working principles.
> BioQUEST Notes, 1989, p 1

For some writers there was no perceived dichotomy between teaching science content and the nature of science (Peterson and Jungck, 1988). Instead, these were perceived to be mutually supportive activities with investigation or problem solving being a useful vehicle for studying deep content issues. 'A good knowledge of biology involves experiencing first-hand the production and application of scientific knowledge' (*ibid*, p 15).

A third scientific argument for the introduction of investigative problem solving is that it is seen as an excellent means of introducing students to the nature and politics of science (Peterson and Jungck, 1988; Stewart, 1988). Stewart contended that:

> ... certain problem types may help students to understand that
> 1. Science is a body of assumptions (theories) that determines what is or is not going to be considered a problem.
> 2. Science process skills, even those as basic as observation are not independent of theoretical presuppositions.
> 3. Inquiry is driven by a theoretical view that influences what data is generated and how it is to be interpreted.
> Stewart, 1988, p 242

It may be that we should not just give students a philosophically restructured view of the history of science but that we should instead let students know how instants of history have influenced scientific discovery (Jungck, 1985). It is argued that personal involvement in problem solving by students opens opportunities for teachers to address these issues. If students are taught only a normatively defined scientific method then we lose our opportunities to generate in them the imagination and insight required for scientific revolutions. Problem solving according to Jungck (*ibid*) also enables students to understand more about the nature of evidence:

> Research doesn't indicate, experiments don't suggest, evidence doesn't show, and data does not imply. These anthropomorphisms hide their author's intentions and prejudices. A problem posing approach which makes the inferences in a direct manner where the authors are explicit about their role in drawing these inferences seems a more honest approach to communicating science to students and involving students in science.
> Jungck, 1985, p 266

These arguments for the inclusion of investigative problem solving in science education are grand claims even for the education of senior secondary science students. Many of the critiques of proposed aims of practical work in science education that were addressed in Chapter 2 are pertinent here also. Research writings which challenge the value of such activity for conceptual development or increased understanding of scientific endeavour can be found in Woolnough and Allsop (1985), Hodson (1993b) and Osborne (1993).

3.4.3 Vocational or 'real life' arguments

A third argument for the inclusion of investigative problem solving in school science programmes is the assertion that problem solving is a process that people will use at work or in their everyday life outside of schooling. Thus students should learn to apply the processes of science (perceived to encompass investigation/problem solving) to familiar and novel situations (Dewey, 1910/1995; Ross and Maynes, 1983; Garrett, 1986; Zoller, 1987; Garrett and Sanchez-Jiminez, 1992; Watts and West, 1992; West, 1992; Watts, 1994), for example:

> ...that the great majority of those who leave school should have some idea of the kind of evidence required to substantiate given types of belief does not seem unreasonable.
> Dewey, 1910/1995, p 396-7

It has also been argued that we need the capacity of both asking questions and seeking information relevant to a given problem, as well as the ability to use ideas and strategies properly and creatively when we solve real problems within real world contexts (Zoller, 1987).

However, the work of researchers in the realm of 'situated cognition', such as Hennessy (1993), Hennessy *et al*, (1993) and Lave (1988) have drawn our attention to the context specificity of problem solving skills. They maintain that the notion of generalisability of problem solving skills is invalid since the thinking of experts and lay people alike is goal directed and intricately interwoven with the specific problem-solving context. They therefore emphasised the necessity for the development and use of problem solving knowledge and skills in specific contexts. Layton (1991), also notes that 'formal scientific knowledge needs to be reconstructed, integrated and contextualised for practical action in everyday life' (p 78).

3.4.5 Social and social action arguments

Investigative problem solving is also perceived to be an excellent way to introduce and develop group co-operative and communication skills (Henderson and Lally, 1988; Ross and Raphael, 1990) and is worth including in school Science programmes for this reason. Through problem solving students can also be given the opportunity to be creative and innovative (Bellamy, 1983, Garrett, 1987, 1989a, 1989b). Since problem solving is highly participatory, students gain confidence and learn to recognise what they can do rather than what they cannot. However, whether working in group situations enhances student learning may depend upon their communicative and social interactive skills. This is an aspect of student learning which may need to be actively addressed by their teacher.

The move to place problems in real life situations and thus to include social, economic and environmental issues within science studies is also acknowledged and valued by some writers (Jungck, 1985; Bransford, Sherwood, Vye, and Rieser, 1986; Zoller, 1987; Henderson and Lally, 1988; Bransford and Vye, 1989), for example:

> Teaching people to be capable problem solvers is a major concern to all those who believe that the cornerstone of any domestic society is the active and responsible participation in decisions by an educated and intelligent citizenry, regardless of their career orientations.
> Zoller, 1987, p 510

It is also proposed that engagement in investigative problem solving helps students to develop values and attitudes that are important to the kind of society which we wish to develop (Jungck, 1985; Nott, 1988; DeBoer, 1991;

Jungwirth and Pottenger, 1992). There may be a conflation between individual and social responsibility, for example:

> If we want our future citizens to be educated for capability so that they can participate in and develop in a society that is a caring community which values the individual and the rights of other, then an appropriate teaching method in schools would be problem-solving, which involves participation, co-operation, positive assessment and a supportive, tolerant atmosphere in which students can develop knowledge and feelings.
> Nott, 1988, p 47

These social and social action benefits perceived to accrue from a problem-solving approach to science education are also challenged by the work of the situated cognition theorists.

3.4.6 Ideological arguments

Another argument put forward for the inclusion of investigative problem solving in school science is that problem solving helps students to better appreciate the nature of science (Jungck (1985). By having students work within a problem-posing and problem-solving domain it is argued that we help them to appreciate that science is not fixed, with all of its major problems already solved, but rather that science is a dynamically growing approach to difficult problems.

Researchers such as Kuhn and Angelev (1976) have also indicated that engagement in problem solving activities within a social framework may facilitate the breaking of barriers to education for female, minority and low ability students who may traditionally avoid science or reach lower achievement levels.

3.4.7 Epistemological arguments

Epistemological arguments for the inclusion of investigative problem solving in school Science programmes state that since the purposes of education include not only acquisition of knowledge but also the development, improvement and application of higher order cognitive processes, then problem-solving strategies are well placed to encourage this (Bellamy, 1983; Hadfield 1987; Heaney and Watts, 1988; Tennyson; 1989; Abell, 1990; Yackel, Cobb, Wood and Merkel, 1990; Jungwirth and Pottenger, 1992; Hennessy *et al*, 1993; Watts, 1994). For example:

> To learn science from a constructivist philosophy implies direct experience with science as a process of knowledge generation in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and teacher.
> Watts, 1994, p 51

During problem solving conceptual construction is occurring as students use previous knowledge from both domain specific and domain general knowledge - they are constructing, reconstructing and fine-tuning their theories (Wallwork, 1988). Gil-Perez and Martinez-Torregrosa (1983) suggested that problem solving strategies are among the methods suitable for changing students' ideas and that these are equivalent to the methods involved in the development and change of scientific theoretical paradigms. They also claim that the use of scientific processes is clearly in evidence as well during problem solving. Since knowledge is socially constructed, collegiality is important. In addition, individual construction of knowledge is also perceived to be occurring, for example:

> ... the constructivist view of learning and its implications are very relevant .... The technique of problem solving gives students the opportunity to work from existing mental frameworks, to modify these as appropriate and to build on them in a way which is meaningful to those involved.
> Wallwork, 1988, p 95

It has been asserted that it is for these epistemological reasons that investigative problem solving approaches have cemented for themselves a strong position within the school curriculum in general and that of science in particular (Jungck, 1985; Heaney and Watts, 1988; Stewart and Van Kirk, 1990). Statements claiming this paramount position occur frequently in teacher directed literature promoting curriculum change, for example:

> [Problem solving] is a process that clearly involves learning and indeed it could be argued that it is the only effective way to learn. If this is so, problem solving must occupy a central position in the curriculum and in our pedagogy.
> Heaney and Watts, 1988, p 8

In summary, such a wide-ranging support for investigative problem solving from a range of perspectives endorses the central position of investigative problem solving in school science programmes. It is, though, a central position which can be challenged. It is also to be expected that investigative problem solving approaches to learning in science have been the focus of considerable research activity and general writing for teachers. An analysis of the directions and emphases of the reports which have helped to direct this study will be discussed in the next section.

3.5 Research relating to school based investigating

The late 1980s and early 1990s brought an increased focus on problem solving and open investigations into New Zealand science education and there was a significant emphasis on the importance of the integrative nature of these activities written into New Zealand's curriculum statements for Science and Biology. However, at the time of the writing of these curriculum statements there had been no detailed study of the effect of the introduction of an investigative approach to learning in either school Science or Biology in New Zealand. As a Biology teacher education lecturer I felt that it was critical to better understand how students approach and carry out investigations in school Biology classrooms and to become better informed about the complexity of the relationships between the teachers and the students in this situation. Before this study could begin it was important to identify past and current research in science education that related to Science classroom based investigative problem solving.

Major findings from science education researchers exploring investigative problem solving have included a focus on the general effect on student learning and the role of the teacher in the investigative classroom, investigation's link with group work, the degree of openness of investigations, specific aspects of the investigative process, investigation's links with essential skill development such as numeracy, the differences between expert and novice investigators and assessment of students who are investigating. These findings will be discussed in turn.

3.5.1 General effect on student learning and the role of the teacher in the investigative classroom

There has been a focus on the efficacy of investigative approaches for student learning and the role of the teacher in facilitating this (Shymansky and Penick, 1981; Tinnesand and Chan, 1987; Toh, 1990; Blumenfeld, *et al*, 1991; Fay, Schauble and Glaser, 1994; Millar, Lubben, Gott and Duggan, 1994).

Others, such as Hall and McCurdy (1990) and Shymansky (1984) have been concerned with comparisons of the effect of different styles of laboratory approach on student outcomes such as content achievement and reasoning ability. The empirical evidence concerning the efficacy of practical work as a way of learning scientific knowledge is often difficult to interpret (Hodson, 1993a). Whilst an investigative approach is claimed by some to support student learning (Shymansky, 1984), investigative practical work has not always been shown to be superior to other forms of teaching for increasing student learning in science. In some instances it appears to be less successful (Hofstein and Lunetta, 1982; Mulopo and Fowler, 1987). For instance, researchers such as Yager *et al* (1969) found that a inquiry laboratory approach provided no 'measurable advantages over other modes of instruction other than in the development of laboratory skills' (p 85).

Other researchers, such as Cothron, Giese and Rezba (1989) and Tinnesand and Chan (1987), have reported on the part teachers play when students are engaged in particular aspects of investigating. The role of the teacher was shown to be that of facilitator or enabler by some (Murphy, 1988). The student-teacher relationship has also been found to be complex with consequent heavy demands placed on the teacher (Blumenfeld *et al*, 1991; Sydney-Smith and Treagust, 1992; Fay *et al*, 1994). The role of information technology in supporting students' investigations is an alternative focus with Watkins (1992), and many others of the BioQUEST teams (Slack and Stewart, 1989; Stewart and Van Kirk, 1990), reporting on the value of computer software to complement a teacher' work.

3.5.2 Investigation's link with group work

There is a wide ranging literature on co-operative learning programmes across many disciplines and some deal particularly with students working in science contexts (for example, Segal and Haigh, 1991). Solomon (1994b) considered the claim that group discussion helps in the planning and design stages of practical work. Reporting on Wallace's 1986 observations, Solomon suggested that we have evidence that students do negotiate common understandings for both declarative and procedural concepts during group work. Blumenfeld *et al* (1991) focusing on project based learning indicated that while students find group work enjoyable they need to have skills to enable them to discuss ideas, communicate clearly and consider alternatives systematically. Garrett and Roberts (1982) reviewed studies which considered the value of demonstration versus small group work over the period 1900 to 1980. Distinguishing between macro strategies such as exploratory versus expository teaching and micro, classroom level tactics, such as small group work and demonstrations, they summarised as their findings that no one tactic is better than another *per se,* and suggested that any future study should cover a wide range of 'learning and attitudinal outcomes in a multivariate situation' (p 141).

3.5.3 The degree of openness of investigations

One aspect of investigations which has been widely researched and reported is the degree to which investigative work for students allows student choice, that is, is it open or closed. An example of this line of research is that of the 'Open Work in Science' (OPENS) project reported in Jones *et al* (1992) and Simon *et al* (1992). Here, openness was considered along three continuum - defining the problem, choosing a method and arriving at solutions. Other science educators have reported case studies of their experience with an open investigative strategy, for example, Watts (1994). Still others have developed schemes for facilitating a more open approach in the classroom (Lock, 1990; Watson and Fairbrother, 1993; Gott and Duggan, 1995). Findings from these research projects indicate that the addition of openness into school curricula helps students to develop scientific knowledge and understanding and provides opportunities for students to use their initiative in making decisions (Jones *et al,* 1992).

3.5.4 Specific aspects of the investigative process

At times the research focus has more narrowly concentrated on specific aspects of investigating or experimenting, such as students hypothesising (Wenham, 1993); students predicting (Lavoie and Good, 1988; Linton, 1994); variable categorisation (Rezba, Cothron and Giese, 1992; Gott and Duggan, 1995); variable control (Rowell and Dawson, 1984; Dawson and Rowell, 1986; Murphy, 1988; Linn, Clement, Pulos and Sullivan, 1989; Hackling and Garnett, 1992, 1993); and relationships between process skills (Tamir and

Amir, 1987). Such focussed research is valuable for providing a detailed analysis of aspects of student investigative behaviour but it has frequently been carried out in a carefully controlled environment rather than in the regular school classroom. A note of caution has also been sounded regarding the dangers of focussing on particular aspects of investigating. For example Duveen *et al* (1993) warn that by focussing on one or two aspects of investigating such as control of variables, we narrow what should be an holistic endeavour.

3.5.5 Investigation's links with essential skill development

Researchers have also concentrated on examining how student ability at what the New Zealand curriculum framework document (Ministry of Education, 1993a) have called essential skills (for example, communication and numeracy) impacts on students' investigating ability and, alternatively, on how engagement in investigating facilitates students' essential skill development. Linn *et al*, (1989) found that students who received logical reasoning instruction prior to carrying out investigations could link their science content knowledge to their procedural knowledge more effectively than those receiving science content instruction alone. Garnett, Hackling and Silver (1990), arguing that facility with science process skills correlates strongly with formal reasoning ability, used carefully designed instructional materials relating to the nature of science, hypothesis testing and experimental design, to show that students formal reasoning patterns could be improved. The cognitive acceleration work of Adey and Shayer (1990) supports Garnett and Hackling's findings as does that of Byrne and Johnstone (1987) and Wilson (1995).

3.5.6 Differences between expert and novice investigators.

There is a wide body of research regarding expert and novice approaches to problem solving with some very prolific writers (for example, Reif and Heller, 1982; Reif, 1986 and 1990; Woods, 1988a, 1988b, 1988/1989, 1989, 1989/1990). The main aim of this research was to identify whether novice investigators approached problem solving in ways that were identifiably different from experts in the field. If such differences could be identified then the findings could be utilised by teachers to help novices. Glaser (1984) distinguished expert from novice knowledge according to how it is organised with the knowledge of novices being organised 'around the literal objects explicitly given in a problem statement' and expert knowledge being organised around 'principles and abstractions' and the 'application of what they know' (p 98 - 99). Bereiter (1992) discussed the differences between expert and novice problem solvers by contrasting the referent-centred knowledge of novices with the problem-centred knowledge of experts. This understanding of novice-expert differences has been used to suggest how different instructional programmes can target particular aspects of problem solving expertise (Glaser, 1990). These differences between novices and experts have, however, been shown to be very contextualised (Perkins and Salomon, 1989).

3.5.7 Assessment of students who are investigating

The assessment of an holistic activity such as investigating has long been recognised as difficult, yet students are strongly influenced by assessment and reporting (Baumgart, 1992). Also curriculum policy requires teachers to report on their student's achievement of learning outcomes, so there is a obligation to ensure that such activity is assessed. However researchers report both a variety of interpretations of such mandates and means of assessment, for example, Buchan (1992), Swatton (1990, 1993), Crossland, 1993 and James and Conner (1993).

There have been attempts to simplify the assessment of practical skills through projects such as Techniques for the Assessment of Practical Skills (TAPS) (Bryce and Robertson, 1985). These approaches have been evaluated and strongly criticised (Hodson, 1991, 1992a) for their reductionism and non-contextualised tasks. Hodson has cautioned about the superficial rationality of schemes such as TAPS which do not give us evidence about students' ability to tackle a whole investigation - of particular concern with TAPS 1 and TAPS 2 material. Bryce (1991b) has, however, argued in support of the more holistic assessment approach of TAPS 3.

There has been attempts to identify whether student achievement of one aspect of investigating is a reliable determiner for achievement of other aspects. Lock (1989) reported on his research into inter-skill relationships, context dependency and construct validity with respect to investigative practical work. Strong relationships were reported between interpretation and planning skills whereas reporting, observation and self-reliance skills were found to be relatively distinct from one another and all other components. The students' performance on interpretation and self-reliance were found to be context generalisable but observation and reporting were context-dependent. Additionally, student performance on very few of the assessed investigative skills correlated highly with external examination grades, suggesting that assessment of practical work should stand alone.

Other assessment-linked research has concentrated on the means of assessing and the development of models for assessment practice, for example the work of Collis and Davey (1986). Such methods include the SOLO (Structure of the Observed Learning Outcome) technique and its link to the assessment of, for example, students' ability at hypothesising presented by Collis and Biggs (1989). In response to the demands on teachers to assess the English and Wales national curriculum Sc1 strand, Crossland (1993) presented a model of purportedly context free questions for teachers to ask to enable them to collect evidence whilst their students are carrying out investigations. It has also been suggested that much teacher assessment of practical work is subjective and unreliable and some researchers, such as Singer and Lock (1984), have reported on a ways of improving the reliability of teacher assessment of investigative practical work.

The Assessment of Performance Unit (APU) has carried out many long term programmes for assessing science with the production of many research reports and reports for teachers (Black, 1990). Their work has been strongly influential in both curriculum and assessment terms but it has been criticised for redefining school science in terms of problem solving 'process skills' which has led to England and Wales Sc1 curriculum strand's perceived over-strict adherence to the 'fair test' model of science (Tytler and Swatton, 1992).

It is clear that science educators have had considerable interest in investigative problem solving, ranging from its possible effect on learning and the assessment of this learning to a consideration of the interactions between the participants in the investigating process. At times this interest has been wide ranging and has had a holistic focus but more often it has focussed on specific aspects of the process.

3.6 The research focus for this study

Aspects of research in science education which are connected to investigative practical work have been surveyed. Research foci which were identified were the general effect of an investigative approach on student learning and the role of the teacher in the investigative classroom; investigation's link with group work; the degree of openness of investigations; specific aspects of the investigative process; investigation's links with essential skill development such as numeracy; the differences between expert and novice investigators and assessment of students who are investigating. This survey has indicated key aspects of investigating to be explored in the New Zealand context. Whilst the late 1980s and early 1990s had brought an increased focus on problem solving and open investigation into New Zealand education, there had not been any detailed study of the effect of the introduction of an open investigative approach to learning in either school Science or Biology in New Zealand.

If we were to better understand how students approach and carry out investigations in New Zealand Biology classrooms it was apparent that we needed to become better informed about the complexity of the working relationships between the teachers and the students in this situation. It was also essential to follow students as they carried out investigations in order to discern which aspects of the investigative process presented barriers to their achievement. Likewise of value was an exploration of students' attitudes to investigating and to find out whether the students and their teachers considered that an investigative approach enhanced the students' learning of Biology. This information was best be sought within a long term classroom-based case study where students were being introduced to investigative practical work. With the information gained from such a case study it may be possible to discern ways by which Biology teachers can be supported when they are introducing openness into their programmes and to determine how learning may be enhanced for the students carrying out these investigations.

3.7 Summary

This chapter has looked in more detail at the nature of scientific investigation and the related process of problem solving. It was noted that attempts to define ~~of~~ one of these processes frequently included a reference to the other process. Therefore the close relation of these processes was explored and a model to represent the relationship as it would be understood in this study was developed. This model presented problem solving and investigation as being tightly interwoven and with each process contributing to the other at various stages of a practical activity.

Investigation is here defined as practical work which requires students to use previous knowledge and new observations as they carry out carefully designed experiments to find answers to a specific problem or a set of problems.

A definition of problem solving includes the notions of problem encountering, problem recognition, problem solution and authenticity. Problems are activities where the means to the solution is not easily identified. There may be more than one solution and the answer may not be necessarily 'correct' but rather simply 'acceptable' by most people involved. The process of problem solving does do not necessarily involve traditional 'wet' practical work at a laboratory bench.

Practical work is defined widely as any activity which provides students with the opportunity to have direct personal experience of the subject being studied and which requires both cognitive and psychomotor participation of students.

Reasons given for the inclusion of investigative problem solving in school Science were examined. These arguments had educational, scientific, vocational, social, ideological and epistemological bases. An analysis of research findings relevant to investigative work in school Science was presented. Research foci which were identified were the general effect of an investigative approach on student learning and the role of the teacher in the investigative classroom; investigation's link with group work; the degree of openness of investigations; specific aspects of the investigative process; investigation's links with essential skill development such as numeracy; the differences between expert and novice investigators and assessment of students who are investigating.

The research directions of this study of students and teachers engaged in investigating in a Biology classroom were outlined. If we were to better understand how students approach and carry out investigations in New Zealand Biology classrooms it was apparent that we needed to become better informed about the complexity of the working relationships between the teachers and the students as the students carried out investigations. We also needed to better understand how students interact with the tasks to carry out the investigations. This information was best be sought within a long term classroom based case study where students were being introduced to investigative practical work.

Investigating is seen as closely linked to learning in most science curriculums. In Chapter 4 it will be argued that the engagement of students in investigative practical work reflects a co-constructivist epistemology and pedagogy.

Chapter 4: A Theoretical Framework For Investigating In Science

4.1 Introduction

Investigating is seen as closely linked to learning in most science curricula. In this chapter I will make a case for a particular constructivist view of learning, specifically a co-constructivist view within a social constructivist paradigm, as being appropriate to inform my view of investigative work.

Personal, radical and social constructivist theories will be outlined in Section 4.2. Investigating will then be considered from positivist and general constructivist view points (Section 4.3). A social constructivist framework for investigating is developed in Section 4.4, with particular reference to a co-constructivist pedagogical model.

4.2 Constructivist views of learning

Constructivism contends that knowledge is not passively received but is actively built up by the cognising subject. Constructivism asserts that 'learning takes place when an individual constructs a mental representation of an object, event or idea' (Bell and Gilbert, 1996, p 44). For constructivists 'information is that which is formed from within the data selected from the environment', whether it be external objects or language, (Watts and Bentley, 1991, p 175) rather than being transformed from the environment to the individual via the senses.

Constructivist theories can be largely defined as personal, radical and social and these will now be discussed.

Personal constructivism

These theories focus on the individual's personal construction of meaning. Early learning theorists who developed personal constructivist views of learning were Piaget and Kelly (as described by Pope and Gilbert, 1983). The assumptions on which personal constructivist theories are based are expressed by Osborne and Wittrock (1985) as:

a) The learners' existing ideas influence what use is made of the sense and in this way the brain can be said to actively select sensory input.
b) The learners' existing ideas will influence what sensory input is attended to and what is ignored.
c) The input selected or attended to by the learner, of itself, has no inherent meaning.
d) The learner generates links between the input selected and attended to and parts of memory store.
e) The learner uses the links generated and the sensory input to actively construct meaning.
f) The learner may test the constructed meaning against other aspects of memory store and against meanings constructed as a result of other sensory input.
g) The learner may subsume constructions into memory store.
h) The need to generate links and to actively construct, test out and subsume meanings requires individuals to accept major responsibility for their own learning.

Osborne and Wittrock, 1985, 65 - 67

Whilst personal constructivist views of learning emphasise the role of the individual in learning they do not acknowledge the role of the social and cultural context of the learner (O'Loughlin, 1992). After questioning the absence of the teacher from many constructivist images O'Loughlin noted that:

> The picture is silent too regarding the historical, social, cultural and physical contexts of the learning process as well as the specific biographical influences that have shaped this child's epistemology.
> O'Loughlin, 1992, p792

It will be argued that the teacher has a very definite and important guiding role to play in science classrooms where students are investigating.

Radical constructivism

Radical constructivism as propounded by von Glasersfeld (1984) in mathematics education has four underlying principles. The first is the rejection of the idea that we can accurately and completely know reality. The second is the assertion that scientific knowledge must be judged by its instrumental value. The third presents the idea of concept formation being the result of an individual's effort to represent his or her subjective experiential reality and, fourthly, von Glasersfeld introduced the idea that these formed concepts are modified until they become functionally effective.

As with personal constructivist views of learning the radical view point has been criticised both for its lack of emphasis on the social and cultural contexts of learning and for its relativistic view of reality (a matter which will be discussed later in this chapter).

Social constructivism

A social constructivist view of learning recognises that the bases for learning in science are social and cultural as well as personal and that the 'social context in which cognitive activity takes place is an integral part of that activity, not just the surrounding context for it' (Resnick, 1991, p 4). Driver, Asoko, Leach, Mortimer and Scott (1994) defined social constructivism by indicating that this 'perspective recognises that learning involves being introduced to a symbolic world' (p 5) but this term, social constructivism, is seen as in need of elaboration (Bell and Gilbert, 1996). Hennessy (1993) referred to the learning which is a 'process of enculturation or individual participation in socially organised practices' (p 2) as situated cognition. Other terms such as social cognition, cognitive apprenticeship, learning in context and everyday cognition also imply a social perspective for learning and 'imply that cognition is not bounded by the individual brain or mind' (Bell and Gilbert, 1996, p 49). Bell and Gilbert (*ibid*) proposed a social constructivist view of learning which recognises that

- Knowledge is constructed by people.
- The construction and reconstruction of knowledge is both personal and social.
- Personal construction of knowledge is socially mediated. Social construction of knowledge is personally mediated.
- Socially constructed knowledge is both the context for and the outcome of human social interaction. The social context is an integral part of the learning activity.
- Social interaction with others is part of personal and social construction and reconstruction of knowledge.
  Bell and Gilbert, 1996, p 50 - 51

Co-constructivism

A co-constructivist view of learning refers particularly to the learning which occurs when a learner is in dyadic (often), or small group, interaction (Rogoff, 1990). In the science classroom this interaction may be a teacher - student relationship or a student - student relationship. An acceptance of the significant role that teacher - student and student - student interactions plays in students' learning enables us to consider the activities of a science classroom from this perspective - in the framework of this study the activities associated with students who are engaged in investigative problem solving practical work.

It is the social constructivist standpoint with its emphases on the social *and* personal perspectives of students' learning in a science classroom which underlies the research carried out for this thesis. This social constructivist standpoint may represent a change for many in science education in New Zealand which, it is argued, has long been underpinned by a positivist paradigm and a predominantly didactic approach to teaching and learning. In order to better understand the change in emphases which result from a shift to a social constructivist perspective the two paradigms will be contrasted in the next section of this chapter.

4.3 Positivist and constructivist viewpoints of learning in science

Table 4.1 is a summary contrasting the nature of the scientific endeavour and science education within positivist and constructivist paradigms. In this instance "paradigm" is used to indicate a network of relationships and shared understandings within a discipline. Positivism is a theoretical perspective that contends that knowledge consists of, or is derived from, actual facts. Thus a Baconian view of science underpins positivism (Chalmers, 1982). Constructivism has been described above. Each of these paradigms is explored for its underlying ontology; its view of knowledge, science and learning; its educational implications, and the role of the teacher and learner in a classroom structured around the beliefs of the paradigm.

The summary has been developed primarily from the following literature: Lawson and Renner, 1975; Chalmers, 1982; Osborne and Wittrock, 1985; Driver and Bell, 1986; Yackel *et al*, 1990; Phillips and Soltis, 1991; Watts and Bentley, 1991; Wheatley, 1991; O'Loughlin, 1992; Davis, McCarty, Shaw and Tabbaa, 1993; Driver, 1993; Carr, Barker, Bell, Biddulph, Jones, Kirkwood, Pearson and Symington, 1994; Driver, Leach, Millar and Scott, 1996; and Hodson and Hodson, 1998.

	Positivist	Constructivist
Underlying Ontology	Realism	Unrepresentative or critical realism Relativism
View of knowledge	Successive theories that progress ever and ever closer to the correct description of reality. Absolute and unchanging. Mind independent.	Not disembodied, arises through the interaction between previously accumulated knowledge and relationships between current data - person-centred. What 'works' and what is 'good' in a particular context. Shared meanings. Adaptive and ever-changing.
View of science	Determination of knowledge of reality in the most objective manner possible. Concepts are precise and unambiguous.	A human and social construct. Development of best agreed on explanation which makes sense and explains observed phenomena.
View of learning	Brain is seen as a sponge, tabula rasa.	Knowledge is not passively received but is built up by the cognising subject. Function of cognition is adaptive and serves the organisation of the experiential world.
Educational implications	Authoritarian model. Behaviourism - careful sequencing of information, emphasis on observable behaviour. Educational dogmatism - rule oriented. Texts source of facts and theories. Classroom characterised as work place.	Learning is a generative process. Meaning is evoked, not conveyed. Self determinant - reflection, metacognition. Acknowledgment of prior learning. Multiple outcomes (detail and direction). Active engagement of learner; students' intention very important. Knowledge would be presented in meaningful settings. Classroom characterised as learning place.
Role of teacher	Didactic, transmitter of precise and unambiguous knowledge. Focus on structure of scientific content. Classroom controller	Diagnostician/ mediator/ co-constructor. Presenter of knowledge and a provider of experiences. Focus on individual student's learning. Classroom manager
Role of learner	Receiver of transmitted knowledge. Not actively involved in the construction of knowledge.	The learner generates links between input and stored memory to actively construct meaning, then tests the constructed meaning against other stored memory or new inputs. The student is required to accept major responsibility for their own learning.
Responsibility for student learning	Teacher	Student and teacher, either by negotiation, or student within the opportunity provided by the teacher.

Table 4.1: Summary of comparison of educational paradigms

The ontology, or theory of the nature of being, underpinning positivism is realism which proposes that scientific theories describe the world as it is really like, or at least aim to do this (Chalmers, 1982). According to realism 'the world exists independently of us as knowers, and is the way it is independently of our theoretical knowledge of it' (Chalmers, 1982, p 147). Scientists strive to describe that reality with successive theories coming ever closer to the correct description of reality. Knowledge is independent of the mind of the knower.

On the other hand it has been argued that the major ontological viewpoints underpinning constructivism are either unrepresentative or critical realism, and relativism, with relativists rejecting the notion of objectivity (von Glasersfeld, 1984; Rose, 1994; Solomon, 1994a). Watts and Bentley (1991) have argued that there are strong and weak versions of constructivism with a strong version representing a more extreme position than a weak version. It is the strong constructivist view of learning which can be been seen as having a *relativist view* of ontological issues. In fact it is sometimes held that a strong version of constructivism necessarily implies a relativist ontology (Matthews, 1994) and thus views knowledge as transitory and provisional with the objective world not directly accessible. However, although radical constructivism is based on the notion that we can not know reality in an absolute way radical constructivism may be seen to be impartial with respect to reality (von Glasersfeld, 1992) rather than rejecting reality. A real world, he argued, may exist outside of the learner but the learner does not have any sure knowledge of that reality.

Others have also critiqued the suggestion that a strong constructivist version of learning necessarily implies a rejection of a realist ontology (Driver *et al*, 1994). Similarly, Duit (1994) and Rose (1994) maintained that a constructivist view does not necessarily lead to a relativist position and claimed that it can be compatible with a critical or unrepresentative realist ontology which accepts that the physical world is the way it is, independent of our knowledge of it, but recognises that our theories about the physical world are social products and subject to radical development and change (Chalmers, 1982). Critical realists accept that objects (things) exist as reality but that knowledge does not. The knowledge that people construct about objects is constrained by the perspective from which the objects are approached and by the past history of the knowledge maker(s). Thus concepts about objects do not exist in reality but are constructed and held individually and socially. Critical realism is realist in that it assumes 'that

[if] theories are applicable to the world they are always applicable, inside and outside of experimental conditions' (Chalmers, 1982, p 163). Critical realists see knowledge as an 'interpretation of experience, an interpretation based on schemas, often idiosyncratic at least in detail, that both enable and constrain individuals' processes of sense making' (Resnick, 1991, p 1). Critical realists assert that knowledge is culturally and historically bound. Thus the fit of our constructions is continually tested by experience as we formally, or informally, search for evidence (Posner, Strike, Hewson, and Hertzog, 1982). Scientific knowledge becomes a social construct where scientists strive to develop the best agreed on explanations for observed phenomena. It is always contextual and not separated from the knower (Wheatley, 1991).

Within a positivist paradigm science is viewed as a means of determining our knowledge of reality in the most objective and unbiased manner possible. Concepts are presented as precise and unambiguous. On the other hand within a constructivist paradigm science knowledge is seen as an individual and social human construct. Scientists work together to develop the best possible explanation of an observed phenomena which makes sense and has explanatory power.

Within a positivist paradigm learning is perceived to be the acquisition of acquired/received knowledge which is transmitted to the learner by the teacher (Davis *et al*, 1993; Jonassen, 1991). The knowledge that experts have acquired is perceived as having to be transmitted to the student since the experts' knowledge is 'much closer to reality than beginners' knowledge' (Davis *et al*, 1993, p 628). The student's brain is perceived as being a sponge waiting to soak up knowledge; a tabula rasa or blank page upon which the teacher writes. Knowledge is received unaltered by the student's mind or thinking. In contrast, within a constructivist paradigm, learning is never simply receptive, but occurs when people construct their own explanations for new information. The learner's prior knowledge, capacity to learn, and disposition; the learning environment; and the learner's previous experiences all influence this learning. Individuals will perceive these influences differently. Such learning does not occur in a social vacuum.

Other people influence both the information that the learner receives and the manner in which it is presented (Cheung and Taylor, 1991; Driver, 1993, Driver *et al*, 1994).

These different views of learning have educational implications. The positivist classroom may be authoritarian. There may be an emphasis on the careful sequencing of information. Texts are seen as the source of facts and theories. There is an emphasis on the mastery of information and the testing of this achievement. The classroom is characterised as a work place. The teacher is a didactic transmitter of precise and unambiguous knowledge. There is a focus on the structure of scientific content. Above all the teacher is perceived as a classroom controller. The learner receives transmitted knowledge and is not seen as actively involved in the construction of knowledge (Davis *et al*, 1993), for example, there is little emphasis on group discussion and greater emphasis on note-copying.

By contrast, in a constructivist classroom meaning is generated, not conveyed (Osborne and Wittrock, 1985). Students are encouraged to be self-determining, reflective and metacognitive (Bakopanos and White, 1990). There is an acknowledgment of prior learning and an encouragement for learners to be actively engaged in their learning. Group discussion and debate is encouraged. Knowledge is presented in meaningful settings. The classroom is characterised as a learning place. The teacher is a diagnostician, a mediator and a co-constructer who provides experiences for the students. The teacher inputs scientific knowledge and will be helping the students to construct scientifically accepted meanings. There is a focus on the students' learning which is managed by the teacher. Students are required to accept responsibility for their learning (Bell, 1993; Carr *et al*, 1994).

Both of these positions have been criticised. A major objection regarding the positivist view is that it is difficult to perceive of the observation of data in a theory neutral manner (Driver *et al*, 1994). It is noted that it is impossible to totally eliminate values and contextual considerations from the science classroom. Students do not, and should not, leave behind their previous learning and their previous experiences when they begin their studies in science. It is also noted that criteria of rationality are always evaluative and dependent on purpose and interest (Davis *et al*, 1993). There are also curriculum concerns arising from the application of a positivist paradigm in science education. Such issues concern what science content will be taught - who chooses who is to make these decisions and then how will these 'experts' select specific science content. Will the 'experts' be scientists, science educators or perhaps textbook writers? And what criteria will be used to guide decisions regarding the specific content of the curriculum given current exponential rates of growth of scientific knowledge?

The constructivist view of knowing and learning is also not without its critics. There has been a concern regarding personal constructivism's continuing emphasis on students' ideas in science and the danger of according to students' ideas the deference and respect normally given to scientific theories (Solomon, 1994a). There has also been concern that the identification of students' alternative ideas or frameworks is not of itself sufficient to ensure that students' ideas will undergo conceptual change such that they will move towards scientific ideas (*ibid*). The social construction of knowledge has not always received recognition (Bell and Gilbert, 1996; O'Loughlin, 1992). Constructivism's emphasis on the individual learner has been seen to create problems for teachers who somehow have to address the individual concerns of thirty or more students within the restricted time frame of a school Science lesson of 45 - 60 minutes. There has been an acknowledged slow application of constructivist approaches to classroom teaching and research projects have been dedicated to supporting teachers who wish to develop instructional methods consonant with constructivist principles (Bell, 1993). A concern closely linked to this study is that expressed by Millar (1989) who queried the notion that students act as scientists when problem solving. The difference between knowledge construction by scientists and that of school children learning science needs to be acknowledged.

Curriculum development concerns also arise from a constructivist view of learning. In a constructivist framework a 'linear means-end model of curriculum development is ... inappropriate' (Driver, 1988, p 138). Instead, the progressive development of curriculum should reflexive with feedback, from all the classroom participants, leading to decisions as to how the learning tasks can be adapted. However, there are constraints on operating classrooms in this manner, such as timetabling, space, equipment and teachers' and learners' expectations. Additionally there is a concern that teachers and students working within a constructivist pedagogy may spend a considerable length of time exploring only a few aspects of science to the detriment of other aspects of science. Thus students may be perceived as having only a limited knowledge of science.

In the next section of this chapter I will consider how my model of investigative problem solving is best explained within a social constructivist view of learning and specifically a co-constructivist view.

4.4 A social constructivist view of investigating

The role of social and cultural interactions with respect to learning have been increasingly recognised in science education (Solomon, 1989) as they have in general accounts of learning (Valsiner, 1987; Wood, 1988; Rogoff, 1990; Resnick, 1991). The view adopted in this study is that whilst learning is a personal activity it occurs within social and cultural frameworks. Thus learning frequently occurs when interactions with more mature or experienced others re-structures one's ways of thinking (Wood, 1988). These interactions may be both spontaneous and controlled. Consequently knowledge production during learning can be seen as a joint construction of understanding by the student and more expert members of the culture. Development of new ways of reasoning, and consequently more sophisticated learning, may also be the result of re-structuring after an internal reflective dialogue with oneself.

The process of learning can be conceived as the development of expertise within a community of practice. In this view, the learning occurs when novices interact with others who have more expertise in a particular knowledge base or with a particular process than themselves; for example, expertise in scientific investigation is not achieved by students by themselves. The processes of science are cultural conventions and are learned and perfected in interaction with those who already possess and practice them. Here, students do not discover these for themselves but adults, who are involved with students in shared projects or activities, provide students with the means to become autonomous and self-regulating - the student not only learns about specific tasks but also how to plan, regulate and organise their own practical and cognitive activity (Vygotsky, 1962).

Students may be able to help each other solve problems and achieve understanding through negotiation of meaning. Conflicting views can lead to discussion and reformulation which may lead to deeper understanding. Personal reflection and metacognition are also important aspects of this process as they may help students to move towards a better understanding of that which is to be learnt, and of themselves as learners.

Learning is a joint activity and knowledge is co-constructed, that is knowledge is constructed by two or more people together. This co-constructivist view is an elaboration of earlier concepts of learning developed by theorists such as Piaget and Vygotsky (Rogoff, 1990). It is a view shared by McNaughton (1995) who defines co-constructivism as:

> A theory of psychological development which explains development as a product of dynamic, mutual and interdependent constructions of an active learner and social and cultural processes.
> McNaughton, 1995, p 199

It is impossible to separate the learner from the social and cultural processes surrounding the learner. Learning is enriched by these processes. A co-constructivist view of learning refers particularly to the learning which occurs when a learner is in dyadic (often), or small group, interaction. In the science classroom this interaction may be a teacher - student relationship or a student - student relationship. An acceptance of the significant role that teacher - student and student - student interactions play in students' learning enables us to consider the activities of a science classroom from this perspective. In the framework of this study the activities are associated with students who are engaged in investigative problem-solving practical work.

A co-constructivist classroom

It can be argued that to adopt a co-constructivist pedagogy is to put social cognitive and social constructivist theories into practice in the classroom. Thus the perspectives of these theorists are of value to our understanding of the workings of a co-constructivist classroom. A co-constructivist perspective of learning means that students will be knowingly involved in seeking meaning as they investigate (Dunlap & Grabinger, 1994; Spiro *et al*, 1991). The students themselves will be discussing and debating and formulating ideas. For this to be so the classroom will be one where there is: recognition of students existing knowledge and the opportunity to restructure understandings (Dunlap & Grabinger, 1994); encouragement of metacognition (Gergen, 1985; Lave, 1991; Thagard, 1992; Ohlsson, 1992; Hennessy *et al*, 1993); open recognition and acceptance of the expert-novice differences regarding task approach (Bereiter, 1992; Glaser, 1993; Hennessy *et al*, 1993); the provision of opportunities for students to learn from others, that is cognitive apprenticeship opportunities (Brown *et al*, 1989; Collins, Brown and Hollum, 1991; Lave, 1991; Perkins, Jay and Tishman, 1993); and the inclusion of cooperative, collaborative activities (Brown *et al*, 1989; Dunlap & Grabinger, 1994). These requirements are closely linked to each other and in each there is a recognition of the social context of learning. There is also an acceptance of the closely intertwined nature of conceptual development and skill development.

Apart from increasing student motivation, allowing students to investigate something that interests them has the added benefit of providing an opportunity for them to make use of their existing knowledge and skills and to structure links with new information and skills (Dunlap and Grabinger, 1994). Motivation to acquire further knowledge and skills is likely to be greater when the problem is relevant to students and when they can work from a base of existing knowledge. There remain some unanswered questions. How does the identification of prior knowledge facilitate the progress of an investigation? How can teachers make more explicit the underlying theories and tacit knowledge that both the teachers and students bring to an investigation? And would this help the students' learning?

It is likely that students who are carrying out investigations will need their co-learners or partners in the learning process (their teachers or peers) to help them to identify past relevant knowledge. Students may need to be encouraged to become more conscious of their learning and knowledge base and to become more keenly metacognitive (Gergen, 1985; White and Gunstone, 1989; Alaiyemola, Jegede and Okebukola, 1990; White and Mitchell, 1994).

It has been suggested (Glaser, 1993) that the difficulties novices face when they are investigating can be attributed largely to the inadequacies of their content knowledge base so that they do not have a wide knowledge base on which to draw. This inadequacy is especially noticeable when the novice's knowledge base is compared to that of an expert investigator with specialist experience in a particular field. An implication for science education arising from the debate about the expert - novice dichotomy may be the challenge for science teachers to recognise and resolve the dilemma of expecting students who are novices to be able to function as experts in a variety of disciplines. It is also possible that limitations in students' procedural and processing capabilities may also be contributing factors.

There are strong links between apprenticeship and cognition in ongoing authentic activity (Brown *et al*, 1989). It is suggested that is through a process of apprenticeship that students enter a culture of practice, cognitively as well as procedurally. Questions that could be addressed here include: How can science teachers help their students to enter the culture of scientific practice? Could teachers facilitate their students' understanding of scientific practice by modelling investigative strategies and by making their own tacit knowledge more explicit? Is there benefit in teachers modelling the process by using think-aloud protocols as suggested by Dunlap and Grabinger (1994)?

It is suggested that students working in groups tend to successfully tackle problems that they would not have been able to handle if they had worked on their own; they share the risk and gain encouragement (Brown *et al*, 1989; Hennessy, 1993). However the value of working in groups can be challenged. Is just being in a group sufficient to ensure students will work productively together on a given task? How can co-operative and collaborative working approaches be encouraged? Will students need additional support such as group dynamics training?

A co-constructivist view of learning places an emphasis on the cognitive within the social constructivist paradigm. Whilst the co-constructivist focus may be narrow, being located within interactions between two or a small number of people, the patterns and focus of their interactions are never-the-less imbued with social and cultural meaning.

Within the co-constructivist view of learning there is a deliberate intrusion of the expert (usually the teacher) in the process of personal construction of meaning by the novice. The teacher usually has greater access to the social domain of 'science' and is therefore more aware of scientific understanding. The 'expert' in the relationship is facilitating or helping the 'novice' to move closer towards scientific understanding, that is, acting as a catalyst or mediator. The teacher is drawing upon his/her scientific knowledge, pedagogical content knowledge and knowledge of the process of learning. In a particular teaching-learning situation the teacher is working towards a defined learning outcome through having an awareness of the student's present knowledge and by extending a challenge to change. There is also the challenge of helping students to identify what may be common in a variety of diverse tasks. These are deliberate acts involving scaffolding (Ninio and Bruner, 1978), unpacking and acknowledgment of tacit knowledge and the extension of the student's zone of proximal development (Vygotsky, 1978).

Students in science learn not only science knowledge but are also socialised into the particularly science ways of thinking and construing the world. There is a distinction between scientists creating new public knowledge and students learning scientific knowledge which is new to them (Kirschner, 1992). Advanced learning requires learners to construct new knowledge from previous knowledge when they are required to apply this knowledge to new situations. This ability to refer to stored memory is especially important when the learner is working within ill-structured domains such as the application of knowledge during scientific investigation and requires cognitive flexibility (Spiro *et al*, 1991).

According to a co-constricutivist view of learning science students do not learn about a scientific theory by reformulating, or by making adjustments to their understanding entirely by themselves. They are given, or seek out resources for learning it. In this regard, the co-constructivist role of a 'teacher' as provider, mediator or enabler is crucial. Teachers present material to students through multiple, non-linear approaches; links are indicated and the context dependency of knowledge is acknowledged. Teachers encourage their students to reflect on their learning - to be metacognitive, to reflect both on the construction of knowledge and the process of doing so.

How does a co-constructivist model of learning help us to understand the learning which is occurring in a science classroom when students are investigating? How is the student interacting with his/her peers, the teacher and the scientific community at large? Figure 4.1 expresses possible interactions within the community of learning. Three sets of knowledge can be identified within this community of learning. There is the teacher's knowledge base - scientific, pedagogical, contextual, social and general. There is the knowledge base of each of the individual students - scientific, contextual, social and general. These two bases of knowledge will be interacting within the wider knowledge domains of the scientific community at large, general knowledge and community knowledge of the school context.

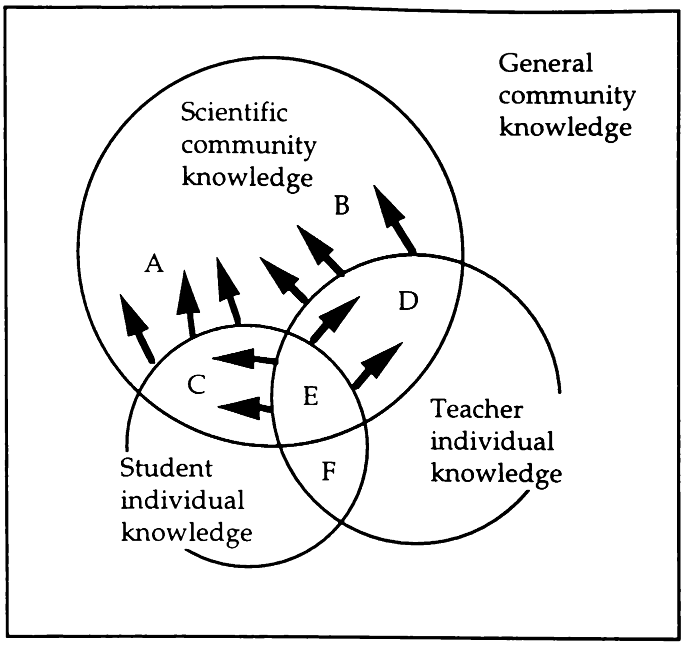

Figure 4.1: Co-construction of understanding in action

The arrows at A indicate the student's extension into scientific community knowledge base outside of interaction with teacher. The arrows at B indicate the teacher's extension into scientific community knowledge outside of interaction with student. At C there is an extension of the teacher's scientific knowledge as a result of interaction with student. Teachers can learn from their students. At D there is an extension of student's scientific knowledge as a result of interaction with teacher. Students can learn from their teachers. Position E represents that region of deliberate/incidental ongoing use of shared scientific knowledge which underpins the extension of knowledge at C and D. As students and teachers share their existing knowledge (positions C and D) the amount of shared scientific knowledge at position E becomes greater. Position F represents a region of deliberate/incidental ongoing use of shared non-scientific knowledge, that is contextual, social and general knowledge which underpins C and D. Such knowledge may include a shared understanding of the culture and mores of the classroom, and a shared understanding of the roles of student and teacher.

The sharing and co-construction of knowledge presupposes frequent communication between the teacher and his/her students, and students who have the ability to access the knowledge base of the scientific community. It will be expected therefore that language expertise is a necessary foundation for learning the knowledge base and culture of science (Wood, 1988). If it is accepted that a fluent, articulate command of language fosters abstract thinking, then the students' ability to articulate (audibly or internally) during investigations will impact on their thinking and knowledge construction. In a classroom based on a co-constructivist epistemology, discussions with a more experienced other will be expected to enable students to overcome initial limitations and to be able to learn to carry out investigations *and* to learn from doing so.

The model of investigative problem solving practical work presented in Chapter 3 on page 59, depicted investigation as tightly interwoven with problem solving and practical work. Carrying out an investigation may be one of a number of alternative or complementary ways of solving a problem and whilst carrying out this investigation the investigator may have to solve a problem and so on ... The activity is likely to be complex and demanding for both students and teachers and to require close conceptual, skill and affective interaction between teachers and students. It is for this reason that I have made a case for a co-constructivist view of learning as being appropriate to inform my view of investigative work.

4.5. Summary

This research is concerned with Year 12 Biology students as they carry out investigative problem-solving practical work. The first literature review chapter (Chapter 2) considered practical work in school Science and Biology programmes from an historical perspective and identified reasons for the inclusion of practical work in school Science and Biology. In the second literature review chapter (Chapter 3), the nature of investigating and problem solving were described and potential links between problem solving and investigation were investigated. A working model of the relationship between investigation and problem-solving, within a framework of practical work, was proposed for this study. Research directions for this study were identified. The final literature review chapter

(Chapter 4) has introduced social and co-constructivist views of learning and has made a case for the appropriateness of a co-constructivist view of learning as a framework for this study of students investigating.

In the following chapter the methodology for this research project which studied the introduction of increased openness into investigative practical work in senior school Biology programmes will be explained and defended.

Chapter 5: Research Methodology

5.1 Introduction

Four questions guided the direction of the research project. These were:

1. In what ways can the students' abilities at carrying out open investigative practical work be enhanced?

2. In what ways can Biology teachers be supported to introduce openness into Year 12 Biology practical programmes?

3. What are the perceived benefits accruing from introducing investigative activities into classroom programmes in Science/Biology?

4. What are the perceived constraints regarding the introduction of investigative activities into school Science/Biology?

This chapter addresses the interpretivist paradigm chosen as the methodology for the research (Section 5.2) and describes the research design (Section 5.3). The people involved in the research are described in Section 5.4. Sections 5.5 - 5.7 outline the types of data which were collected, the means of collecting the data and the sources of the data. Issues of validity associated with an interpretivist methodology are discussed in Section 5.8. Ethical issues which needed to be considered are covered in Section 5.9 and the coding system used in the research report is described in Section 5.10.

5.2 The research methodology

In this research project the data were gathered, analysed and discussed with the participants within an interpretivist paradigm. Such an interpretivist approach, with its goal of revealing the participant's views of reality (Lather, 1992; Robottom and Hart, 1993), allowed the understandings and reasons for actions of the participants to be elicited (Borg, Gall and Gall, 1993; LeCompte and Goetz, 1982). Four key factors led to an interpretivist paradigm being used. These key factors are that it allowed the use of case study and naturalistic inquiry approaches; that it enabled close collaboration between researcher and teachers; that it allowed the complexities of different classrooms to be acknowledged and explored; and that it was compatible with a social constructivist epistemology. Each will be elaborated on, in turn.

The use of case study (Yin, 1988) and naturalistic inquiry techniques (Lincoln and Guba, 1985; Smith, 1982; Welch, 1983) within this paradigm enabled analysis of a multiplicity of classroom dynamics and teaching approaches, an examination of a range of preferences, motivations and actions of students and teachers and the development of a shared understanding by all parties to the research (Mather, 1995).

An interpretivist framework also enabled close collaboration between the researcher and teachers. A persistent concern in science education is the minimal impact of research on practice (Tobin, 1988; Gilbert, 1994). Research which involves collaboration between researcher and teacher, which focuses on an issue identified as significant by the teacher and which is carried out in the classroom is more likely to have impact on practice (Huberman, 1993). Huberman noted the more pronounced impact of research findings on practice if the researcher-teacher relationship involves interaction over a length of time. In this case, exchanges occurred before the study, during the study and during the data analysis and write-up phases of the study. The close collaboration between the researcher and the teachers also allowed the researcher and teachers to more readily reach agreement about the significance of the gathered data (Lin, 1996).

Another reason for using an interpretivist framework was that it allowed for the complexities of different classroom situations to be acknowledged and explored. Throughout the three years of the research project data were gathered from a number of different schools and classrooms each with the potential for differing teaching and learning approaches and where teachers and students worked together and defined their relationships in multiple ways. An interpretivist methodology was able to reflect the complexity of such classrooms and research based in these classrooms (Lacey, 1976; Brown, 1992). In addition, it had the potential to encompass and elucidate the inconsistencies and the personally subjective nature of a teaching and learning context (Eisner, 1984). An interpretivist approach also allowed for an uncovering and description of the research context so that others might be able to connect to the findings and determine the correspondence of such to their own context and then 'imagine whether [the measurement procedures] would yield the same data if replicated' in their context (Borg *et al*, 1993, p 130).

This research project is framed by a social constructivist epistemology and the selected research methodology had to be compatible with and reflect this view. An interpretivist framework allows for an affirmation of the significance of the participants' knowledge:

> The constructivist perspective holds as a chief assumption about much complex behaviour that the 'subjects' being studied must at a minimum be considered knowing beings and that this knowledge they possess has important consequences for how behaviour or actions are interpreted.
> Magoon, 1977, p 651

This research project required that all participants shared not just in the construction of developing knowledge but also had an understanding of each others' objectives and underlying reasons for participation so that these could also be taken into account (Johnston, 1990; Lather, 1992; Cohen and Mannion, 1994). An interpretivist paradigm allowed for this broader and deeper shared understanding through its embedded processes of reporting and discussion at all stages of the development of the story. In this way changes that occurred over time as a result of the intervention could be recorded.

In order to be able to answer the research questions, the project required an approach which would allow for the complex task of monitoring a context specific curriculum intervention over a period of several years. The research context of a New Zealand secondary school was significant because the curriculum innovation that was being monitored had arisen from a national curriculum change. Since a response to a curriculum innovation varies with the individual, the research approach had also to be able to take into account the 'uniqueness of each individual, each culture, and each setting' (Borg *et al*, 1993, p 195). The chosen research methodology had to allow for analysis of 'discrete aspects of an educational problem' (Borg *et al*, 1993, p13) - the goal of quantitative research - and to allow for an overall grasp of an 'educational phenomenon in all its complexity' (Borg *et al*, 1993, p13) - the goal of qualitative research. The research thus required an integration of quantitative and qualitative approaches in order to gain a more complete picture of the changing confidence and abilities of the students and the change of classroom interactions across the period of the research project (Nau, 1995).

The research questions and pathways to their solution were also chosen to allow for an identification, and analysis, of changes to students' approaches to their learning, of changes in the manner and confidence with which students dealt with an increase of openness in practical work and of concurrent changes in their teachers' approaches and used strategies.

At the same time, limitations to the amount of time available for face-to-face interaction of the researcher and the students and teachers participating in the research necessitated a combination of both direct collection of data by the researcher and indirect means of gathering data.

5.2.1 The case study as an approach

Case study research has a place in an interpretivist paradigm as it may help to explain real life interventions that are too complex for experimental strategies. The case study can thus provide a description of a real life context in which an intervention has occurred. Yin (1988) defines a case study as:

> an empirical study that investigates a contemporary phenomenon within its real-life context; when the boundaries between the phenomenon and context are not clearly evident; and in which multiple sources of evidence are used.
> 1988, p 23

In particular, illustrative case studies (Yin, 1988) can describe the intervention itself and may be used to explore those situations in which the intervention being evaluated has no clear, single set of outcomes.

The case study approach was appropriate to this research because the focus was on contemporary as opposed to historical events and the researcher had only limited control over actual behavioural events. The case study approach was also applicable because the researcher collaborated intensively with the participant subjects to find out their phenomenological perspectives. It was relevant to use because the phenomena were studied in their total context and observed over a long period of time and thus the researcher and teachers knew what specific instructional situations and contexts were being referred to. The complexity and richness of a typical school Biology laboratory provides an abundance of data sources and thus a case study approach was appropriate to use because case study research typically uses multiple data sources.

Whilst having the advantage of allowing the generation of rich, in depth data the case study approach is sometimes criticised. If a case study research project is to overcome traditional challenges and prejudices (Yin, 1988) then the researcher must be careful not to allow equivocal evidence or biased views to influence the direction of findings and conclusions. Whilst the aim of any researcher is to produce findings that have relevance beyond the immediate context of the study, the researcher must also acknowledge that case study findings, whilst generalisable to theoretical propositions are not generalisable to populations. In addition, researchers who do case studies may be regarded as having deviated from their academic disciplines because their research is seen as having insufficient precision. The issue is one of validity which will be addressed in Section 5.8. However, 'the continuing relevance of the method raises the possibility that we have misunderstood its strengths and weaknesses and that a different perspective is needed.' (Yin, 1988, p 10).

Within the case study a multiplicity of techniques were used, for example questionnaires and participant observation (which in turn can involve a multiplicity of techniques). For a full description of the data gathering techniques used see section 5.6.

5.2.2 An element of action research

For the teachers who participated in the 1993 and 1994 intervention there was an element of action research (Kemmis, 1981; Peters and Robinson, 1984; Alcorn 1986; Carr and Kemmis, 1986; Sommer 1987; McTaggart, 1989; Feldman, 1994), whose objective to 'effect and monitor change in existing practice through an action phase' (Alcorn, 1986, p33) aimed at bringing about a desired end. It is research carried out by practitioners with a view to understanding, and improving, their own professional practice. Carr and Kemmis (1986) linked action research to curriculum development, professional development and school improvement programmes, claiming that these activities had in common:

> the identification of strategies of planned actions that are then implemented, and then systematically submitted to observation, reflection and changes.
> Carr and Kemmis, 1986, p 164

The teachers who participated in the first and second phase of this research project were involved in a collaborative manner (Johnston, 1990) in defining the problem, selecting a design, selecting a sample, selecting measures, analysing the data and in interpreting and applying findings. However, overall the research can not strictly be called action research because the researcher led most of the decision making; the identification of the problem arose from a formal search of literature carried out by the researcher as well as relating to the commitment of the researcher to science curriculum development and science teaching efficacy in New Zealand; the research design incorporated a long time frame; and it used measurement procedures some of which were not routinely used in the classroom. However the selection of the schools and teachers who participated in the research was in 1993 from teachers who chose to respond to a registration of interest, and in 1995 from teachers who responded to a request after their involvement in a conference presentation by the researcher in 1994. In addition the 1993 and 1994 teachers were personally interested in the analysis of the innovation as it was closely linked to concurrent curriculum change and they were actively involved in analysis of the data as it was being generated. They had adopted the researcher's problem as their own.

5.3 Research design

The procedures and design of the research project were negotiated with the teachers at the research school near the end of 1992. The researcher attended a Biology meeting at City High where the nature of the intervention was discussed as was the range, and nature, of the information which would be gathered as evidence. In addition, aspects of an ethical nature were discussed with the teachers. These included the procedures that would be followed in setting up the observations and interviews, and the procedures for maintaining confidentiality and accuracy of transcripts. The procedures for the validation of data analysis were also discussed. Following this meeting the school's principal and Board of Trustees were formally contacted and permission to carry out the research project in the school was received.

The negotiation for, and nature of the intervention, and the nature of the evidence will be discussed in this section. Ethical aspects will be addressed in Section 5.9 (page 135).

5.3.1 Negotiated intervention

The researcher worked with the teachers and students following a process of negotiated intervention (Simon *et al*, 1992) where the researcher and the teachers together determined the direction of the research project, an approach commensurate with action research. Figure 5.1 summarises the process of negotiated intervention for this research project. The phases of the negotiated intervention remain the same as that designed by Simon *et al* (1992) for the OPENS project, but the given titles and examples are specific to this research project. The components will be discussed starting with the initial exploration and negotiation. The researcher and the teachers at the research school together explored the existing situation during a regular Biology staff meeting towards the end 1992. At this meeting the nature of the intervention was established and decisions taken as to when to begin the research project in the school. The intervention involved the introduction of open investigative tasks to the practical work programme of Year 12 Biology students - refer to Section 5.3.2.

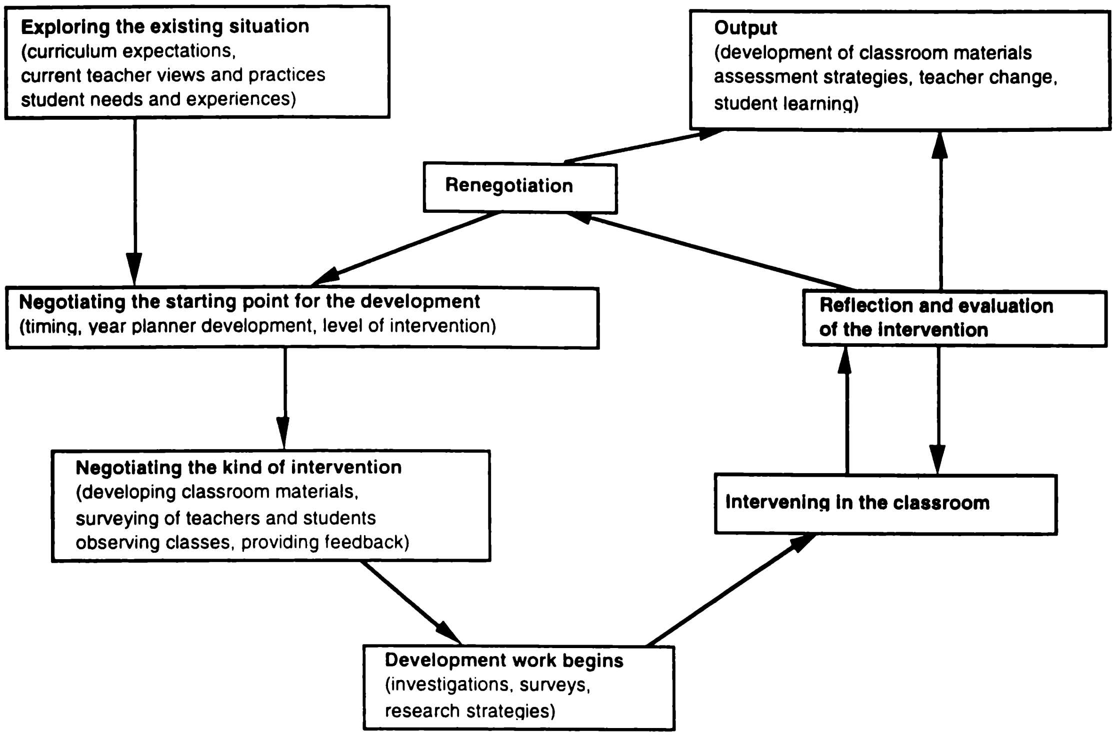

Figure 5.1: The process of negotiated intervention for this research project. (Adapted from Simon *et al*, 1992)

The teachers completed an initial questionnaire designed to elicit their views regarding a problem-solving investigative approach to practical work and the researcher carried out pre-intervention student questionnaires and classroom observation. Following discussion of the data gathered up to this point the specific nature of the investigative tasks was discussed and they were developed ready to be used in the classroom. On the completion of these tasks there was ongoing evaluation of the data followed by discussion with the participating teachers and students. Further intervention was then negotiated. This process was repeated on a micro level following each of the investigative tasks throughout the two years of the research project at the school. On a macro level it was repeated on a yearly cycle for the academic years of 1993 and 1994.

For Phase III of the trial in 1995 a simplified negotiated intervention was followed. After the 1995 participating teachers had indicated that they wished to be part of the ongoing trial of developing materials, access to the schools was negotiated through the Heads of Science, principals and Board of Trustees chairpersons. The trial took place and data was returned to the researcher with only limited access by the researcher to the classrooms and students.

5.3.2 The nature of the intervention

In addition to negotiating the intervention, the nature of the intervention was discussed with the teachers at the research school during initial consultations in November of 1992. The intervention involved the introduction of a way of presenting practical work to students in the Year 12 Biology programme which was different from the school's normal approach. The introduced practical work required students to carry out investigative problem solving. The investigations were linked to curriculum topics and the students were expected to apply their prior declarative, and procedural, conceptual understandings to these new situations. Degrees of openness were introduced as students were required to design their own investigations in order to come up with answers to a given problem.

The tasks

In 1993 the students carried out three investigations specifically for the research project. These were "Green streams", "Factor X" and "Water efficient plants". For details of the other investigative tasks used during the intervention see Appendix B. In 1994 the City High students carried out "Green streams", "Sweet export", "Factor X", "Potatoes for dinner", "Plant cells at work" and "Plants for dry conditions" (initially called "Water efficient plants"). The intervention investigations were linked with different parts of the Year 12 Biology programme. "Green streams" was linked with the ecology section. "Sweet export", "Factor X" and "Potatoes for dinner" were linked with the cell form and function section and "Plant cells at work" and "Plants for dry conditions" were linked with the plant form and function section of the year's programme. In both 1993 and 1994 additional teacher-developed investigations were also carried out during the time span of the intervention. All of the 1994 investigations were included in the 1995 package which was sent to the participating schools.

Data gathered as students carried out the investigative tasks are analysed in detail in Chapter 6. Data from three of the investigative tasks were analysed in particular. The nature of these tasks and the timing of their use will be discussed below.

(i) "Green Streams"

The investigation "Green streams" was designed by the researcher. "Green Streams' was the investigation used for the pre- and post- intervention surveys of students' scientific skill abilities during the 1993 and 1994 phases of the research project. It was also used by some of the teachers and students who trialed the material in 1995.

Green streams!

A small slowly moving stream flows through the corner of your school grounds. You have noticed that the water has become much greener than it usually is. When you discuss this with other members of the class someone mentions that the school playing field had been fertilized recently. Another student suggests that the green colour could be due to the presence of microscopic plants in the water. Perhaps the fertilizer had washed off the field into the stream causing the increase of microscopic plants?

How could you test this hypothesis? Does it matter how much fertilizer has been washed into the stream? Or how long the fertilizer is in the stream? Design and carry out an investigation to demonstrate what could happen when fertilizer gets into a small stream. Write a report for your school newspaper explaining what you did and what you discovered.

Hint: Start with a some pond water and plant fertilizer. Read the instructions on the fertiliser pack carefully. Make sure that you design a "fair test"! What factors would you have to control?

When you think you have got an answer to your original problem what other questions could you ask about this system which you might be able to investigate?

Figure 5.2: The "Green Streams" investigation

(ii) "Factor X"

"Factor X" was part of the year long practical programme for the students in all three phases of the research project from 1993 - 1995. The investigation called "Factor X" was adapted from a similarly named investigation designed by Gayford (1989) during his research into the factors affecting students' effectiveness at carrying out investigations. The investigation "Factor X" was adapted so that its underlying concepts fitted more directly to the section of the New Zealand Year 12 Biology course related to factors affecting enzyme controlled reactions.

How much Factor X?

Imagine that you are working for a company that extracts substances from living material.

You are asked to find two good sources of a substance called Factor X It is known that Factor X occurs in a wide variety of living things. Previous investigations have shown that Factor X occurs in potatoes, celery, broccoli and carrots.

A simple test for Factor X is to pour a small quantity of hydrogen peroxide on to the material which is thought to contain Factor X. A foam is produced. The amount of foam produced indicates how much Factor X is in the material.

Your job is to find the best two sources of Factor X, *in order,* from the four given plant materials.

Your employer wonders if it may be possible to preserve the plant material by heating it to boiling point so that it can be stored until it is required. Does this heating affect Factor X?

You will need to tell your employer the reasons for your decision. You do not need to worry about extracting Factor X. You are provided with the plant materials as well as some apparatus which should be helpful.

HINT: Remember to carry out a "fair test". You may need to consider the amount of the living material which you use and the surface area of this which will react with Factor X

Adapted from Gayford, C.: 1989 *Journal of Biological Education,* **23** 3.

Figure 5.3: The "Factor X " investigation

Following analysis of the 1993 students' approaches to the initial "Factor X" task, the degree of difficulty of this investigation was increased. The students were required to identify two sources of "Factor X", in order, rather than to simply identify the best source. Thus the students were required to make more detailed and accurate measurements. The altered investigation was thoroughly trialed with pre-service science teachers and discussed with the teachers involved in the research project.

The teachers and the researcher had also concluded that, with all the investigations, the 1993 students did not link specific investigative tasks to relevant prior knowledge. Nor did they consider a wide range of factors which could possibly influence the results of their practical work. The students had also been slow to indicate, with exactness, any equipment they might use and measurements they might take. Therefore, in 1994, three additional questions were added to the task sheet and organised to fit beneath the task on one side of an A4 sheet, in order for the students to have easy reference during the design stages of the investigation. The three additional questions directed the students to consider relevant background theory, to identify relevant variables and to identify appropriate types, and degree of precision, of measurement. These three additional focussing questions were added to all investigative task sheets from 1994 onwards.

The investigation called "Factor X" has been carried out by many groups of students during the intervention phases of this research project over the years 1993 to 1995.

In 1993 eighty-four Form 6 Biology students completed all aspects of this particular investigation, working with four teachers. These students completed a worksheet for the investigation and their teachers filled in teachers comment forms. The researcher personally observed the investigation process in two of the classes. The teachers were interviewed by the researcher following the investigation. A follow up discussion took place between the researcher and the students from two of the classes involved.

In 1994, one class of 30 students was observed carrying out this investigation. The students also filled in a detailed worksheet for the investigation and, immediately following the investigation they completed a lesson evaluation form. The teacher completed a teacher's comment form and was interviewed by the researcher.

In 1995 students from 21 schools around New Zealand were involved in a year-long project on open investigative work and during this time they completed the investigation "Factor X", using the tasksheet, student worksheet and lesson evaluation forms provided by the researcher. These task related student writings were returned to the researcher at the end of the year by the teachers.

"Factor X" was not carried out at a comparable time of the Biology programme for all of the students involved in the research project. Some students had had considerable introduction to the theory of enzyme function before they engaged in the task and others carried out the task without any recent review of enzyme function. These differences occurred across years and for classes within a year. The different student experiences are explained in detail in Chapter 6, Section 3 prior to the analysis of the data derived from this phase of the intervention.

(iii) "Sweet Export"

The "Sweet Export" investigation was designed by the researcher and included in the intervention in 1994 and 1995. It was carried out by the students during the first half of each of these years.

Sweet Export

A fruit exporter wishes to export apples to a country where he knows sweet apples are preferred. You are employed to select from five different varieties of apples the two that contain the highest sugar content.

Information: A number of different glucose solutions were tested by boiling with Benedict's solution. They were found to change colour at different times and to produce different coloured results: some turned green, some orange and some brick red.

Hint: Remember to carry out a fair test. For quantitative results heating your solutions in a water-bath will provide more accurate results.

Figure 5.4: The "Sweet Export" investigation

After each investigation and at the end of the year the researcher and teachers discussed the nature of the investigations and ways in which students could be better helped to approach and carry out the set tasks. There was ongoing development in the design of the investigations and in our understanding of the ways in which teachers could work with the students to help them to investigate.

5.3.3 The timing of the research project

The ongoing developmental nature of the research project required trials over three school years as shown in Table 5.1. The research project was carried out over the years 1992 - 1996 allowing for preparation, pre-intervention negotiation and final data collection.

Year	Phase of research
1992	Negotiation of research direction with teachers at City High
1993 Data collection Phase I	First intervention at City High. Four teachers and their classes trial three open investigations.
1994 Data collection Phase II	Second intervention at City High. One of the four teachers and her class trial an extended series of open investigations.
1995 Data collection Phase III	Trialing of open investigation units by biology teachers and students at twenty-two schools throughout New Zealand.
1996	Completion of data gathering. Reaching agreement with regards to data analysis and interpretation with participating teachers.

Table 5.1 Summary of the three main parts of the research

5.4 People involved in the research

5.4.1 1993 - 1994

The teachers

An invitation was made in May 1992, in the Auckland Science Teachers newsletter for schools to register interest if they wished to be involved in ongoing research in the ares of an investigative problem solving approach to school science. Whilst many schools expressed informal interest two responded formally. City High was selected because all the teachers in the Biology department were willing to be involved in the project. City High is a large co-educational secondary school in an upper decile socioeconomic status urban area. In 1993 the ethnic composition of the school was approximately 80% Pakeha. There was a significant Asian roll and small numbers of Maori and Pacific Island children. There were four teachers in the Biology department at City High. Of the four teachers who began the project three were at City High for both years of the intervention at that school. One moved to become Head of Science at another school in August of the second year of the project. All four of the teachers had had more than ten years experience teaching Biology. There were three females and one male. (For the purposes of ensuring anonymity the teachers will be referred to as all female.) In both 1993 and 1994 there were six Year 12 Biology classes taught by these four teachers. In 1993 four of these classes participated in the research project and in 1994 one class was linked to the project. The school had a strong involvement in Science Fairs and one of the teachers was part of the regional Science Fair organising committee.

The researcher's relationship with the 1993 to 1994 teachers

In any situation where a researcher enters a classroom (literally or through the printed medium) the teachers' response will be mediated by the teacher's past experience of, and expectations with regard to, the researcher. This will particularly be the case in New Zealand where the number of Biology teachers is not large and where the researcher had a high profile as the Co-ordinating Writer for the 1991 - 1993 curriculum development in Science (*Science in the New Zealand Curriculum*, Ministry of Education, 1993b). The participant teachers in this research project had previously related to the researcher in a number of different roles - as a College of Education lecturer who frequently visited the school, general biology teaching colleague, curriculum developer, regional and national Science Fair organiser and judge, conference presenter and senior Biology textbook author. It therefore seemed important to acknowledge possible power differentials in these relationships and to discuss these with the teachers.

The students

Each of the four teachers selected a class to work with them on the project. Two of the teachers were working with two Year 12 Biology classes but only one of each of these was selected for involvement in the research project. In

1993 there were ninety-eight students involved at some stage of the year. In 1994 there were thirty-two students involved at some stage of the year. Not all students completed the whole academic year at City High. The students in any one year were aged between 15 and 17 years at the start of the year. All had sat School Certificate Science as this was compulsory at City High. Most were studying Biology for the first time with five students repeating the subject for a second time. The project's aims and procedures were explained to the students and all of the students were asked if they wished to be involved in the project. All agreed. They were given permission to withhold their personal data (interview, taped discussions and worksheets) whenever they wished. All student generated data was coded so that only the researcher and student could identify any student's particular data.

The researcher's relationship with the 1993 and 1994 students

The students saw the researcher as a person who had a very real interest in what they were thinking, something which they saw as different from their regular teacher's role (see field notes 14/3/94). In time they began to approach the researcher to tell of some aspect of their work and their thinking that they thought might be of interest. Some indicated that they saw their research involvement as a welcome break from the everyday routine. Sometimes the activity of the students placed the researcher in the teacher's role. At times the students would ask for help with their work - a request which was often deflected back to the teacher but at other times a discussion between the researcher and students ensued which elicited the students' thinking and thus generated data.

During the research period the researcher was not aware of any particular gendered response. It was possible that the more outgoing and outspoken students were more likely to share their thought and insights. As the students became familiar with the researcher's presence in the room and they became used to having their opinions asked a response was able to be elicited from all of the students.

Feeding back research findings to the students promoted a richer response when their regular teacher absented herself and the researcher could talk directly to the students about what the data was showing. These opportunities were used to confirm interpretations and the students came to accept the researcher as someone genuinely interested in how they functioned as scientific investigators and with a concern to identify those aspects of the task that hindered their progress. They were never put in a position of having personally identifiable data fed back to their teachers - anonymity and pseudonymity having been explained to them very clearly and scrupulously adhered to. The 1994 students in particular developed an easy relationship with the researcher, chatting and sharing aspects of their lives such as career aspirations, sporting activities, and their responses to other daily school tasks such as tests. Four of the 1994 students collected data when the researcher was not in the school - tape recording planning sessions for investigations and collecting worksheets.

5.4.2 1995

The teachers and students

The teachers involved in this phase of the research project expressed interest in becoming involved after they had attended a workshop presented by the researcher during a science teachers' conference (SCICON, Wellington, New Zealand, September, 1994). More than half of the teachers at the workshop responded to a request for teachers to become involved in the ongoing trial and others contacted the researcher individually when they heard of the proposed trial. These teachers taught Biology at senior levels in their schools. One had been involved in the earlier intensive case study trials at City High but had since moved to another school. Of the initial thirty one teachers who expressed interest twelve were unable to complete the 1995 trial. Two changed institutions; two were not teaching in their schools for 1995 - one was offered paid study leave and the other took up a Ministry contract; in two schools the teacher-in-charge of the Biology programmes did not have a 1995 class suitable for trialing and thus five teachers in two schools did not get involved; two did not have a Year 12 biology class in 1995; and one was promoted to administrative tasks and "lost" her Year 12 biology class. After the initial setting up period, one teacher was not able to continue due to other heavy professional commitments. One teacher has not returned any material nor supplied any explanation for not completing her involvement. Of the teachers who did carry out all, or most aspects, of the trial, one was interviewed along with her student group as well as submitting a formal return, another was interviewed individually as well as submitting a formal return, and teachers in twelve other schools sent returns which were partially complete (5), or complete (9). In addition, informal contact by letter, telephone or personal conversation occurred during 1995 with the teachers involved in the project. Written reports came from individual teachers in schools covering boys (1), girls (6) and co-educational (7) schools.

Formal permission for access to the schools involved in the trial was gained from Heads of Science, Principals and Boards of Trustees. Ethical considerations such as anonymity of student, teacher and school were outlined to all the participating teachers and explained to the schools' management.

5.4.3 Participant observation or observer participation?

The relationship between the researcher and the participating teachers and students is a significant aspect of research which takes place in regular school classrooms. The question as to whether the researcher is carrying out participant observation, or is acting as an observer who is participating, arises.

Participant observation requires a total involvement in the activities of the research situation whereas participation by an observer enables a looser connection by the researcher with the situation. Participant observation by an adult in a secondary school classroom presented a range of challenges both with regards to data gathering and the analysis of data (Ball, 1985). This was because the researcher was inevitably identified as an adult and thus conceptualised by the students as being with the teachers. This had the possibility of distortion of student accounts with students telling the researcher what they thought the teachers would want them to say or, if they assumed the information they give the researcher will be passed on to the teachers, what the teachers would want to hear.

To overcome this the researcher visited the classrooms and the wider school regularly during 1993 and 1994. The researcher took a soft-line position as participant observer in that the need to be there as an observer was recognised but the researcher did not feel constrained to 'share in the activities of the researched in a direct and complete way' (Burgess, 1985, p 25). The students and teachers were followed through their classroom interactions, with note taken of what they did, when, with whom, and under what circumstances, and the researcher queried them about the meaning of their actions. In this instance, the researcher was therefore more of an observer who participated (demonstrator, teacher, helper, discussant) as required and requested by the students and teacher. Students frequently asked for help with equipment, report writing, definition of terminology, and even permission to leave the room - a request which was immediately redirected to the teacher.

The vast bulk of the 1993 and 1994 observations were done at City High, in the Biology classrooms or in other school rooms or out in the grounds for interviewing as available. The researcher also accompanied the 1993 Year 12 students on their ecology field trip and went with the 1994 Year 13 Biology students as they visited a beach in the initial stages of their small animal studies. The researcher also met some of the students in unscheduled meetings outside of the school situation - at the shopping centre or sports field. Some did talk informally about the research at these times. However the work with the 1993 and 1994 students was concerned primarily with their student lives within the Biology classroom and that principally when they were engaged in practical work. It was a study largely restricted to within the institution.

5.5 Types of data

The data gathered from the various educational settings where investigative practical work was being introduced was descriptive in nature rather than experimental, correlational or causal. The gathered descriptive data were both qualitative and quantitative. The gathering and analysis of both qualitative and quantitative data provided a richness of material to support the interpretivist aim of 'understanding the complex world of lived experience from the point of view of those who live it' (Schwandt, 1994, p 118).

Qualitative aspects of the research

Those aspects of the research project that define it as qualitative (Burgess, 1985) are, firstly, the researcher worked in a natural setting (Lincoln and Guba, 1985), that is, regular Year 12 Biology classrooms. Secondly, aspects of the intervention were designed and redesigned as a result of the students and teachers' interactions with them. Thus the research methods were flexible and allowed for the formulation, reformulation and modification of concepts as the collection and analysis of the data proceeded. Thirdly, the research was concerned with 'social processes and with meanings that the participants attributed to the contextual classroom activities and situations' (Burgess, 1985, p 8). In addition, data collection and data analysis occurred simultaneously with categories and concepts being developed during the course of the data collection in the manner of grounded theory approaches (Glaser and Strauss, 1967).

Quantitative aspects of the research

Within the limitations of the number of students carrying out practical investigations, procedures for the gathering and analysis of numerical data were used to establish patterns of responses such as degrees of confidence with respect to carrying out investigations, or the degree to which students had shared understandings of aspects of investigating, such as validity of their gathered data. Such information was used to provide perspectives from which to analyse the qualitative aspects of the research. Similarly findings from a large scale questionnaire of Auckland science teachers' attitudes to, and understanding of, a problem-solving approach to practical work (see Appendix F) formed the basis of the questionnaire used early in the project to find out the attitudes of the teachers at City High to such an approach.

5.6 Data collection techniques

The principal data collection methods for this research project were classroom participant observation, interviews and the completion of written reports such as work sheets and questionnaire forms by teachers and students. Each of these is addressed in turn.

5.6.1 Classroom observation

During 1993 and 1994, data were collected through the processes of observation as detailed by Burgess (1985, p 2). Such observation included genuine social interaction (Ball, 1990), direct observation, formal and informal interviewing, some systematic counting, collection of documents and artefacts, minuting of meetings and audio recordings of classroom activities. It was also characterised by open-endedness in the direction that the study took.

The researcher observed each of the 1993 City High teachers and their classes at least once a week, for most school weeks, during the 1993 intervention phase and the 1994 teacher and her class at least twice a week during the 1994 intervention. During the observations the researcher kept field notes and some of the lessons were audio-taped (see Appendix C for research audit trail and Appendix D for details of transcripts). The researcher only became a participant in the classroom activities when asked by the teachers or the students (Tasker and Osborne, 1981). In the early stages, field notes were taken about a wide range of classroom activities in order to build up a general picture of classroom interactions. Eventually the focus of the observation became narrowed to the identification of the teachers' and students' interactions as they were involved in an investigative approach to practical work. Field notes included verbatim speech when possible.

Audio-tapes of classroom interactions supported early observation notes, with note-taking easier as the researcher became more familiar with the students' names. All classroom transcripts were transcribed by the researcher, with this difficult and time-consuming task made challenging by the intrusion of background noise and quiet student responses. Field notes were read and analysed as soon as possible after the lesson and additional comments added to them or referenced in the researcher's reflective diary. Observations were shared and discussed with the teachers and the students and often formed the basis for decision making about the next phase of the research.

5.6.2 Written documentation

During the course of the research written documentation was gathered through questionnaires, student work sheets and teacher comments' sheets.

Questionnaires

Three questionnaires were used to quickly gather base-line information about a variety of variables relating to the carrying out of practical investigations in Year 12 Biology classrooms. These questionnaires were

- A investigative process confidence questionnaire (see Appendix E). This questionnaire asked students to indicate their confidence regarding fourteen aspects of investigating. It was administered both pre-intervention and post-intervention with all students in 1993 and 1994 and with students in some of the 1995 schools. (The questionnaire was trialed prior to its use. This trial involved twelve students from a Year 12 Biology class at another Auckland secondary school being asked to complete the questionnaire and immediately following this they were interviewed by the researcher regarding the phrasing of the items and any difficulties they experienced when answering the questionnaire.) At the end of each questionnaire completion the students also answered some more general questions about their response to investigative practical work.

- A questionnaire used to elicit the 1993 - 1994 teachers' perceptions of the advantages and difficulties of an open investigative approach (see Appendix G). This was developed from findings of a questionnaire which had been responded to by 256 Science teachers in Greater Auckland in 1991 (see Appendix F). The teachers were asked whether they strongly agreed, agreed, disagreed or strongly disagreed with statements regarding the perceived advantages and difficulties of an open investigative problem-solving approach which had been listed by the 256 Auckland Science teachers.

- A 1995 teacher questionnaire response form used to gather information regarding their response to the introduction of open investigative practical work (see Appendix H). The questions in this questionnaire were developed after extensive analysis of data gathered during 1993 to 1994 and reflected the major concerns and outcomes arising from the earlier phases of the research project. The teachers had the opportunity to make a free response to the given questions.

Other written documentation

During all three intervention phases the teachers and the students were asked to document aspects of the practical investigative work they were doing. These included the completion of student planning forms by the students when they were carrying out investigative practical work; the completion of teachers' response forms for each investigation detailing the context of the investigation; and the students' completion of evaluation forms after each investigation [see Figures 5.5 (i) - (iv)]. The actual forms included spaces for written comments. Aspects of the written documentation were elucidated and elaborated through follow-up interviews with the teachers and their students.

The Teacher's Investigation Comments' Sheet is shown in Figure 5.5 (i). This was completed by the teachers at the time of the investigation.

TEACHER'S INVESTIGATION COMMENTS' SHEET

Name of investigation ....

Teacher's Name: School:

A. The students in this class have

- studied the relevant background theory for this investigation Yes/No
- previously carried out a related investigation Yes/No

  If "Yes" what was the source of the investigation?

  Life Science text/ Form 6 Bio Prac Guide/ Other (please name)

B. Before the students carried out this investigation I had told them about:

C. While the students were carrying out the investigation we discussed *in whole class situations:*

D. When the students were carrying out the investigation I found myself having to *talk to individuals* about:

E. The learning outcomes from this investigation included:

F. My comments about what the students did and their response to the task:

Figure 5.5 (i): Teachers' investigation comments' sheet

Students completed personal planning guide sheets for each investigation. Auxiliary questions designed to help the students focus on different aspects of the task were added to the original students' task sheet and were later developed into a planning guide sheet shown in Figure 5.5 (ii).

STUDENT PLANNING GUIDE SHEET
"Things I need to think about"

What am I trying to do or find out? (Rewrite this in your words)

Background theory?
Is there any background theory I ought to consider? If so, where could I find out about it?

Variables
What variables do I need to think about? What is going to be the independent variable (i.e. the one I am going to change (manage)? What is the dependent variable (i.e. the one that I am going to measure changing)? What variables am I going to have to keep constant or unchanging (i.e. which ones am I going to control)?

How am I going to make sure that I am carrying out a "Fair test"?

Measurements
What sort of measurements will I need to do? What equipment will I need? How often will I need to take the measurements? How many times should I repeat the experiment? Will I need to draw up a table for my results?

Reporting
Who am I reporting my results to? How am I going to report my results? Will I need to draw any diagrams (graphs etc)? How much background information will I need to include in my report?

Figure 5.5 (ii): Student planning guide sheet

As well as planning the investigation as individuals, students were asked to complete a plan for the investigation as a group. The group report sheet is shown in Figure 5.5 (iii).

STUDENTS' GROUP REPORT SHEET
Name of investigation:
Student's identification:
I am working with:
In our own words this is what we are trying to do:
Our hypothesis is:
Our group plan:
Changes we made to our plan during the investigation:
The data that we collected:
Our report to ....: (Fill in who this report is written for)

Figure 5.5 (iii): Students' group report sheet

In order to find out if the Year 12 Biology students who were participating in the research project were able to recognise the effectiveness of the procedures they had used during their investigations, the students in the 1994 and 1995 research projects were asked to evaluate their work. At the completion of each investigation individual students were encouraged to write down their thoughts and feelings about the lesson to give them the opportunity to think and write about how, and what, they were learning and to encourage them to more readily monitor their own learning. They were asked to focus on what they had learned during the practical session and what made it easy or difficult for them to learn about the process of carrying out investigations in Biology. The student lesson evaluation sheet is shown in Figure 5.5 (iv).

STUDENT LESSON EVALUATION SHEET

Name (or code):

Date:

When you write an evaluation of a lesson you write down your thoughts and feelings about the lesson. It gives you the opportunity to think and write about how you learn and to monitor your own learning. In particular you should focus on how you learn during practical sessions and what you feel makes it easy or difficult for you to learn about the process of carrying out investigations in biology.

Title of investigation:

Some questions for you to answer at the end of the lesson are:

How well do you think you carried out the practical work?

When you were carrying out the practical work what more would you have liked to have known?

What do you think you have learnt today?

How valid do you think your results are? Explain your answer.

Do you have any questions about things you don't understand yet?

Do you have any more comments to make about today's lesson?

Figure 5.5 (iv): Student lesson evaluation sheet

A cautionary note regarding the written evidence relating to the intervention tasks

For each of the investigative tasks, students and teachers completed accompanying written tasks as detailed above. The 93 - 95 students' and teachers' responses on these planning and reporting worksheets have been analysed as a indicator of the teachers' and students' thinking and understanding at the time they were completed. It must be acknowledged that when students report their planning, findings and conclusion in written form, they may not present all of their knowledge for scrutiny. There is evidence that this is so when written reports and audio-tape transcripts of the same episode are compared. Students did not always put all the information they had down in writing. For example when students were planning for the "Green Streams" task one boy clearly asked the self-appointed scribe to '... put insufficient knowledge to test pH levels' but on the written sheet this was translated as 'didn't know how to test' (93T3 students). The incomplete nature of presented written material is also illustrated by the following conversation from a "Green Streams" task related transcript:

> *S1 Take two artificially cultivated samples of ...*
> *S2 Spell it, take..*
> *S1 Artificially ....* [not spelling, just repeating]
> *S2 Why not just say samples ...* [which is written down]
> 93T3 students

In addition, when planning ability was scored, analysis of the 'group scores' and individual scores of the members of the group indicated that in some instances the group plan scored lower than the plans from some, or all, of the individuals in the group. It appeared that this was partly determined by the group member who had most influence over the group decisions, as was indicated by the students. In several cases a workable plan was rejected in favour of a less rigorous design.

5.6.3 Interviews

As well as requiring the participating teachers to complete pre- and post-intervention questionnaires and task linked comments' sheets, the researcher regularly interviewed the City High teachers throughout the two intensive stages of the intervention at the school and the transcripts from these interviews formed another data source.

The purposes of the interviews were to acquire information, to test interpretations of observed data and to enable greater shared understanding between the researcher and the participant teachers. The procedures used followed those outlined in Bell, Osborne and Tasker (1985). Focus questions within a semi-structured format were used during formal interviews to allow for discussion of emergent issues (see Appendix I). The teachers were provided with a copy of the focus questions before the scheduled interview. In addition, informal, variable length, discussions occurred before and after teaching sessions and were unstructured. Such conversations often took place as we were walking between the staff-room and classrooms and notes regarding these were jotted down as soon as possible afterwards. Semi-structured group interviews of students were used to clarify developing interpretations and to probe for further understanding of patterns arising from written reports and questionnaires.

5.7 Sources of data

Table 5.2 summarises the main sources of data. For each year of the data collection period the main focus of the research is indicated, the research activities are described and data collection methods are listed.

TIME FRAME	FOCUS OF RESEARCH	DESCRIPTION OF RESEARCH	DATA COLLECTION
1992	Research question 3 and 4	**Preparatory stage I: planning, literature review and establishment of research programme at City High** • Requested registration of interest in ongoing research • First departmental meeting at City High - initial discussion and negotiation of intervention • Administered first questionnaire to teachers at City High regarding their attitudes to problem-solving and open investigative practical work • Interviewed teachers who were to be involved in 1993	• Departmental Meeting audio-tapes • Pre-intervention questionnaire data from four teachers at City High • Interviews
1993	**Research questions 1 and 2**	**First intervention at City High: March - November** • Researcher in classrooms of four teachers • Trial of student confidence questionnaire at second school • Formal interviews with the four teachers • Administration of confidence questionnaire and planning task ("Green Streams") • Observation of students carrying out investigations • Observation and participation at Biology departmental meetings - discussion of gathered data, further negotiation of intervention • Gathered biology education support material from teachers	• Classroom observation • Interviews (teachers) • Questionnaire response forms from students • Student worksheets • Student group interview audio-tapes • Teachers investigation response forms • Departmental meeting audio-tapes • Biology education-support material
Nov 1993 - Feb 1994		**Review and Preparatory Stage II** • Planning for second intervention phase	Confirmation of data interpretation by participating teachers

Table 5.2: Summary of data collection methods

TIME FRAME	FOCUS OF RESEARCH	DESCRIPTION OF RESEARCH	DATA COLLECTION
1994	**Research questions 1, 2, 3 and 4**	**Second intervention at City High: February - December** • Researcher in classroom of one of 1993 teachers • Formal interviews with the four teachers • Administration of student confidence questionnaires • Students carrying out investigations • Departmental meetings • Interviews with Year 13 and Year 12 Biology students • Information from TRCC course • Ongoing feedback of data by researcher to participating teachers and planning sessions • Gathered biology education support material from teachers • Collected Education Review Office report for City High • Reading report of findings from parent questionnaire	• Classroom observation • Interviews (teachers and students) • Questionnaire response forms • Student worksheets • Student group interview audio-tapes • Teachers investigation response forms • Departmental meeting audio-tapes • Biology education-support material
Nov 1994 - Feb 1995		**Review and Preparatory Stage III** • Planning for third intervention phase - Preparation of 1995 Teachers' Guide package - Carrying out entry procedures - Distributing 1995 package to schools	• Interpretation of 1993 data • Confirmation of data interpretation by participating teachers
1995	**Research questions 1, 2, 3 and 4**	**Intervention III: Evaluation of the developed classroom materials across a wider school base** • Maintaining contact with 1995 teachers • Interviewing teacher and students in one school • Interviewing City High teacher (T3) • Collation of 1995 teacher and student data	• Classroom observation • Interview audio-tapes • Questionnaire response forms • Student worksheets • Teachers investigation response forms • Teacher questionnaire response forms
1996		**Completion of data gathering** • Follow up discussions with City High teachers and 2 of 1995 teachers • Confirmation of data interpretation by participating teachers	• Interview tapes and field notes

Table 5.2: Summary of data collection methods (cont)

Data were sourced and gathered in a variety of ways which included:

A. Transcriptions of tapes of teacher interviews (12 in total); departmental meetings (3); formal interviews with other science educators (2); class room proceedings (16); Year 13 Student group interviews (2); Year 12 Student group interviews (7); student groups planning investigations (14);

B. Questionnaire of 256 Auckland science teachers regarding the inclusion of problem solving in their teaching programmes and the linked follow-up questionnaire of the four teachers involved in the 1993 intervention - both early 1993 and at the end of 1994;

C. 1995 teachers responses to "Open investigative practical work in Level 7" package;

D. Collected handouts detailing assessment of investigative work at 1993 - 1994 school;

E. Researcher's classroom observations in researcher's classroom field note book over the period of March 1993 - October 1994;

F. Researcher's diary kept over period of intensive classroom visiting - includes additional notes relating to the research context which arose from the researcher's reflection about the context and activities which had been observed;

G. Student pre- and post-intervention questionnaires regarding declared confidence at carrying out investigative work - 1993, 1994 and 1995;

H. Student evaluations of their handling of investigations and their learning - available for all of the research linked investigations in 1994 and from some of the 1995 students;

I. Teacher response forms detailing prior learning and students handling of investigations - for 1993 to 1995;

J. Student questionnaires re value of open investigative work at the end of the intervention phase - 1993 and 1994;

K. Results of mid year assessment of investigative skills for 1994 class 1994 including photocopies of student work and copies of marking comments made by the teacher;

L. Student worksheets for the open investigations carried out during 1993 and 1994 - individual and group planning sheets:

1993	Green streams (beginning and end of year) Factor X Water efficient plants
1994	Green streams (beginning and end of year) Sweet export Factor X Potatoes for dinner Photosynthesis Plants for dry conditions (originally Water Efficient Plants);

M. Student worksheets for the open investigations carried out during 1995 - individual and group planning sheets from students in some of the 1995 schools;

N. Other documents accessed for information

- 1993 and 1994 student sixth form (Year 12) certificate grades for City High Biology students;

- Ministry of Education materials including *Science in the New Zealand Curriculum* (Ministry of Education, 1993b), *Biology in the New Zealand Curriculum* (Ministry of Education, 1994) and *Investigating in Science* (Ministry of Education, 1995)

- Education Review Office assurance audit of 1993 - 1994 research school.

- Parent questionnaire carried out by City High in 1994

5.8 Issues of validity

An interpretivist research methodology conceptualises the world being researched as socially constructed: both the researcher and the participating teachers construct their own knowledge and reality. Within a social construction of reality theoretical perspective, all knowledge claims are dependent on the 'process, assumptions, location, history and context of the knowing and the knower' (Altheide and Johnson, 1994, p 499). If one holds this view of knowledge, then validity, Altheide and Johnson argue, depends on the readers of the research and the goals of the research and may be quite different for different audiences. However, they also identify four general criteria of quality for interpretive research: plausibility, credibility, relevance and importance of the topic. If a report is plausible and credible then its findings will appear convincing and probable. Its readers will find its findings acceptable and relevant, and its topic will appear to have considerable importance for their context. However there may be challenges to the validity of the findings from an interpretivist research methodology from other sources. These will be addressed next.

5.8.1 Threats to the validity of the research findings

Threats to validity of the findings of this research project, as seen from a traditionally positivist viewpoint, include the lack of pre-conceived hypotheses, a concern regarding the emerging and developing nature of the data gathering and analysis, and a possible lack of objectivity regarding the research design and data gathering. There is also concern regarding the small number of participating teachers. These concerns and the manner by which they were addressed will be considered in turn.

Working to pre-conceived hypotheses is not in the nature of interpretive research in that interpretive research does not set out to test a pre-conceived hypothesis but develops as an ongoing synthesis of observation and review of academic literature (Wainwright, 1997). In addition when negotiated intervention sets the framework of the research directions, the data analysis and evaluation design is necessarily emergent rather than preset. The validity of the findings becomes dependent on the evaluator's expertise or educational connoisseurship (Eisner, 1979). The practice of reflexivity (Carr and Kemmis, 1986) involving a sceptical approach to the testimony of the participants and to the development of theory can enhance the validity of both the synthesis of observation and review of academic literature and the design of the research.

Research whose goal is the revealing of the participants' views of reality (Lather, 1992), and which relies on descriptive approaches such as interviews and observation for much of its data gathering, may be considered by some to be less objective than other approaches (Borg *et al*, 1993). However, a totally objective viewpoint can only be gained if there is a high degree of detachment on the part of the researcher, a situation which may not be desirable if a researcher is to gain access to information other than superficially. It is doubtful that data is ever totally objective. The researcher deliberately interacted with the participants in the study - allowing modification of data collection methods and a shared analysis and interpretation of the gathered data. In this research project, relevant themes and patterns became the focus of more intensive or focussed observation, or interview, in later stages of data collection. The concern was with the validity of the information collected, whether it represented the genuine and carefully thought-through views of the person, rather than with the representativeness of the person's thinking to the general population of biology teachers.

One approach to strengthening the validity of such research was to report on the multiplicity of perspectives of the social reality in any setting and to indicate the researcher's perspective. In the research report, direct quotes are used to describe the 'individual's phenomenological reality' (Borg *et al*, 1993, p 199). It is through these quotes that the individual's constructs of the events in the classroom context are expressed - although these may be mediated by minor editing, as indicated, by the researcher.

For interpretive researchers working with descriptive data, it is inappropriate to apply quantitative criteria of validity such as the number of the participants or the number of times the data is analysed by independent researchers. It is the quality of the insight from people who have a direct involvement which is important rather than the number of people who hold that view. As noted above it is also the quality of the researcher's reflexive perspective which will influence the validity of the reported findings. The chosen research report format is one of a 'narrowing and expanding focus' where the analysis moves between specific observation and consideration of broader issues to make the research process more apparent and allow for validity to be more clearly assessed (Wainwright, 1997).

5.8.2 Measures to increase validity of interpretive research findings

The validity of the methods and interpretations of this research project was strengthened through the gathering of data from multiple sources and by establishing a chain of evidence between interview questions and observations, and between the data collected and the conclusions drawn. The teacher participants reviewed the gathered information and had the opportunity to alter transcripts before analysis began. They also had the opportunity to discuss and respond to the data analyses as they were developing. The data analyses were not significantly disputed by the teachers. Rival explanations of the significance of data were explored with the teachers. The researcher kept a research diary which was both for self-reflection and a record of remembered incidents, and additional information which came to hand outside of the classroom and interview situation. Careful records were kept and information regarding the procedures used to gain access to individuals or events were filed. The questions used to prompt semi-structured interviews are on record (see Appendix I).

5.8.3 Selectivity in research

Allegations of bias are common in the social sciences (Hammersley and Gomm, 1997). Bias can refer to a the way in which a particular point of view can make a difference in the way one observes and makes sense of a specific situation, or it may refer to a systematic error, especially that 'deriving from a conscious or unconscious tendency on the part of a researcher to produce data, and/or to interpret them in a way that inclines towards erroneous conclusions which are in line with his or her commitments' (*ibid* , abstract).

Bias can also result from interactions between participants and researcher. Opportunities for the researcher to influence findings exist in any case study research where the sample size is small and the relationships between researcher and participants is frequent and close. In addition, participants may not report fully to the researcher if they perceive that the information given may display them in a negative light (Borg *et al*, 1993). Possible sources of perceived power relationships between the researcher and the participant teachers have already been presented in Section 5.4.

5.8.4 Validity issues and data gathering

Validity issues, which are the focus of this section of chapter 5, are addressed in more detail for the four data gathering techniques used extensively during the research project The four data gathering techniques were questionnaires, worksheets, interviews and direct observation.

Questionnaires

Both student- and teacher-targeted questionnaires were designed to not include any leading or psychologically threatening questions. The subjects were likely to have the information which was requested. Whilst a criticism of questionnaires is that they often elicit shallow responses the validity of this data was strengthened by additional questioning relating to the questionnaire domains/responses during follow-up interviews. Additionally the analyses of the student questionnaires were discussed with the teachers and with students in whole class and small group interview situations in order to check interpretations arising from these analyses.

Worksheet completion

Students completed worksheets as they carried out the investigations. Such worksheets questioned the students regarding the plans they developed for the investigations, the modifications that they had to make to their initial plans (and the reasons for these modifications), the findings and their conclusions. Students were also asked to evaluate their experimental techniques, conclusion development, the degree of validity of their findings, to indicate what they had learnt from their involvement and what they still wished to know. It was to be expected that students would not necessarily expose all their uncertainties on paper. General classroom observation did not indicate that the students were attempting the tasks lightly. Some of this information was available from other sources. Some student groups taped their planning discussions and these could be cross-referenced to their written reports. Other follow-up activities such as formal interviews and informal discussions enabled the researcher to gather broader and more in-depth data in this regard and thus strengthen the validity of the research findings.

Interviews

Interviews were used with both the students and the teachers as they were perceived to be an excellent technique for collecting data with greater depth, breadth and detail than, for example, questionnaires. The researcher was aware of the need to avoid subjectivity and bias and used a system of semi-structured interviews with the teachers in 1993 and 1994 and with students in 1994. The interviews were set up to be an interactive dialogue with opportunities for both the researcher and participant to seek shared understanding (Lather, 1992). Interviews of teachers and students in 1995 and 1996 were more informal and unstructured. The interviewer was the researcher and all the interviews were conducted by the researcher. This was deemed necessary so that the researcher could respond quickly to the information arising from the interview and thus could use tacit professional knowledge, both as a teacher and a researcher, to help frame questions during an interview. In addition, the design of the next phase of the research, based on information to hand, often formed the latter part of an interview. The researcher's personal involvement in the interview also allowed for data analysis to occur with a full understanding of the interview context. All teacher interviews were returned to the teachers to enable checking of the accuracy of recording and transcribing and the researcher's interpretation of this data was discussed with the interviewees for teacher confirmation.

Direct observation

Since the purpose of the observation was that the researcher should learn the 'perspectives of the individuals being observed and the context in which their activities occur' (Borg *et al*, 1993, p 118) the researcher was unable to observe in an inconspicuous manner. While the classroom behaviours which were observed required both low and high levels of inference the majority required some level of judgement on the part of the observer. As a qualitative researcher in a classroom context the researcher drew on her previously gained expertise to observe and interact with the teachers and the classroom environment to collect data. As at the beginning of 1993 the researcher had had 5 years of experience of practicum observation of senior Biology classrooms as a College of Education lecturer. The researcher believes that this experience enabled her to understand what she observed and what she was told. Classroom transcripts and field notes were discussed with the teachers and students for confirmation of interpretation.

5.8.5 Triangulation of data

Triangulation methods were employed where possible to ensure the accuracy of the developing story by deriving data relating to an aspect of the research from more than one source. Multiple sources for data have been listed above. Other triangulation methods included confirmation of the data and data analysis by the participants (Hammersley and Gomm, 1997) and observation over an extended period of time. The extended and frequent observation of the participating teachers in addition to interview/questionnaire response addresses, to some extent, concerns related to ecological validity. That is, the problems arising from drawing inferences from what is expressed in interviews, to what people do in everyday life, when people are 'expected to behave differently according to context' (Hammersley and Atkinson, 1983, p 10).

The direction and refining of the data analysis began with early discussion of the research questions with the research supervisors and participant teachers and continued throughout the reading of the written material and ongoing discussion. In this way the selection of data to observe became more focussed.

The classification of themes arising from the data analysis and the choice of quotations to illustrate them raises fundamental issues about the validity of the choice of the identified themes and the passages selected. There will remain concerns over whether the researcher has selected only those quotations which serve to illustrate her particular argument. To counter this accusation the participating teachers were asked to review all classroom and interview transcripts and to verify the narrative as it was developed for this thesis. Follow-up interviews of individual teachers and discussion at departmental meetings were also opportunities to check analysis, judgements and interpretations. Opportunities to check observations of students arose as they interacted with the researcher in the classroom situation. In addition, the 1994 participating students were interviewed in small groups at the end of the 1994 intervention phase, as were a group of twelve students from one 1995 school. These interviews enabled questions relating to developing issues to be raised, allowing for clarification and verification of interpretations. At times, checking observations and judgement statements with the participants led to an enhancement of the data since discussions following querying of interpretations often provided more information.

Constant comparisons between multiple sources of data relating to common situations were also used for validation of data (Glaser and Strauss, 1967). As the investigations, which formed part of the intervention, were refined and again presented to students the interpretations of observed data which directed the refinements were able to be checked. Changes to the wording of task sheets and teacher presentation techniques were able to be checked for increased clarity of instruction.

Long term and repeated observation enhanced the validity of the interpretations (LeCompte and Goetz, 1982) by allowing for a comparison of data from different years and different students and teachers, that is time triangulation (Cohen and Mannion, 1994). In addition the continued involvement of the early participating teachers over the following years enabled reflective checking of data over the three data collection years. One of the 1993 participant teachers was involved in the 1994 intervention and another of the 1993 teachers was involved in the 1995 phase of the research. The long term presence of the researcher in the school setting at City High has ecological validity implications, in particular from the perspective of the teachers. Whilst the teachers were involved over several years the students were largely 'new' to the situation with no students in the 1994 cohort who had been in the 1993 cohort. There were two students from the 1994 cohort who were also in the 1994 teacher's Biology class in 1995 and the teacher reported on these students' achievements but this 1995 class was not directly observed by the researcher.

It is not possible to remove all sources of non-validity from qualitative analysis of data arising from a social situation which is as complex as that within a school science laboratory. With Ball (1990) this researcher believes that we should 'expect different researchers to pick their way through field work differently' (p167) as they struggle to find a way through the complexity of real world classrooms. This researcher agrees with others who view fieldwork and analysis within the qualitative domain as creative arts rather than as science (Woods, 1986).

5.9 Ethical considerations

Science education research carried out in classrooms presents ethical problems for the researcher (Bell, 1992; Tobin, 1992). Questions such as

'Why are we doing the research?' and 'Whose story is it? need to be asked and kept constantly in the frame of the data analysis. 'How reciprocal should the research be - how can the teachers and students gain from their involvement in this research?' (Bell, 1992; Brickhouse, 1992). The main ethical concerns are informed consent, confidentiality and potential harm to the participants. Ethical considerations and confidentiality issues were discussed with all participants prior to the intervention at each phase of the research.

To address the ethical concern of informed consent the general aims of the research project were discussed with the teachers prior to the beginning of the study and at times of renegotiation of the research direction. Permission to gather data in the schools was sought from the teachers, the Heads of Department: Science, the principals and the Board of Trustees of the schools. Students had the research questions and approaches carefully explained to them and were given the opportunity to withhold their individual data and worksheets.

Informed consent was also sought with respect to the data and data analysis. All participating teachers had access to transcriptions and field notes of classroom observations and to their transcribed interviews. They were able to make changes to these transcripts. Draft reports and developing theses were also discussed with the participating teachers, either face to face, or by mail (in the case of the 1995 teachers) and with follow-up personal discussion when requested. Findings from each phase of the project were also shared and discussed with the participating students.

Confidentiality was another ethical concern to be addressed. Anonymity was protected by use of changed or coded school names and codes and/or personally selected pseudonyms for teachers and students (New Zealand Association for Research in Education, 1981).

The minimising of potential harm for participating teachers and students was also addressed. The question as to how much of the data to make public poses difficulties for a case study researcher where the number of participants is small and in an educational environment where there is an increasing emphasis on staff appraisal. There is a need to ensure that the research process or findings do not damage or harm any of the participating teachers or students (Bell, 1992). Such concerns have led to an awareness of the unethicality of releasing data analyses into the public arena before the participating teachers and students have had the chance to comment on them. In addition, Bell (ibid) proposed that, to minimise any uncomfortable aspects of change, a researcher may have to become an adviser when requested, a role this researcher took when asked and which grew naturally out of genuine dialogue between the teachers and researcher. Such genuine reciprocal dialogue is the result of the active development of sound ethical relationships which are seen by Brickhouse (1992) as leading to an improvement in the quality of teaching, learning and research.

With respect to the question of what to publish there is 'not a general solution except one as may be dictated by the individual's conscience' (Becker, 1964, p 280). The procedures of participant confirmation of data analyses, a careful consideration of confidentiality issues, and protection of anonymity will, I trust, enable these findings to contribute to the growing debate regarding the introduction of open investigations into a secondary school Biology curriculum without causing the participants any harm.

5.10 The coding system used in the thesis

A coding system has been used for the reporting of data to support the developing story. Table 5.3 summarises this coding system which is used when references are made to teachers and students. The source and date of the data are also indicated.

Examples:

- 'T3 Interview 29/4/94' indicates a statement by teacher number 3, in an interview on April 29, 1994;

- '94 Grp2, 29/4/94' indicates a statement which occurred during the second group's discussion on April 29, 1994.

Field notes and diary notes are indicated by type and the date on which they were made.

YEAR	TEACHER CODES	STUDENT CODES
1993 School = City High	T1 - T4	Year Teacher, Student number eg 93T2,18
1994 School = City High	T1 - T4	Year Student number eg 9412 or Year Group [date] eg 94 Grp, 29/4/94
1995 Schools = A - V	95A - 95V	Year Teacher code, [student] eg 95B, student

Table 5.3: Summary of the coding system used in the reporting of the research findings.

5.11 Summary

In this chapter I have outlined the interpretivist paradigm which acted as a framework for the research project. The educational settings and the people involved in this research have been described. The research design was outlined and sources of data and techniques for their collection were explained. Issues of validity regarding the collection and analysis of data and ethical considerations have been addressed.

In Chapters 6 - 10 the collected data are analysed in order to reveal the complex interaction of cognitive and affective approaches and responses which may occur when an investigative approach to practical work is introduced to Year 12 Biology programmes. Chapters 6 and 7 explore the students' approaches and responses. Chapters 8 - 10 consider the introduction from the teachers' standpoint.

Chapter 6: Students investigating

6.1 Introduction

In order to address the research question (1) "In what ways can the students' abilities at carrying out investigative practical work be enhanced?" it was necessary to observe students who were engaged at this task. In this way, the researcher and the teachers involved in the research project could identify aspects of scientific investigation which presented challenges to the students and attempt to find ways to support the students at their task.

Although the process of carrying out an open investigative task is iterative in nature, for the purposes of this part of the research project three particular aspects of the process were identified for intensive observation. These were hypothesis generation, planning and gathering data. In addition, the students' post-investigation evaluation of the quality of their gathered data and themselves as investigators were also investigated. Data interpretation and drawing conclusions are also important aspects of the investigative process. However, these have not been analysed because I was not able to gather enough first hand or written evidence to support a valid analysis of these aspects. This was because it was impossible for me to be present in the school for all of the Biology sessions during the week.

The *Biology in the New Zealand Curriculum* document (Ministry of Education, 1994), echoing the New Zealand science curriculum statements, requires students in Years 12 and 13 to be working towards achieving curriculum levels 7 and 8. For scientific investigation this involves being able to

- integrate their scientific ideas and personal observations with the scientific ideas of others to make testable predictions or to identify possible solutions for trialing
- design systematic tests, experiments, trials and surveys with rigorous identification and control of variables;
- select and use equipment to make qualitative and quantitative observations and measurements with appropriate precision;
- carry out procedures to systematically observe and record information and measurements;
- locate and process relevant information using a variety of sources such as books, newspapers, periodicals, catalogues, indexes and computers

and to

- evaluate the quality of information gathered and its degree of relevance
- evaluate the reliability and validity of their findings or possible solutions using statistical procedures where appropriate.

Ministry of Education, 1994, p 38 - 39

Students are not necessarily expected to demonstrate high levels of achievement with regard to these objectives at the beginning of their Year 12 Biology year. The students in this research project, as a group, and with respect to each other, would therefore be expected to be demonstrating a wide range of ability with respect to these achievement objectives.

In Chapter 6 data relating to aspects of students investigating will be analysed. Section 6.2 focuses on students hypothesising; Section 6.3 presents the students' approaches as they planned for gathering data; and Section 6.4 describes the students' own evaluations of the quality of their gathered data and themselves as scientific investigators.

6.2 Hypothesis generation

Hypothesis generation and testing has been seen, for some time, as central to investigating in science (for example, Lawson, Karpus and Adi, 1978; Glasson and Garrison, 1989). This first section of Chapter 6 explores the understanding, and generation, of hypotheses by the students in this research project, using the schema developed by Wenham (1993) as a framework for the discussion. Changes which occurred, over the period of the intervention, in the students' demonstrated ability when generating hypotheses are also explored.

6.2.1 Students' understanding of 'making hypotheses'

Wenham (1993) identified the making of hypotheses as an activity of central importance in any scientific investigation. He noted that the National Curriculum in science for England and Wales (Department of Education and Science, 1991, p 3) encourages students to "hypothesise and predict" and claimed that:

> There is no effective and generally accepted concept of hypothesis in relation to the investigative work which pupils undertake in schools.
> Wenham, 1993, p 232.

He grouped concepts of hypothesis as (i) *hypothesis-as-explanation,* when a cause is proposed for an observed effect, an "I think ... because" statement, (ii) *hypothesis-as-prediction,* for example a statement such as "The [Granny Smith apple] will be [the sweetest]" and (iii) a *descriptive hypothesis* which is a simple statement of what is supposed to be the case, for example "[Mud crabs] prefer [damp conditions]. It is expected that students can produce all three of these types of hypotheses. In particular it is hoped that students are able to propose a cause for an observed effect in order to write an explanatory hypothesis.

Students' approaches to investigating were analysed through the work of the twenty-nine students in the 1994 case study class. These students were asked to respond to the following question in a short pre-intervention questionnaire. "When scientists are doing investigation or setting up experiments they often talk about making an **hypothesis**. What do you think this means?" Of the twenty-eight students who answered this question all but three indicated that a hypothesis was either a form of prediction or a statement which directed the scientist's attention/activity.

For the twenty-two students whose definitions included elements of a hypothesis as a prediction, common statements were:

> *making an educated prediction of the likely outcome of the experiment*
> 9420

> *what the scientist plans will happen from the experiment. What he/she believes will or will not happen during the experiment. Thus a hypothesis is written before the actual experiment is carried out. It is a prediction.*
> 9414

Ten students actually used the term 'prediction' whilst seven others used terms such as 'forecast' or phrases such as 'your ideas on the outcome'. Five students defined a 'hypothesis' in terms similar to 'a statement which they think that they can prove' and for the purposes of this analysis they have been included in the group of twenty-two students who wrote about an hypothesis in predictive terms.

Six of the twenty-nine students (that is, not necessarily exclusive of those who defined an hypothesis as a prediction) focussed on the idea of an hypothesis as a statement which directed attention to a particular aspect of a problem and consequent activity regarding the collection of relevant data. Such responses included:

> *A statement a scientist makes at the start of an experiment, eg "That all mice that are brown are smarter than those that are white". Then the scientist must prove whether this statement is true or not.*
> 9401

> *They have some sort of idea what the outcome of the experiment will be so they make or state a question and try to answer the question in the experiment.*
> 9425

Five students included the idea that scientists carried out experiments to prove the truth of their hypotheses, for example:

> [an hypothesis] *is what the scientists think will happen or what should happen. By doing the experiment they are either proving their hypothesis right or wrong.*
> 9426

> [an hypothesis] *what it is that you are going to prove or disprove with your experiment. Sort of theory what you think is the answer and you try to give* (sic) *evidence to support it.*
> 9424

It is interesting to note that only one student confused writing an hypothesis with an overall purpose for carrying out an investigation and for another there was confusion with experimental approaches. Only one student made no response to this question. As might be expected of fifteen to sixteen year olds commencing their studies in specialist Biology, none indicated that they had any concept of the null hypothesis.

Unlike explanatory hypotheses which require of the students some relevant theoretical background, descriptive and predictive hypotheses are often nothing more than simple informed guesses relating to testable questions. This facet of hypothesising was emphasised by three students who used the phrase 'educated guess' and others who wrote about 'educated prediction' or 'estimated conclusion'.

One group of students' written responses regarding hypothesising was readdressed during a discussion session led by the researcher with the 1994 case study class (CT 21/2/94). When asked what they based their prediction-making on, a student responded to the question with one word "Knowledge" Asked to elaborate, they explained that it was from previous experimental work. They also conceptualised a prediction as a question that "you go about answering", that it is a "positive statement" and a "statement predicting the outcome the scientist expects". All of these statements had been previously noted in the written explanations of 'hypothesis' by this group of students. When asked to identify previous practice at writing hypotheses they indicated that they had done so in Geography but did not refer to their previous study in Science.

6.2.2 Students' demonstrated hypotheses generation

Detailed data regarding hypothesis generation during the research based investigative practical work (see Appendix J) was available from the 1994 case study students and from the students in the two classes of one teacher in one the 1995 trial schools. Four hundred and forty seven cases of hypothesis generation were analysed - see Table 6.1.

	No hypothesis stated	Hypothesis as description	Hypothesis as prediction	Hypothesis as an explanation
Percentage of type of hypotheses stated n=447	28	12	51	9

Table 6.1: Overall frequency of hypothesis type stated by the case study students in 1994 and students from one 1995 school (95P) for the five investigations carried out in common by the two groups (reported to the closest whole number)

It should be noted that the categorisation of a student's given hypothesis as an *explanatory, predictive* or *descriptive* hypothesis was not straightforward due to the particular wording, phrasing and ideas' linkage in the students' statements. The categorisation of all of the students' statements was therefore completed at the same time and repeated after an interval of time to strengthen consistency of categorisation.

Overall, just over a quarter of the students did not state an appropriate hypothesis when doing their investigations, approximately half gave predictive hypotheses and close to ten percent gave explanatory or descriptive hypotheses. For both groups of students the most common type of hypothesis put forward was that of an *hypothesis as prediction* with the students stating such hypotheses for approximately 50% of the time over the two years. However the student groups varied widely in the percentage of times they produced the other types of hypotheses - see Table 6.2.

Year	No hypothesis stated	Hypothesis as description	Hypothesis as prediction	Hypothesis as an explanation
1994 (one class)	19	24	50	7
1995 (two classes)	31	0	50	19

Table 6.2: Percentage frequency of different types of hypothesis stated by students from three classes over the period 1994 and 1995 (total n=447)

Since the hypothesis-generation experiences of the students at City High and the students at the 1995 school were likely to have been different the data from these two groups of students has been separately analysed. The 1994 students gave descriptive hypotheses more commonly than the 1995 students (24% of the time compared with none for the 1995 students). The 1995 students were much more likely to offer no hypothesis than the 1994 students (31% in 1995 compared to only 19% of the times in 1994). The 1995 students offered the more sophisticated explanatory hypotheses more frequently than the 1994 student group. As these students were in different schools with possibly different amounts of experience in hypothesis generation in junior school Science such differences in response may be able to be explained by differences in the students' past experiences of hypothesis generation. Differences in the teacher's preparation of the students for hypothesis generation may also have influenced the type of student response. It is possible that the teacher in the 1995 school may have taught hypothesis generation more explicitly to her students than the 1994 teacher. However the researcher has no data to indicate if this was the case.

Data from these 1994 and 1995 students appear to indicate that the context of the investigation also influenced the particular type of hypothesis which was furnished by the students. The intervention investigations were linked with different parts of the Year 12 Biology programme. The 1994 and 1995 students carried out six investigations. "Green streams" was linked with the ecology section. "Sweet export", "Factor X" and "Potatoes for dinner" were linked with the cell form and function section and "Plant cells at work" and "Plants for dry conditions" were linked with the plant form and function section of the year's programme.

The frequency of 1994 students' production of the three types of hypotheses as outlined by the Wenham schema over two investigations is shown in Table 6.3(i) and that for the 1995 students' in Table 6.3(ii). The full data relating to hypothesising which was available from these 1994 and 1995 students is shown in Appendix J (i) and (ii).

Investigation **(Title, date and number of student completing worksheet)**	**No hypothesis stated**	**Hypothesis as description**	**Hypothesis as prediction**	**Hypothesis as an explanation**
Sweet Export 23/3/94 n=29	3	10	84	3
Factor X (i) 8/4/94 n=31	0	61	39	0
(ii) n=31	74	0	26	0

Table 6.3 (i): Percentage frequency of different types of hypotheses stated by students for two investigations carried out during 1994 (reported to the closest whole number)

Investigation **(Title, date and number of student completing worksheet)**	**No hypothesis stated**	**Hypothesis as description**	**Hypothesis as prediction**	**Hypothesis as an explanation**
Green Streams 29/5/95 n=39	0	0	39	61
Factors affecting photosynthesis 8/11/95 n=17	53	0	0	47

Table 6.3 (ii): Percentage frequency of different types of hypotheses stated by students for two investigations carried out during 1995 by students at one participating school. (reported to the closest whole number)

The particular type of hypothesis which was produced by the students varied with the investigation. The particular concept of hypothesis used by students was also influenced strongly by the wording of the investigation task sheet. When the investigation task sheet included a causative statement or suggestion such as 'Perhaps the concentration of dissolved carbon dioxide in the water had an effect on the rate of photosynthesis of the water weed', a greater number of students responded by writing an explanatory hypothesis. For example, 61% of students in the 1995 cohort gave explanatory hypotheses for the investigation entitled "Green Streams" which included a question to cue the students into possible causes of the described situation. If the task sheet did not include possible causative statements the students appeared to be less likely to make explanatory hypotheses.

To illustrate how the particular context of an investigation can influence students' hypothesis generation a more detailed qualitative discussion of the 1994 students' hypothesising tendencies for the six 1994 research linked investigations follows.

Pre-intervention "Green Streams" planning exercise

The task set for "Green streams" concluded with two sentences which read 'Had the fertiliser washed into the stream? Perhaps an increase in the amount of these chemicals present in the stream had caused the increase in the number of small plants.'. Twenty nine students completed this task at the beginning of the 1994 year. They were all shown a sample of water which was very green in colour due to its high concentration of single celled plant life. Somewhat predictably, since 'cause' was mentioned in the task all the students except one included some idea of causation in their hypothesis, such as " ... the higher concentration of the fertilizer will make the stream greener'. The one who did not wrote a descriptive hypothesis:

> *There is a high level of fertiliser in the stream.*
> 9421

Of the other twenty eight students, ten linked the colour change with the solution of fertiliser granules - five linking the change in colour with an increase in the fertiliser concentration in the stream and five linking the change in colour merely with the presence of fertiliser in the stream. Five linked the increase in greenness of the stream with the growth of plants, and thirteen linked the increase in fertiliser concentration with an increase in the number of unicellular plants and thus explained the consequent increase in green colouration of the water.

A cueing statement or suggestion appears to help students to think about a cause and effect relationship.

"Sweet Export" planning exercise

Another illustration of how the particular context of an investigation can influence students' hypothesis generation relates to the "Sweet Export" investigation. The "Sweet Export" investigation required the students to select, from five different apple varieties, the two that contained the highest sugar content. Twenty-eight of twenty-nine 1994 students who completed this investigation wrote an hypothesis for this investigation. Thirteen of these hypotheses were simple predictive or descriptive hypotheses such as:

> [I think that] *that the Royal Gala and Ballarat will have the highest glucose content.*
> 9401

> [I think that] *the redder the apple the higher the sugar content.*
> 9403

Comments which indicated that they were bringing past experience to the task were offered, for example:

> *Kidd's Orange and Royal Gala could be sweet (I don't really know). Granny Smith isn't very sweet.*
> 9427

Sixteen of the students wrote a hypothesis relating to the procedure of the investigation, for example:

> *The apples containing different amounts of sugar will produce a range of colours when heated in Benedict's solution. The ones with the highest sugar content will be brick red or closer to brick red than others.*
> 9413

In the case of the "Sweet Export" investigation the students were required to select the two sweetest brands. The students were given no hints about a requirement for any particular type of hypothesis and they responded by producing predictive hypotheses or linking their hypotheses to the procedure they were to follow.

"Factor X" planning exercise

Another illustration of how the particular context of an investigation can influence students' hypothesis generation relates to the "Factor X" investigation. After an initial session thinking about the task, identifying relevant theoretical background, variables and suitable measurements as individuals the 1994 students worked together in groups to plan the investigation called "Factor X". There were nine groups. The students were asked to identify the two best sources, in order, of Factor X (an enzyme) from four given vegetables. The hypotheses developed by the groups were descriptive (six groups) and predictive (4 groups). Only one group wrote an hypothesis relating to the second part of the investigation and this was the group who wrote a descriptive hypothesis for the first part of the investigation and a predictive hypothesis for the second:

> [Our hypothesis is] *that the two with the highest amount of foam have the best sources of Factor 10. And that heating each substance to its boiling point will affect its level of Factor 10. We believe ?* (sic) *that there will be a decrease in Factor X after being boiled.*
> 9412, 9413, 9414, 9417

Again, all the groups developed predictive and descriptive hypotheses for this investigation. If they are required to provide explanatory hypotheses it appears that this must be more explicitly stated. They may also need reminding to develop hypotheses for different experiments within the investigation.

"Potatoes for Dinner" planning exercise

One more illustration of how the particular context of an investigation can influence students' hypothesis generation relates to the "Potatoes for Dinner" investigation. In the investigative task "Potatoes for Dinner" the students were asked to find out if (i) potato juice is isotonic with water and (ii) if larger pieces of potato would change relative mass less than smaller pieces when placed in water over a period of ten or more hours. This was a group task and in 1994 nine groups completed the worksheet. One group did not clearly state a hypothesis, simply stating that salt and surface area affect size. Multiple hypotheses were given by the remaining eight groups for the two experiments, with only some students clearly indicating which hypothesis related to which experiment. Nineteen hypotheses were stated, nine being descriptive hypotheses and ten predictions. Although the accompanying teacher's comment sheet clearly indicates that these students had previously studied the theory of osmosis and had been told about isotonic, hypertonic, and hypotonic solutions and had discussed the effects these solutions would have on a cell, only one group moved slightly towards an explanatory hypothesis as one of their three statements:

> [Our hypothesis is] *salt will have an effect on the swelling depending on the amount of salt.*
> 9412, 9413, 9414, 9417

This hypothesis was classified as predictive rather than explanatory since the explanation did not include any logical reasons for their decision. Again the students were not indicating that they were considering possible causes for a possibly observed effect and thus were not proposing explanatory hypotheses.

'Plant Cells at work" planning exercise

An additional illustration of how the particular context of an investigation can influence students' hypothesis generation relates to the "Plant Cells at Work" investigation. When the 1994 students were asked to find out about the factors affecting photosynthesis by designing an investigation using single celled plants immobilised in sodium alginate beads, they wrote hypotheses which were either descriptive, for example:

> *Light intensity affects the rate of photosynthesis.*
> 9418

or predictive:

> *I hypothesise that red and blue light will [produce] a greater rate than green.*
> 9414

There were no explanatory hypotheses and few of the predictive hypotheses gave a clear indication of the relationship between the rate of photosynthesis and the factor chosen for experimentation, whether discrete or continuous.

"Plants for dry conditions" planning exercise

The final illustration of how the particular context of an investigation can influence students' hypothesis generation relates to the 'Plants for dry conditions' investigation. When asked to design an investigation to help a plant supply company to select a plant suitable to withstand dry conditions, five of seven groups (17 students) of the 1994 students indicated a predictive hypothesis, making statements about a particular species. The other two groups (6 students) made tentative explanatory hypotheses linking surface area and water loss, for example:

> *[Our hypothesis is] that the lower the leaf surface area (total) the less transpiration occurs.*
> 9419 and 9420 Worksheet 7/10/94

As with the other investigations it appears that students do not generate explanatory hypotheses very often. If teachers value explanatory hypotheses over descriptive or predictive hypotheses it would appear that students require direct teaching in this regard, and encouragement to do so. If the investigative task includes causative clues then the rate of given explanatory hypotheses was higher than it is if the task does not include any causative statements as clues. Thus the students' hypothesis generating response appears to be context and task format dependent.

6.2.3 Demonstrated changes in hypothesis generation over the period of the intervention

Section 6.2 is focussing on students' demonstrated hypothesis generation. In order to find out if a year's experience of hypothesising had a demonstrable impact on the students' ability to hypothesis, the students in the 1994 case study class were asked to repeat the planning exercise for "Green streams". This repeated exercise was carried out towards the end of 1994 after the students had completed the six intervention investigations. The student's responses were analysed to establish if any change in their approach to hypothesis generation could be observed. As with their beginning of year response, the hypotheses they formed in relation to this situation were largely explanatory with only one student making a simple predictive hypothesis.

However, the underpinning understandings which enabled the students to write explanatory hypotheses for this investigation was not demonstrated in their experimental planning to test their predictions. The student pre- and post- intervention survey worksheets relating to this "Green Streams" investigation were also analysed to establish the students' changing ability, over a six month period, at (i) recognising possible causal relationships between variables and (ii) designing appropriate fair tests to determine these relationships. This data analysis is shown in Table 6.4.

	No recognition of relationship (%)	Recognition of relationship only (%)	Recognition of relationship and design of a fair test for this relationship (%)
Pre-intervention n = 29	45	48	7
Post-intervention n = 26	46	15	38

Table 6.4: Number of 1994 case study students who could identify the relationship between fertiliser concentration and density of single celled plants and design an appropriate fair test of this relationship

At the end of the intervention almost half of the students' (46%) reports did not indicate that they had recognised a causal relationship within this investigation. This is a very similar proportion to those whose reports indicated that they had not recognised a connection at the start of the year (45%). Since so many of the students did not recognise a possible direct causal relationship between fertiliser concentration and the density of the single celled plants, they were not able to design a simple technique for testing this. However, of those that could recognise a causal relationship between variables, the majority (71.5%) could design a test for the relationship by the end of the year compared with only 12.5% at the start of the year.

Of the twenty-six students who completed the post-intervention task five explained the relationship between increased fertiliser and the growth of plants; fourteen the relationship between the fertiliser and the number (density) of plants; one explained the greenness of the water as a function of the increase of fertiliser concentration and six explained the colour change by the presence of fertiliser - see Table 6.5. Two students, now more familiar with my request that they communicate to the researcher directly on their sheets if they made changes to their original ideas, explained why they had altered their first stated hypothesis. One had realised that she had not actually written a hypothesis but a question, the other changed her hypothesis to match the method she had described.

Relationship identified by students	Percentage of 1994 students on pre-intervention survey (n=29)	Percentage of 1994 students on post-intervention survey (n=26)
Relationship between fertiliser concentration and growth of individual plants	17	19
Relationship between fertiliser concentration and density of plants	45	54
Relationship between fertiliser concentration and colour of water in stream	17	4
Relationship between simple presence of fertiliser and colour of water in stream	17	23
No relationship described	3	0

Table 6.5: Relationships identified by 1994 students when they were formulating their hypotheses for the investigation "Green Streams" - a comparison between the pre-intervention and post-intervention responses (percentages reported to closest whole number)

The only notable change in percentage of students making a particular relationship link occurred for the link between fertiliser concentration and stream water colour, with fewer students at the end of the year linking fertiliser concentration in the stream with the colour of the water. There was a higher percentage of students at the end of the year who made the less sophisticated linkage of the simple presence of fertiliser and stream water colour (though in student terms this was only one extra student) and the total percentage for linkage between fertiliser (both concentration or simple presence) and colour of the water in the stream dropped from 34% to 27%. Thus there appeared to be little change in the students' abilities to formulate explanatory hypotheses based on scientific understanding.

The investigations which the students carried out in between the two engagements with the "Green Stream" investigative task did not contain explicitly stated causal relationships. It may be, therefore, that these students had not considered drafting explanatory hypotheses and had little ongoing experience of doing so. Some students could still not generate predictive hypotheses at the end of their Year 12 Biology programme. This suggests that direct teacher interaction with students is required to help students reach the level 8 curriculum achievement objective which states that 'students should be able to integrate their scientific ideas, and personal observations, with the scientific ideas of others to make testable predictions, or to identify possible solutions for trialing' (Ministry of Education, 1993b, p 44). It is apparent that if students who are investigating are to be able to write hypotheses from which they can form predictions, the students' endeavours will require support until they become competent by themselves. Teachers will need to be working with their students to mediate the students' understanding of this aspect of scientific enquiry.

This section of chapter 6 has explored the understanding, and generation, of hypotheses by the students in this research project, using the schema developed by Wenham (1993) as a framework for the discussion. The students demonstrated that they had a limited understanding of the role of hypotheses and they did not find hypothesis generation easy. Nor did they find it easy to generate testable predictions from their stated hypotheses. Their hypothesis generation abilities were both context and task format dependent. The following section of this chapter examines the students' abilities as they planned procedures for gathering data.

6.3 Students planning and gathering data

Once students have formed hypotheses to guide their planning of investigations, the next step was for them to plan how they would attempt to find answers to their questions. This section of Chapter 6 examines the students' performance as they plan and carry out procedures to help them answer the questions posed by an investigative task. The ongoing developmental nature of the tasks, the timing of the involvement of the school students with these tasks over the three year period of the research project were introduced in Chapter 5, Section 3. Further information follows.

The investigation called "Factor X" has been carried out by many groups of students during the intervention phases of this research project over the years 1993 to 1995. In 1993 eighty-four Year 12 Biology students completed all aspects of this particular investigation, working with four teachers, T1 to T4. In addition to field notes compiled during direct observation of two of these classes, student worksheets and teachers' comments forms were available for analysis. Follow-up interviews with teachers and students took place. In 1994 one class of 30 students, working with teacher T3, was observed carrying out this investigation. Student worksheets, the teacher's comment form and interview notes were available for analysis. In 1995 students from 21 schools around New Zealand completed the investigation "Factor X", using the tasksheet, student worksheet and lesson evaluation forms provided by the researcher. These task related student writings were returned to the researcher at the end of the year by the teachers.

"Factor X" was not carried out at a comparable time of the Biology programme for all of the students involved in the research project. Some students had had considerable introduction to the theory of enzyme function before they engaged in the task and others carried out the task without any recent review of enzyme function. These differences occurred across years and for classes within a year. The different student experiences are outlined below.

(i) 1993

During the 1993 intervention phase of research project, four classes of Year 12 Biology students, working with four different teachers, carried out this investigation during June and July. The students in two of the classes (T2 and T3) had had some prior introduction to the functioning of enzyme systems and had carried out related practical work. The other two (T1 and T4) had experienced neither. See Table 6.6 for the teachers' comments in this regard.

	T1	T2	T3	T4
Previous exposure to related theory	No	Yes	Yes	No
Previous exposure to related practical work	No	Yes	Yes	No
Recent practical experience(s)	Osmosis - uptake of water by potato chips in different concentrations of salt solution	• Starch and saliva • Egg white and pepsin	Liver peroxidase	None cited
Information given to students before the investigation began	• importance of conducting a "fair test" i.e. the hint was emphasised • read the sheet through to the students twice and had them take notes	• very little except the theory	• reminded them about the liver enzyme experiment	• mentioned enzymes and that they would be in the exam • that an investigation would be in the exam and that it would be similar to the Term 2 project • mentioned what makes a "fair test" and that there were two aspects to the investigation
Comments made to students during the investigation	• continued usual teaching approach of presenting questions for students to consider • prepared to stay out of the immediate student space	• told them about measuring froth • discussed what Factor X might be	• discussed equipment needed • suggested collection of gas	• helped groups with modifications of method to lead to more accurate measurements • suggested cleaning of equipment to prevent cross contamination
General comments	None cited	Mentioned a student who became very excited as he recognised for the first time that he was thinking "I'm thinking, [T2], I'm thinking!"	The students were unable to relate previous experimental work to this task, students had difficulty identifying the problem, and difficulty in carrying out a scientific inquiry	Needed to help students with methodology, students were insecure, students needed considerable help in getting measurable results.

Table 6.6: 1993 teachers' comments regarding "Factor X" - summarised from the teachers' comments sheets and from interviews following the practical sessions

Worksheets from eighty-four individual 1993 students were available for analysis. In addition teacher comments' sheets, researcher field notes of classroom observations, whole class classroom transcripts and transcripts of groups of students working together at the planning stage of the investigations were analysed.

(ii) 1994

The 1994 students involved in the case study research project carried out the "Factor X" investigation during the first week of April, before they had considered any theory relating to enzymes. Nor had they previously carried out any related enzyme investigations. During the investigation their teacher (T3) found it necessary to discuss in a whole class situation matters relating to the quantity of the sample and the quantity of hydrogen peroxide used. She also talked to individuals about possible ways of boiling the samples and whether Factor X would still be in the material after boiling or whether it may have moved into the water used for boiling (see Table 6.7).

	94 T
Previous exposure to related theory	No
Previous exposure to related practical work	No
Recent practical experience(s)	None cited
Information given to students before the investigation began	Nothing
Comments made to students during the investigation	• quantity of sample to use • quantity of peroxide to use • how to boil sample in water • solubility of Factor X in water
General comments	The students did well with this task and were able to obtain good results

Table 6.7: 1994 teacher's comments regarding "Factor X"

(iii) 1995

There was a wide variety of timing indicated for the "Factor X" investigation in 1995, for example, April, July and August. Some teachers did not furnish this information to the researcher.

For the most part the comments in this section of Chapter 6 focus on students as they planned for an investigation entitled "Factor X". In addition, the students' planning approaches to another investigative task, "Green Streams", will be discussed to add additional support to the comments or assertions made.

6.3.1 Students' as planners of an investigation

The students ability at planning was monitored both during the initial focussing phase carried out by individuals and during the group planning phases. These phases are considered in turn.

Planning as individuals

In 1994, 30 students completed the "Factor X" task. These 30 students' responses to the focussing questions will be considered in turn in order to demonstrate how the questions intended to provide support to the students were used by the students in 1994. The focussing questions directed students to consider relevant substantive concepts, to identify possible variables impacting on the investigation and to consider what measurements it would be appropriate to take during the investigation. The students' responses to these focussing questions will be considered in turn.

(i) Considering relevant declarative concepts

The researcher and the teachers felt that a recognition and application of prior substantive knowledge could help the students to make decisions about investigative design and the first focussing question centred on this. The 1994 students were asked to respond to the question: *Is there any background theory I ought to consider?* The students furnished 21 responses and 9 blank returns to this question. Three students restated, or closely so, the given introduction to the task and five students claimed that there was nothing that they needed to consider (one very forcibly - 'No!!!'). The majority of the responses focussed on Factor X (n=8) and, as will be discussed later, their not readily knowing just what Factor X was, caused concern to many of the students. Three students considered the possibility that Factor X was a catalyst. One hypothesised that:

> *Factor X may be a light speeding up the mixing of the two chemicals - hydrogen peroxide [and] chemical in sample.*
> 9419

Three of the 30 students identified that it would be helpful to consider general chemical concepts such as the specific chemical reactions of hydrogen peroxide (n=2) or reaction rates in general (n=1), for example:

> *The hotter the condition for an experiment the fast[er] the reaction occurs.*
> 9425

It is pertinent to note that hydrogen peroxide was not listed in the index of the Year 12 Biology text that they were using (Relph, Pedder and deLacey, 1986), thus the students were not able to access information regarding hydrogen peroxide easily.

It may be that the wording of this investigation and the attempt to introduce a mystery element acted against the students being able to access relevant declarative concepts that could have helped them in their design of the investigation. This may have been particularly significant for the second part of the investigation where an understanding of the nature and function of enzymes may have helped them to understand better what they were trying to find out.

(ii) Identifying possible variables impacting on the investigation

The identification of variables and the taking of the decisions as to which to manipulate, measure or control is an early requirement of an investigative plan (Duggan, Johnson and Gott, 1996). Hence, the second question that students were required to address was *What variables do I need to think about?* The 1994 students' responses to this question are summarised in Table 6.8.

The amount of the material used, whether measured by dimension or mass was the most frequently identified variable, followed by surface area of sample, amount of heat added and the source of the samples. Three of the students left a blank for this question; two indicated only one variable needing consideration; twelve indicated two variables; eleven students indicated three variables and two students indicated four possible variables needing consideration during the investigation. The reply from two of the students demonstrated their confusion regarding the control of variables with replication and sample size.

Variable identified as requiring consideration	Number of students indicating this variable (n=27)
Amount (size) of living material used	16
Amount of hydrogen peroxide added	14
Surface area of vegetable matter	7
Temperature of samples	7
Amount of heat added	6
Source of samples	4
Consistency of vegetable supply	3
Length of time sample is heated for	2
Freshness of vegetables	1
Amount of Factor X	1

Table 6.8: Variables identified by students as those requiring consideration during the "Factor X" investigation

Analysis of the students' plans and reports after they had carried out the investigation showed that the identification of a variable as requiring consideration does not automatically indicate that this variable identification will be operationalised by the student when he/she is carrying out the investigation. For example, in one instance two out of three members of a working group clearly identified that the size and surface area of the plant material would need to be carefully controlled but they failed to consider the surface area during their initial planning. For instance one of the students in this group commented, in response to the question regarding variables:

> *You need to have the same amount of hydrogen peroxide to each plant material. Each has to have the same surface area, be the same size.*
> 9423

Yet the group plan contributed to by this student gave precise measurements of amount of vegetable to use in mass terms only and not in volume nor dimension of the cut piece of the various vegetable:

> *Using 2 pieces of each of the 4 plant materials (each piece 5g) ...*
> 9423, 9424, 9431

The only indication that these three students finally addressed the question of surface area during their investigation was given under the heading of "Changes we made to our plan during our investigation" when they mentioned that they 'chopped up the vegies to give greater surface area'.

The different nature of the plant materials and the consequent difficulty of getting similarly shaped pieces of celery stalk, potato tuber and broccoli flower head was not reported as being considered by any of the students even though they were shown the materials in advance of their planning.

The variables which are significant to this investigation were identified in most instances by fewer than fifty percent of these 1994 students and identification did not necessarily lead to careful control as the students carried out the investigation. Hence, teachers may need to increase the time spent addressing these aspects of investigating.

(iii) Selecting appropriate measurements to take during the investigation

Once the students had recognised the pertinent variables they had to decide whether to define the variables quantitatively or qualitatively. As a response to the noticed tendency of the 1993 students to define variables qualitatively rather than quantitatively the 1994 students' were directed to respond to the question *What measurements will I need to do?* Their responses are summarised in Table 6.9. Three students did not fill in this section of the table. Of the twenty-seven students who did only seven indicated any volume or mass measurement units such as millilitres or grams.

Forty-two percent of students made statements indicating the need to take some measurements but did not identify the type or level of accuracy of these measurements. Instead they made more general statements such as:

> *... measure sizes of samples, measure amount of hydrogen peroxide, measure volume of foam produced in order to compare them.*
> 9413

Nearly half of the responses indicated the need for care and precision when measuring, particularly when preparing the samples for experimentation and the use of hydrogen peroxide; fourteen students used the words 'same' or 'equal' or a phrase such as 'precise measurements ... that don't change' (9422).

Aspects identified by the students as requiring measurement	**Numbers of students listing measurement of this aspect (n=27)**
Amount of hydrogen peroxide used	13
Sample size	12
Foam produced	10
Weight of vegetable samples	4
Surface area of plant material	3
Concentration of foam	1
Heat of flame	1

Table 6.9: Responses of the 1994 case study students when they were asked to identify measurements they would need to take during the investigation "Factor X"

As the students in the study were senior secondary school students with ages ranging from 15 to 18 years these results are of concern. With only approximately twenty-five percent of the 1994 case study students indicating measurement units and less than half indicating the need for precision of measurement it is apparent that these students required more guidance in this aspect of investigating. The teachers could have usefully discussed this aspect of investigating with their students.

Refining the plan in groups

After the students had completed their individual plans they joined together in groups to produce a group plan. In order to supplement the data available from individual students' written responses, groups of 2 - 4 students were audio-taped in 1993 and 1994 as they planned the details of their investigation. Four groups in total were taped (T3Gp:30/4/93; T2Gp:2/6/93; T2Gp:16/6/93 and T3Gp:7/4/94). In addition, following one of the taped group discussions the researcher interviewed the students in the group and asked them what they were thinking as they made their planning decisions (T2Gp:2/6/93). These tapes have been analysed and the processes of planning and the dynamics of a group planning exercise are discussed below. Aspects of the group planning exercise which will be covered are:

(i) Getting started
(ii) Identification of variables
(iii) Moving towards precision of measurement
(iv) Designing a fair test
(v) Gaining consensus regarding the meaning of terms
(vi) Making decisions regarding equipment
(vii) Cooperating as a group at a cognitive level

(i) Getting started

The first aspect of group planning to be considered was how the groups started to prepare their plan. Of the four groups taped, the first activity of three of the groups (T2Gp:16/6/93, T2Gp:2/6/93 and T3Gp:7/4/94) involved sorting out the task. One of the groups (T3Gp:7/4/94) spent a considerable amount of time discussing this, debating both the task and possible hypotheses for several minutes. As part of their discussion they searched for similarities between the vegetables as a means of establishing a hypothesis regarding the 'best two sources' of Factor X. When establishing similarities they used as criteria: level of starch (making a decision that the two vegetables with the highest starch content were potatoes and carrot); colour - greenness - thus celery and broccoli; and crispness - thus celery and potato. Although this group appeared to be using some prior knowledge here, the discussion was not pitched at any great depth and the decision that they finally made appeared to be chosen more at random than anything else. They eventually hypothesised that celery and potato would be the best source of Factor X because one of the group was 'happy' with the decision. Another group (T2Gp:16/3/93) collected samples of each vegetable to help them focus on the task and the hypothesis setting.

Two of the groups considered doing a trial run with the vegetables and hydrogen peroxide (T3Gp:7/4/94 and T2Gp:16/6/93), with the decision making process for one of the groups as follows:

S1 We could just do it first, for one, like have a rough go and see how much it really makes, like if its going to be piles and it is going all over the place we might have to ..

S2 Cover it [laughter]

S1 Change what we might do. It might go mad!
T2Gp:16/6/93

The teachers working with these students commented that trialing generally involved testing to see if largish lumps of the vegetable material produced measurable amounts of foam, how much certain volumes of vegetable weighed, how much hydrogen peroxide to use and how much foam was produced per unit mass of vegetable (Teachers' comments sheets). Research field notes confirm the teachers' observations (Field notes 30/4/93, 28/5/93).

One group, only, made a definite link with recent previous practical experiences. As they were debating about whether the material had to be ground up, they made reference to a liver - enzyme experiment where they had been required to grind up the living material (T3Gp:30/4/93):

S1 So did everyone put you cut it up and then you grind it up with a mortar and pestle.

S2 No, no, no. You don't need to

S3 You don't have to

S4 Who says you don't have to grind it up? With the liver experiment we did .. it was ground up so ...
T3Gp:30/4/93

During their discussion as to how much hydrogen peroxide to use another group (T2Gp:16/6/93) referred to an experiment that one of them could remember having done in Year 9 Science when they had used far too much material with obviously dramatic and memorable results.

For these students, group discussion allowed for a sorting out of some of the variables which might possibly affect the experiment they were to carry out. As well as discussion some of the groups moved onto carrying out trial runs with equipment and materials. This phase of the investigation appeared to be beneficial as they tried to find out the nature, and degree, of the reactions which might occur. These early trials appeared to be helpful to the students as they determined the amounts of materials to use and pertinent measurements to take. Accessing prior knowledge also appears to have been a significant factor in helping these students get started on the task in hand.

(ii) and (iii) Identification of variables and moving towards precision of measurement

The second and third aspects of group planning were the identification of variables and moving towards precision of measurement of these variables (see Table 6.10 for the transcription of their discussion).

S1 "OK Let's get one of each so we know what they look like.	A
S2 Pour some concentrated hydrogen peroxide on the material and the foam is produced.	B
S3 Do we just put it on the outside? How do we do an even thing for all the vegetables?	C
S1 Well, when I was reading it I was thinking about a weight thing because if you had a certain weight, like if you take 10 grams of carrot and ten grams of potato, then you decide with and without skin and what part of the broccoli	D
S3 Yes	E
S1 The only thing is some have more water than the others but ..	F
and later in the discussion	
S1 Cos we are going to have a problem here, look, if we don't squash them up the broccoli flowers have got a big sur....	G
S3 Would occupy far more	
S1 than just a lump of carrot. It would make more wouldn't it.	
S3 it would make it more even that just a lump of celery and a cut surface isn't enough so let's go for weighing bits.	
S1 Grind and weigh.	
S2 Grind and weigh. Do you want me to write it down?	H

Figure 6.1: Transcription of a planning discussion within group T2Gp:16/6/93

Students who looked directly at the vegetables moved quickly into a discussion of the different nature of the vegetables, for example T2Gp:16/6/93 examined variables such as the presence of skin and differing percentage of water content. This led them quickly to ponder the need to consider different parts of the vegetables and precision in weighing out the vegetable matter. This particular group also moved early in their discussion into a consideration of the effect of surface area and the need for carrying out a fair test, paying particular attention to the nature of the broccoli flower and its consequently larger surface area before they ground the material up.

An analysis of their dialogue indicates that they began by employing a starting strategy (refer to Figure 6.1 - point A). The first comment of student S2 is probably referring to the task sheet since on the tape this sounded more like a question rather than a statement (point B). At point C student S3 considered aspects of surface area to volume ratios and fair testing. Student S1 then introduced the idea of precisely stating measurement and a consideration of different nature of vegetable matter (D). He/she received encouragement regarding the importance of considering these aspects from student S3 (E). Continuing to reflect on these matters student S1 then expressed his/her concern regarding the variable nature of vegetable matter (F) and this led on to their discussion as to how to overcome this variable nature so as to make fair comparisons with respect to surface area (G). Note that S2 who originally read the statement from the work sheet was not engaging actively in the conversation and continued to assume the role of scribe (H).

This group's concern to move to precision with measurement and their early identification of possible variable factors is in contrast to the other three groups whose discussions were transcribed. The other groups did not discuss the need for precision in measurement until much later on in their planning. Even when measurement was hinted at it was often in general qualitative, rather than quantitative, terms such as 'add hydrogen peroxide to each of them' (T2Gp:2/6/93). At times the students consulted both the teacher and researcher regarding aspects of equipment and materials such as the concentration of the provided hydrogen peroxide (T3Gp:7/4/94). An example of lack of consideration of precision of measurement is demonstrated in this statement:

First I thought that we should take, like a big piece of the four plant materials and mash them up ah with a mortar and pestle so that its not like all different sizes and stuff and then like, start with one, potato, and measure out two equal portions of each. Like, so you can heat one and keep the other not heated. Like, make it one teaspoon or something like that .... and add hydrogen peroxide to each of them, record in order of one to five as to what produces the most foam, like the hot one and the not hot one and then compare.
93T218 in T2Gp:2/6/93

Not all students or student groups in the research project described amounts of materials to use with high degrees of accuracy. Nor did they define carefully the conditions under which to carry out any experiments. Nor did they move quickly to indicate how precise any measurements of products needed to be. It would appear that these Year 12 students required direct instructions and reminders if they were to move to higher precision of measurement.

(iv) Designing a fair test

Another aspect of group planning is the design of a fair test with considerations of reliability and validity. Analysis of the 1993 written records and the transcription of the group discussion for these students indicated that the students were considering techniques for improving the reliability of their results. The areas covered in their discussions included attempts to keep variables as constant as possible. For example, as they carried out this investigation to find out the best vegetable source of an enzyme, they talked about:

- whether or not all samples had to have the skin removed;
- whether the samples had to be of the same size and weight;
- whether the samples had to be ground up with a mortar and pestle, and
- how much of the hydrogen peroxide had to be used.

The 1993 students also considered aspects of precision with experimental techniques, for example they considered whether the boiled vegetables needed to be cooled to room temperature before the addition of hydrogen peroxide.

The students in all four of the taped groups moved towards designing a method which included aspects of fair testing, or the identification and control of variables. They used terms such as 'same', 'equal', 'even' (regarding size, weight, volume, surface area) and employed notions of comparison, especially with regard to the need to carry out equivalent procedures for Part A and Part B of the investigation. One group mentioned the need to control variables other than those that they were testing. When asked by the researcher about this they responded with:

> *Its got to be the same temperature and the same amount of time.*
> 93T217

> *The same amount of pieces of plant.*
> 93T218

Another group introduced the term 'control' into their deliberations but unfortunately chose an inappropriate control:

> *I sort of thought we should use a control for the experiment, like freeze one, boil one and then leave one of them at room temperature.*
> 93T318

When this comment was disputed by one of the student's peers and he was reminded that he had not been asked to freeze one, he replied 'I know, but you've got to use a control.' (93T318) indicating his awareness that he should set up his experiment in such a way as to allow for comparison of results obtained from situations differing in one condition only.

Uncertainty with the concept of 'control of variables' was not limited to the "Factor X" task. Analysis of ten tapes from groups of students planning other investigations also provided examples which illustrate this uncertainty. For example one group of students discussing the variables impacting on the rate of photosynthesis of *Chlorella* in alginate beads debated, at length, both the nature and degree of the variables and which to choose as the independent variable. However, once they had chosen light intensity as the independent variable there was no more discussion as to how to keep other variables constant. The possibility, for example, of heat being given off by the light bulb was not considered by the students (94 Gp, 14/6/94).

However, analysis of audio-tape data from four groups of students designing the group plan for the "Green streams" task indicated that these students had some understanding of the need for careful control of variables and the use of a control. In one short 10-minute transcript the students used the term control six times, for example:

> *Would it be called a control like if, say, we got a sample of the fertiliser and mixed it with water?*
> 93T3 students

The idea of controlling variables was often implied, for example, when the students were discussing how to get plants for the "Green streams" investigation

> *S1 No, if you get them from the pet shop ... anything else could have happened to them.*
>
> *S2 But at least they are the same ...*
>
> *S3 They are the same...*
> 93T3 students

A conversation between the students in a group which was planning an experiment related to the "Green Streams" task showed that, although they wished to use a control, just how this was to be accomplished, and what would be appropriate presented difficulties:

> *S1 I sort of thought we should use a control for the experiment like freeze one, boil one and then leave one at room temperature.*
>
> *S2 But you weren't asked to freeze one.*
>
> *S1 I know, but you've got to use a control.*
>
> *S3 Use the one at room temperature.*
>
> *S2 Yeh, but why freeze it?*
> T3 Gp: 30/4/93

The discussions of these Year 12 research project students has demonstrated that, whilst they did have some understanding of the concepts of 'fair testing' and 'control of variables', they were sometimes uncertain as to how to operationalise the concepts.

(v) Gaining consensus regarding the meaning of terms

Another aspect of group planning is reaching consensus with regard to the meaning of terms that were being used. Two of the four groups

(T2Gp:2/6/93 and T3Gp:7/4/94) spent time discussing the nature of Factor X with one group returning to discuss this again after they had completed their experimental design (T2Gp:2/6/93). The uncertainty regarding Factor X appears to have been a distraction, even though general discussion initiated by the researcher with the students suggested that they liked the mystery solving aspect of this task. This concern regarding the unknown substance is also apparent in post task evaluations with ten of thirty of the 1994 students indicating that they would liked to have known what Factor X was. There is a clear implication for task planners in this response. It may be necessary to be more explicit about the nature of Factor X, although other students have definitely stated that they do not want to know what Factor X is.

Three of the groups (T2Gp:2/6/93, T3Gp:30/4/93 and T3Gp:7/4/94) spent some time defining terms used before progressing far with their plans. Terms debated were 'plan' with the requested 'group plan' being defined as 'the method', and 'best source' defined as the 'most amount of Factor X per weight' after a discussion regarding a possible definition as 'cheapest' or 'the most available'. One group spent some time in a spirited debate considering the meaning of 'foam' and 'gas':

> *S1* (93T312) *Listen to this, listen to this. It says here - the amount of foam produced indicates how much Factor X is in the material .. so we should measure how much foam is produced*
>
> *S2* (93T325) *Not how much gas is produced*
>
> *S3* (93T318) *OK Shh*
>
> *S4* (93T311) *I put - you can measure the amount of foam produced or [his emphasis] collect the gas in the water bath*
>
> *S1 No, because it says measure the foam*
>
> *S3 No, that's not, that's not an actual thing*
>
> *S1 The foam is an indicator of the gas given off*
>
> *S3 That's sitting on the fence.*
> T3Gp:30/4/93

Further discussion with groups of students carrying out this investigation also indicated a confusion regarding the concepts of 'foam' and 'gas'. In 1994 we (the researcher and the 1994 case study teacher) asked the whole class during a post investigation evaluation session about the relationship between foam and gas and, although the number was not audibly counted on tape, subsequent conversation indicates that there was a confusion for approximately one third of the students (CT T3 11/4/94). Since this conceptual confusion appears to have impeded the students as they carried out the investigation this is an aspect to be heeded by task developers.

(vi) Making decisions regarding equipment

A further aspect of group planning is making decisions about the equipment the group will use. When the students discussed the equipment that they would require for their investigation they often made reference to previous experiments that they had carried out, both during their Year 12 Biology course and in earlier years at school. For example, Group T2Gp:16/6/93 wondered about adding the hydrogen peroxide to the vegetable matter in a 'little beaker with a balloon over the top' which may be a direct reference to a gas production experiment carried out in the junior school. Others directly referred to an experiment carried out in the third form. Discussing the amount of foam that would be produced and hence the appropriate container for collection they said:

> *S1 We won't use 200g or a kilogram of the stuff all at once, you mean ...*
>
> *S2 When we did the polystyrene one we didn't know how much to put in. [laughter]*
>
> *S3 Oh. no it just goes mad doesn't it.*
>
> *S1 When did you do that?*
>
> *S2 Last year sometime .... No, no, no third form Science.*
> T2Gp:16/6/93

The students in all of the four groups monitored during 1993 and 1994 by an audio-tape recorder as they carried out the 'Factor X' investigation moved to using a mortar and pestle to grind up the vegetable early in their discussion. This may have been because the teachers had this equipment on view in the classroom during the planning process.

It is apparent that the students were somewhat concerned about boiling the vegetable material in water and then testing for the presence of Factor X, as required in Part B, when the vegetable material was tested directly in Part A.

The researcher has observed another student, in a class not associated with the research project, attempting to extract Factor X in water by crushing the vegetable matter, stirring a fixed volume of water into this crushed vegetable material, filtering and testing the filtrate for the presence of the enzyme. However, none of the four monitored groups carried out a technique as rigorous as this and thus had concerns regarding the consistency of their approach. Students also used prior knowledge, both science knowledge and everyday knowledge in this regard. They chose to boil the vegetables using a water bath technique and in their discussions they linked the possible loss of Factor X into the water in Part B with their knowledge of the loss of vitamins from vegetables when they are boiled in water, for example:

> *It could be like, vitamins or minerals or nutrients or something like that which escape when you boil them.*
> 93T218

Audio-tape transcripts of students discussing the 'Green Streams' task also show students grappling with required degrees of accuracy and frequency of measurement taking, for example, after a discussion as to how long to take measurements of plant growth:

> *S1 A week!*
>
> *S2 Oh, not a week.*
>
> *S3 It wouldn't take that long.*
> 93T3 students
>
> *S1 Observations of what?*
>
> *S2 No, you need measurements because you can hardly say "OK, bigger than yesterday" because you can't remember how big it was yesterday, so you will need to take measurements.*
> 93T3 students

In summary the students frequently referred to their past experiences of practical work as they planned the equipment they were to use. They were also influenced by the equipment that was on display in the room. They often debated the efficacy of the particular technique that they had chosen to use. In particular, they were concerned about the consistency and accuracy of their chosen technique and their measurement taking.

(vii) Co-operating as a group at a cognitive level

Another aspect of group planning is working together at a cognitive level (Gayford, 1992; Solomon, 1994b). One feature of the four group discussions captured in these 1993 and 1994 'Factor X' group transcripts was the interrupted nature of the discussion between the students. Often there was considerable emphasis by an individual of his or her own viewpoint, without apparent consideration for others who were also trying to make a point. In one five minute, 29 second section of a tape there were one hundred and four interchanges with many sections of speech being less than eight words before the speaker was interrupted (T3Gp:7/4/94, students 9401, 9402, 9426, 9422). There were sixty one changes of speaker and in the other forty-three instances the speaker continued, ignoring the interruption which may have just been a grunt or the beginning of a word. The bar-graph in Figure 6.2 indicates the word length of the sixty-two sections of the discussion which were transcribable as separate utterances. The mean word length was 7.5. Two of the three longer statements occurred when the students were either speaking out loud as they were writing on the worksheet, or when they were referring to the task sheet.

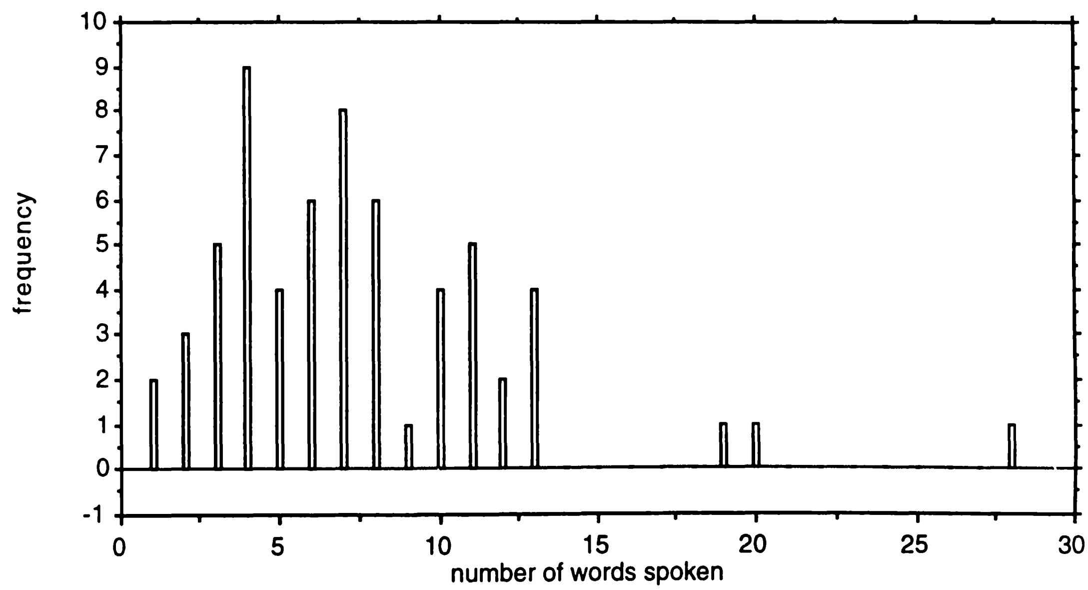

Figure 6.2: Bar graph showing frequency of number of words spoken before interruption, taken from a Transcript of T3 1994 students, 7/4/94

This rapid change of speaker may be a measure of interest in the activity, with students clamouring to contribute their point of view, but the students in this group did not spend a great deal of time listening to each other's points of view or helping each other's confusion. For example, in the following conversation a student (9426) is trying to establish whether one or two sources of Factor X are required to be identified. This query is answered early in the quoted section of the conversation but it continues to concern her and she asks again. However, the other students carry on with their conversation without addressing her on-going queries:

9401 *... this is what we are trying to do ...*

9402 *Find Factor X*

9426 *... that's what we are trying to do. Find the two, the two*

9401 *Find the two substances that contain the most of Factor X*

9426 *We want to find, yeh*

9402 *the two best sources*

9401 *the two best sources, that contain the most factor x ..*

9426 *two or one?*

9402 *what are we going to put down?*

9426 *is it two or one?*

9402 *my hypothesis is ....*

9401 *the best source is the potatoes.*
T3Gp:7/4/94

Whilst this rapid changeover of speakers was particularly obvious in one of the tapes of students discussing "Factor X" and not in the other three relating to this particular investigation, lively, interruptive debating has also been noted by the researcher in other interactions as students debated the approach they were going to take to find an answer to the contextually based questions of these investigations (94 Gp:2/5/94; T2Gp:2/6/93).

Whilst this pattern may indicate a limited level of co-operation between the students it may also be interpreted from a different viewpoint. It may be considered that the students did not have to say <u>in full</u> what they were thinking as they constructed their meaning of the task, because they already shared an understanding of the meaning of the task. This is an aspect that could be researched more deeply in follow-up studies.

The students' demonstrated planning abilities

The final aspect of group planning to be considered relates to the students' demonstration of their planning abilities. The thirty students who carried out the "Factor X" investigation in the case study class in 1994 worked as nine groups. Their group plans, as the students wrote them, were analysed using the scoring schedule outlined in Appendix K. The results of this analysis are given in Table 6.10.

The students provided evidence that they could:	Number of groups who			
	Strongly indicated that they could	Moderately indicated that they could	Weakly indicated that they could	Showed no indication that they could
• take into account a range of factors	1	2	5	1
• utilise an appropriate sample size	3	5	1	0
• provide an appropriate replication technique	0	4	1	4
• select appropriate equipment	0	1	7	1
• take appropriate measurements	0	0	7	2
• identify sources of error in their proposed method	0	0	0	9

Table 6.10: Frequency of indication of aspects of planning by students carrying out "Factor X" investigation, 1994

Aspects of planning which were analysed were the students' ability to take into account a range of factors, to utilise an appropriate sample size, to provide an appropriate replication technique, to select appropriate measurements and to identify sources of error in their proposed method. Examination of the students' written records shows that the majority of the student groups were not demonstrating high skills at considering a wide range of the factors which may influence the investigation (6 of 9 groups). They were not indicating clearly the appropriate equipment to use (8 of 9), nor did any of the groups define the actual measurements they intended to take. Most (8 of 9 groups) utilised an appropriate sample size. Only 4 of the groups were able to even moderately indicate appropriate replication techniques. At this stage of the year the students had not been taught to consider possible sources of error in their proposed method and none of the 1994 student groups did identify any sources of error in their proposed method.

It should be noted that analysis of the accompanying transcriptions of group discussions, observations by the teacher and researcher and analysis of the students' findings indicate that some of the apparent lack of understanding and precision as demonstrated in the presented plans may in fact not truly reflect the students' understanding but rather a lack of expertise at presenting their thoughts in a written form - or a lack of willingness to spend time writing rather than "getting on with it". Given this qualification, the scoring data indicates that the students are more competent at some aspects of planning than at others.

Overall the findings from this analysis of seven aspects of group developing plans for their investigative experiments, and their demonstrated planning abilities, indicate that students may benefit from greater discussion with their teachers as to what to consider when planning for an investigation. They may benefit by being encouraged to spend time considering what prior knowledge may be applicable to the new situation. Such prior knowledge could relate both to linked theory and to previous practical activities. They could be encouraged to trial possible techniques or to gain some idea as to appropriate measurement scales to use. They could be encouraged to gather quantitative rather than qualitative data and to be precise in the measurements that they take. The students whose work was analysed in detail in this chapter demonstrated considerable uncertainty with the concepts underpinning 'fair testing' and this suggests that teachers could teach about concepts of evidence more directly. Aspects of experimental design such as replication and the identification of sources of error were particularly poorly demonstrated.

These students have demonstrated that they were keen to come to a shared understanding of the terms used in the investigative worksheet. They engaged in lively and interruptive debate as they developed shared understandings of the task requirements. The opportunity for developing shared understandings, that group planning presented to these students, resulted in a richer understanding of the tasks.

6.3.2 Students gathering data

Section 6.3.1 reported on the students' ability to plan an investigation. This section reports on their data gathering ability. Student reports of their experimental results were used as a source of additional information relating to students taking appropriate measurements during their scientific investigations. Of the nine 1994 student groups who returned written information to the researcher regarding the investigation "Factor X", three groups reported in qualitative terms only. Six reported measurements either in terms of volume of foam produced or the height that foam rose in the reacting or collecting container. One group added descriptive notes to their measurements. Six groups reported only one experiment, one group measured the volume of foam produced over two attempts and one group carried out three replications. Table 6.11 summarises the methods used by the 1993 students to measure the amount of foam produced during the reaction. Of the eighty four students who carried out the investigation into "Factor X" in 1993, twenty seven (32%) reported foam production in terms of the height it had risen up the collecting container in centimetres, using this measurement as a crude indicator of volume; thirty five (41%) indicated the volume of foam produced in mL; sixteen (19%) reported their data in qualitative terms only, three (3.5%) gave no results.

System used for recording foam produced	Percentage of 1993 students
Change in height of foam in container in cm	32
Volume in mL	41
Time taken for production of 100mL of foam	4.5
Qualitatively descriptive terms only	19
No results	3.5

Table 6.11: The methods used by the 1993 students to record the amount of the foam produced (n=84)

Teacher guidance alone may not lead students to take quantitative measurements since six of the 1993 students who reported only in qualitative terms were working with a teacher who indicated that she had discussed the need to make quantified observations with her class. Four (4.5%) students (all from one class, working together in a group) measured the amount of time taken for the redox reaction to produce 100mL of foam. Of those students indicating quantitative data two added descriptive observations. Only four (4.5%) of the eighty-five 1993 students reported any repeated measurement taking.

That a significant number of these Year 12 Biology student groups (33% in 1993 and 20% in 1994) had not thought to support their decisions as to the best two sources of Factor X with quantitative data is concerning, particularly as some of these students had received teacher instruction to make quantified observations. A greater emphasis by the teacher on the need to make quantified observations may be required.

6.3.3 The possible role of previous experience and knowledge in determining expertise at planning and carrying out of an investigation

Another aspect of student planning and gathering data is the possible role of previous experience for determining their expertise. Data from the 1993 study have been analysed in an attempt to establish whether immediate previous theoretical study, and practical experience, influences the students' decision making during an investigation. The following analysis is based upon the data provided by the four classes of students who carried out the "Factor X" investigation in 1993 and from written and oral comments made to the researcher by their teachers. Two of the four 1993 classes of students (T2 and T3) carried out the "Factor X" investigation after studying theory relating to enzyme systems and having previously carried out an enzyme-connected practical experiment; two (T1 and T4) had had neither related theory nor practical experience beforehand. A summary of the four teacher's comments regarding their students' prior knowledge and the degree of help required by the students was given in Table 6.6, page 152.

The students' individual plans for "Factor X" were scored using the scoring schedule given in Appendix K. An unpaired two-tailed t-Test indicated that there was a significant difference in these means (D.F. = 76, p = .0005) with the classes who had had previous linked theoretical and practical experience scoring significantly lower than those who had had no such previous experience. These findings did not support those reported by Gayford (1989) who found that students' investigative planning abilities were improved when they had previously studied linked theory and had carried out related practical experience.

In an attempt to establish whether scoring differences were arising from general differences in student ability the Factor X planning scores for the seventy seven students who completed the 1993 year, and who were given a grade for Sixth Form Certificate, have been analysed and compared with their sixth Form Certificate grades.

The means and standard deviation error bars for the Factor X planning scores for the four classes were calculated, as was that for the students' Sixth Form Certificate grades - see Appendix L. The correlation coefficient between the "Factor X" planning scores and the Sixth Form Certificate scores for all 77 of the students who completed the year was -.207. (see Table 6.12). Since Sixth Form Certificate grades are given from 1 (high) to 9 (low) the general direction of correlation was as expected but the degree of correlation was low for these students.

Class(es)	Correlation between Sixth Form Certificate grades and planning scores for "Factor X"
T1	.011
T2*	-.424
T3*	-.392
T4	-.164
T1 and T4	.106
T2 and T3*	-.372
All students	-.207

Table 6.12: Sixth Form Certificate grades correlated with "Factor X" planning scores for the 1993 student cohort. * indicates those students who had had previous exposure to either theory or practical work related to enzymes

There was overall a very low correlation between the students' Sixth Form Certificate scores and "Factor X" planning scores with $p = .08$ on a two-tailed test for significance. The correlation was greatest for students in T2 and T3, lower for students in T4 and negatively correlated for students in T1.

Demonstrated "Factor X" planning scores were therefore adjusted for differences in Sixth Form Certificate scores during analysis of covariance.

A one factor ANOVA comparing students' "Factor X" planning scores for the four teacher's classes showed a significant difference at the 95% level between the students for T1 and T2, T1 and T4, T2 and T4 and T3 and T4. A one factor ANOVA comparing students' Sixth Form Certificate grades in these four teacher's classes showed a significant difference at the 95% level between the students in T1 and T2, T1 and T3, and T1 and T4 (see Appendix L).

Following analysis of covariance there were still significant ($F_{3,72} = 6.05$, $p = .000$) differences between the four classes' "Factor X" scores after adjusting for differences in Sixth Form Certificate scores. Inspection of the pattern of adjusted means showed a similar pattern to the original means (Table 6.13).

Class	N	Mean	Adjusted mean
T1	22	12.8182	12.5224
T2	19	11.0526	11.1434
T3	21	12.1429	12.2541
T4	15	15.0667	15.2296

Table 6.13: Means and adjusted means of 'Factor X' planning scores for 1993 students

Thus, the demonstrated greater ability of students in T1 and T4 to plan an investigation such as "Factor X" can not be explained by differences in their overall ability as demonstrated by their Sixth Form Certificate grades. The reasons for these demonstrated differences in planning ability need to be found elsewhere. It is possible that different teaching strategies employed when the students were carrying out scientific investigation, for example differences in the degree of help and direction provided by teachers, could account for the demonstrated differing abilities of students at planning for the "Factor X" investigation as indicated by the scoring of their plans. As indicated in Table 6.6 (page 152) teachers T1 and T4 had spent time before the

"Factor X" investigation emphasising the need to conduct a "fair test" whereas teachers T2 and T3 did not indicate that they had emphasised this aspect of the task. Teacher T1 indicated that she had continued her usual approach of challenging the students' thinking by asking questions. T4 had directly intervened during the course of the investigation to encourage the students to consider taking more accurate measurements and commented generally that the students who were insecure had needed considerable help. In contrast teachers T2 and T3 had not given their students much direct help with aspects of the planning process before the planning phase of the investigation and indicated limited help during the investigation.

Alternatively we can assume that there is no direct correlation between an individual student's overall obtained Year 12 Biology grade and an individual student's ability at planning a scientific investigation. Further research remains to be done in this area.

Section 6.3 has examined the students' performance as they planned and carried out procedures to help them answer the questions posed by an investigative task. The students did not always demonstrate sound procedural approaches. The findings indicate that the students would be supported in this aspect of investigating if they were helped to identify the declarative concepts underlying an investigation. Although these students knew about the principles of fair testing they did not always demonstrate consistent application of these principles. They would benefit from direct teaching regarding the identification and manipulation of variables and ways to operationalise these. Their poor identification and specification of required measurements indicates that they might be helped by suggestions of equipment and techniques to use. Additionally, encouragement from their teachers to move from qualitative to quantitative measurements, when appropriate, may be necessary.

6.4 Students as evaluators of themselves as practical investigators

Sections 6.2 and 6.3 of this chapter data have focussed on students hypothesising, planning and gathering data during a scientific investigation. In Section 6.4 the students' own evaluations of themselves as scientific investigators are considered. It is considered that scientific literacy requires not only a sound knowledge of the major declarative concepts of science but also of 'ideas related to the collection, validation, representation and interpretation of evidence' (Gott and Duggan, 1996 p 793). The New Zealand Science and Biology curriculum documents indicate that it is expected that students in Years 12 and 13 will be working towards being able to:

> evaluate the quality of information gathered and its degree of relevance.
> *Biology in the New Zealand Curriculum*, Ministry of Education, 1994, p 38

However, it has also been suggested that, for a majority of students an understanding of the meaning of scientific evidence does not emerge automatically as a result of their doing practical work. It appears that students need direct teaching to help them reach these understandings (Duggan and Gott, 1996; Gott and Duggan, 1996).

In order to find out if the Year 12 Biology students who were participating in the research project were able to recognise the effectiveness of the procedures they had used during their investigations, the students in the 1994 and 1995 research projects were asked to evaluate their work. Questions were also asked of the students to help the researcher and participating teachers ascertain how the students could be better helped to understand how to carry out reliable experiments and to reach valid conclusions. In addition questions were asked to elicit students' perceptions of their learning as a result of carrying out an investigation.

These questions were part of a post-investigation evaluation sheet prepared by the researcher (see Figure 5.5 (iv), page 119). At the completion of each investigation individual students were encouraged to write down their thoughts and feelings about the lesson to give them the opportunity to think and write about how, and what, they were learning and to encourage them to more readily monitor their own learning. They were asked to focus on what they had learned during the practical session and what made it easy or difficult for them to learn about the process of investigating in Biology. They were also asked to evaluate the effectiveness of the procedures that they had used and to indicate the validity of their findings.

The information presented in this chapter is derived from a sample of student evaluations. The sample comprised the 1995 evaluation forms completed after the "Sweet Export" investigation. (This investigation was selected because there was a greater amount of student evaluation data gathered for this investigation than for any of the other investigations.) The "Sweet Export" investigation required students to identify, from a sample of five different varieties of apples, the two varieties with the highest glucose content. Whilst seventy-two students worksheets for the "Sweet Export" investigation were returned to the researcher by the 1995 participating teachers, of the seventy-two only fifty-six students had completed the evaluation form. The responses on these evaluation forms are analysed below (Sections 6.4.1 - 6.4.2) using the questions from the evaluation sheet as foci.

6.4.1 Students' views of their ability as investigators

The first question asked students *"How well do you think you carried out the practical work?"*. Of the fifty-six students whose responses were analysed, ninety-one percent indicated that they had carried out the investigation 'well', with twenty percent of these students indicating that it went 'very well'. Nine percent of the students expressed concerns and indicated that their investigation had 'not gone well'. When explaining their responses the criteria used by the students for determining "well" or "not well" included

- working co-operatively to carry out the practical work (18%), for example:

> *I think I carried it out well because I left my group to join a student in my class who was on her own and had no idea of what she was to do.*
> 95P student

> *I think we worked well as a group, with everyone a willing participant.*
> 95P student

I think that I took an active part in the practical work.
95P student

- working accurately and with precision (18%), for example:

I think we did not do extremely well, I think we got the results needed, but felt the experiment was not accurate enough.
95B student

- repeating tests (13%), for example:

Quite well, we did it twice to get fair results.
95B student

I think we need to investigate even more to back-up our conclusions, and the reason why is because of that I didn't carry out the investigation to my fullest ability.
95B student

- working efficiently (7%), for example:

I think the practical work we [did] in class was done efficiently and accurately with unusual conclusions.
95B student

- carrying out the investigation as planned (5%), for example:

Well, we covered all the plan properly and did our experiment precisely and it worked.
95U student

- getting results (5%)

I think that we have obtained accurate results quickly, efficiently and fairly.
95P student

Other responses from individual students included a recognition of extra work done or still required to be done. For example students wrote of

- redesigning the investigation when necessary, for example:

It was done well, because when the practical didn't go very well we did it other ways.
95B student.

- being organised

I think we did well. We were very organised.
95S student

- working through confusion to understanding, for example:

I think I carried out the practical work well. At first it was confusing to realise how we were to test for glucose and compare, but we worked it out in the end.
95P student

- a recognition that they could have worked more thoroughly, for example:

I think we needed to investigate even more to back up our conclusions, and the reason why is because of that I didn't carry the investigation out to my fullest ability.
95B student

The criteria that students were using to report the robustness of their approach to the investigation were, therefore, related to the manner in which they had carried out the investigation - either personally or as a group - or to the experimental approach that they had taken. These responses are probably to be expected given the open nature of the question.

6.4.2 Students' acknowledgement of the need for additional information or help

The second question on the self-evaluation sheet asked *'When you were carrying out the practical work what more would you have liked to know?'*. The responses from the students ranged from not requiring additional help, to general requests for considerable additional information, to specific and general procedural requirements. Some of the students recognised that the additional information could have been generated by themselves rather than be asked for from another person - teacher or peer. None of the students indicated that they would have liked help with the interpretation of their results.

Thirty eight percent of the students indicated that they had all the information they required as they carried out the investigation. One student wanted to know 'lots' and three wanted specific details of 'the answer', for example:

I would have liked to know exactly how much sugar was in each sample.
95P student

Assistance with the general procedure was required by twenty-five percent of the students, for example:

I would have liked to know how to begin the experiment and why we had to do a glucose test - I didn't know that a glucose test had to be done.
95P student

I would have liked to know what I was doing instead of doing what people told me.
95P student

Specific help with the glucose standardisation procedure was required by twenty-one percent, for example:

I would like to know exactly how much Benedict's we needed to add to the apples for the results, how long to heat it until the first colour change or until it totally changed colour.
95P student

Three only of the fifty-six students signalled other possible tests, or procedures, that might help them answer some of their questions, for example:

I would have liked to know what temperatures or condition change the amount of sugar in an apple, eg does hot heat have an effect on the taste of certain apples?
95B student

Would we get more accurate results if we use apple juice instead of smashed apple pieces?
95B student

Less than ten percent of the students (five students) identified additional specific background information that they would liked to have had before they started the investigation, for example:

[I would have liked to know] how far into the ripening process the apples [were].
95P student

These variations in the students responses may indicate that teachers could offer to be available for when the students had identified their need for additional information, rather than providing information before the students begin the investigation. Teachers could also encourage students to become more independent and to look for answers for themselves before requesting teacher help.

6.4.3 Multiple learning outcomes

The third question asked of the students on the post-investigation evaluation sheet was *'What do you think you have learnt today?'* As with the other investigations in this research project, multiple learning outcomes, varying with the student, resulted from the students' involvement in this investigation. Learning outcomes were either related to the findings of the investigation or the process that they had undergone with nearly half of the students referring directly to their experimental results. The fifty-six students evaluating their "Sweet Export" investigations collectively identified seventy learning outcomes across the following range:

- those learning outcomes relating to their understanding of the glucose level of apples such as that specific apple varieties contain the most glucose, all apples are of approximately the same sweetness, that different apples have varying sugar levels, and their surprise when 'bitter' tasting apples tested high for glucose. Sixty-four percent of students indicated learning outcomes related to glucose content of apples, for example:

  I learnt that Granny Smith was one of the apples which had the highest sugar (sic) content which I though would be the least because it is usually quite sour.
  95S student

- those learning outcomes relating to the purpose of a Benedict's test and procedures for carrying it out (34%), for example:

  I learnt how to do a glucose test, the colours involved in glucose test.
  95B student

- those learning outcomes relating to aspects of investigative procedures such as how to plan and do an experiment of their own and how to make adjustments when things go wrong, how to prepare samples of apple material for testing, to take care not to contaminate samples, to be more accurate and precise when weighing and how to test fairly (14%);

  [I learned that] sometimes it is necessary to repeat experiments to get the clearest reliable results.
  96B student

  [I have learnt] to look for ways to overcome problems.
  95P student

In addition to identified learning outcomes which were shared by a number of students there were also some that were identified by a small number of the students. Examples of these were:

- those learning outcomes relating to the practical value of Biology in real life (4%), for example:

  [I have learnt] the practicality Biology has in everyday situations.
  95P student

  [I have learnt] that food tests can be used in practical situations.
  95S student

- those learning outcomes relating to an understanding that co-operation and delegation within a group is important (4%), for example:

  If you work in a group you learn about something faster if you don't (sic) know anything about a subject in the first place.
  95P student

  [I have learnt] delegation.
  95P student

- those learning outcomes possibly relating to development of a sceptical view point (2%), for example:

  [I have learnt] that the true results are not always what they seem.
  95S student

For comparative purposes the learning outcomes reported by seven teachers whose student groups had completed the "Sweet Export" investigation were compared with the learning outcomes acknowledged by the students. The teachers' list also included the learning of specific techniques for testing glucose concentrations in apples, general procedural expertise relating to selection of appropriate equipment and processes, and the value of students working co-operatively to complete an investigation in a short time frame. Additional to the students' list, the teachers believed that their students had learnt the value of participating in post-investigation reflection and evaluation.

The wide variety of learning outcomes that were acknowledged by the students for this investigation has important implications for classroom practice. There could be more direct emphasis on expected student outcomes before the investigation was commenced. There could be a wider acknowledgment and acceptance of the possibility of multiple learning outcomes. The students' learning may be enhanced if the teacher regularly includes opportunities for acknowledgement and discussion of the students' learning arising from an investigation.

6.4.4 Students' understanding of reliability and validity

In question four of the post-investigation evaluation form the students were asked *"How valid do you think your results are? Explain your answer."*. The fifty-six students' comments fitted into five categories of response. These are shown in Table 6.14.

Response Category	Percentage response
Students who claimed that their results were valid	48%
Students who claimed that their results had limited validity	14%
Students who did not claim validity or were uncertain about this	30%
Students who did not know how to respond to the question	6%
Students who gave no response	2%

Table 6.14: Student representations of the validity of their investigations

A quarter of students claiming validity for their data did so on grounds which would not necessarily be shared by scientists. For example, validity was claimed because

- their results were closely comparable with those of other students' (18%), for example:

I thought that they were good because the two best apples compared the same as the other groups.
95U student

and because

- the results fitted their expectations (7%), for example:

I think that our results were very correct because ... we were told to look out for brick red colours in our results which is what we got.
95P student

I think that they were quite valid because our hypothesis was correct with our answers.
95P student

Others however claimed validity on procedural grounds which would be more acceptable to scientists, such as:

- they were careful with their procedures (61%), for example:

  I think our results are valid because we were careful to avoid contamination ...
  95S student

- they repeated the procedure to improve accuracy (14%), for example:

  I thought our results were very valid as we carried out the experiment two times. Further experiments would need to be done before recommending apples to a company.
  95B student

This reasoning was also put forward by students who repeated their experimentation when the first results did not give results that they expected, for example, (though their reasoning is questionable):

> *Our results are very valid. Our first test did not give the results intended but after redoing the exercise we got the results that were correct.*
> 95S student

The students who limited their claim of validity were concerned with factors which had prevented them from obtaining what they perceived as less than accurate results. Such factors were largely procedural concerns, for example, the difficulty in obtaining standards against which to compare apple sugar levels, time constraints and the difficulty in making decisions over a narrow range of colour variations. One student claimed that her results were:

> *... precise but less than accurate, because there are some random uncertainties made by the students, for example, equipment not washed properly, observations inaccurate. Experiments not enough trials. Not very reliable. Different types of apples, from different trees and different conditions.*
> 95 B student

Another student was concerned about generalising from small samples:

> *[The results] are all valid except though they are the same type [of apple] they may not have the same sugar results.*
> 95P student

One student, lacking confidence in her own experimental skills, said that she no longer felt confident about the validity of her results after the class discussion because the class results were different from her own:

At first I thought they were valid as they could get, but after working out the class average they are not terribly valid.
95P student

53% of the students not claiming validity indicated procedural concerns, constraints or uncertainties as their reasons for not claiming valid results. They mentioned practical difficulties such as juice extraction, and problems with particular aspects of the test for glucose levels. They also referred to time limitations for completion of the investigation, and their own uncertainties about carrying out a standardised colorimetric test. 32% indicated that their results were not valid as they had not repeated their experimentation. As with the students claiming validity for their results, these students were concerned that the small numbers of apples they had used may not be representative of the variety (12%) or that their results were not valid as they were different from those of other groups (12%).

There was some evidence that, whilst the students were working together to obtain group results for this investigation, not all groups of students discussed the issue of validity of results before completing the personal evaluation forms. In one instance four students working together declared widely different views of the validity of their investigation. One claimed that the results were valid as the group had 'tried to make sure we kept the same amounts of apple in each test'. A second group member claimed that the results were 'fairly valid' as the amounts of the apples used were kept constant. Another indicated that the results were not valid as they could change over time [it was not clear whether she was talking about possible short term changes during the investigation or longer term seasonal changes in apples] and the fourth member of the group said that they were 'not very valid [since], due to the time available, tests could not always be fully completed' (95P students). There were clearly different degrees of critical analysis being used by the students. Such comments could also indicate that questions of validity and reliability were not discussed by this group during the course of the investigation.

It has been claimed (Gott and Duggan, 1995) that we have very little direct evidence concerning children's understanding of the validity and reliability of an investigation. These researchers were interested in students' ability to keep the requirements for a valid and reliable investigation - that is, one which produces believable evidence - in mind during the course of an investigation. They stated that 'this notion of [believable evidence] is at best patchy and at worst non-existent' (*ibid*, p 84) and that finding successful techniques for teaching this notion is not easy. They cited Assessment of Performance Unit data (Harlen, Black and Johnson, 1981) indicating that when 11-year olds were assessed as to their willingness to be critical of the procedures used, only twenty percent were aware of the need to repeat measurements, to control variables and able to recognise ineffective procedures. The data from this research study, which was gathered from students who were on average five years older than the students in the APU sample, have also demonstrated a limited understanding of concepts of evidence. The students appear to claim validity on grounds which the scientific community would not find acceptable. However, there were those who questioned the validity of their results more critically, following scientifically accepted criteria. Even given Gott and Duggan's (1995) comment that direct teaching to address this issue is not easy, direct teaching appears to be required. For example, for the "Sweet Export" investigation the teacher could ask questions such as: Do you think that every apple on the tree(s) will have the same sugar content? How could you be sure of this? Have all the apples been picked at the same time? Would picking apples at different times in the season affect these results? Working groups of students could be asked to consider how reliable their results were, whether there was a need for replication, a need to ensure similar procedures with each variety of apple, and how they could avoid contamination of their results.

6.5 Summary

This chapter has focussed on some cognitive aspects of students carrying out open scientific investigations. The students' demonstrated abilities at three aspects of investigating have been described: their ability to generate testable hypotheses; to plan an investigation which will provide quality data; and their capacity to reflect about their competence as practical scientific investigators.

The key findings of this part of the research project indicate that the Year 12 Biology students who were involved in this research project in 1993 - 1995 demonstrated a wide range of ability at hypothesis generation and planning of an investigation. The students demonstrated that they had a limited understanding of the role of hypotheses and they did not find hypothesis generation easy. Nor did they find it easy to generate testable predictions from their stated hypotheses. Their hypothesis generation abilities were both context and task format dependent.

The students' understanding of the inherent requirements of gathering reliable and valid scientific evidence and their ability to evaluate their own expertise at scientific inquiry was also very variable. When planning an experiment to test a hypothesis in an open investigative situation, the majority of these students were unable to function unsupported at the levels described by the statements for levels 7 and 8 in the "Developing Scientific Investigative Skills and Attitudes in Biology" Achievement Aim of *Biology in the New Zealand Curriculum* (Ministry of Education, 1994, p 38 - 39). The majority were unable to generate explanatory hypotheses from which testable predictions could be developed. When planning and gathering data their writings, discussions and classroom behaviour indicated that they had a poor understanding of experimental protocols relating to sample size and replication. Similarly, their initial measurement strategies tended to be qualitative or crudely quantitative rather than precise.

Teacher instruction and facilitation with respect to investigative procedures could be a significant feature of student success at scientific inquiry. The students themselves acknowledged their need for support as they carried out practical scientific inquiry processes. It was also identified that it is essential to acknowledge the complexity of this classroom experience and to recognise ensuing multiple learning outcomes. These findings will be discussed in more detail in Chapter 11 as will possible implications of these findings for classroom practice.

Affective aspects of learning contexts are also of interest when students are investigating in Biology classrooms. The students involved in the research project approached open investigations with variable degrees of confidence. They also had strong views regarding the value of such investigations in a Year 12 biology programme. The students' response to investigating will be discussed in Chapter 7.

Chapter 7: The students' response to investigating

7.1 Introduction

In order to address the research questions (3 and 4) "What are the perceived benefits accruing from introducing investigative activities into classroom programmes in Science/Biology? and "What are the perceived constraints regarding the introduction of investigative activities into school Science/Biology?" it is necessary not only to study the activities of students carrying out investigations, but also to analyse their developing understandings of, and attitudes towards, such work.

Although it is difficult, and at times undesirable, to separate cognitive and affective aspects of learning (Gage and Berliner, 1984) this chapter focuses on the affective aspects of students investigating. It was deemed necessary to carry out this analysis as students who are engaged in carrying out open investigative practical work could be expected to be forming and changing their attitudes towards scientific inquiry. Such affective learning which occurs as a result of experience (Lefrancois, 1982) will influence the confidence with which the students approach their work and their understanding of biological concepts - both declarative and procedural. The chapter presents the findings from surveys of the students' declared confidence regarding their ability to carry out open investigative practical work (Section 7.2), and their overall response to an open investigative approach to biological studies (Section 7.3). The students' stated preference for investigative practical work is described in Section 7.4. The key findings from this part of the research project are presented in Section 7.5.

7.2 Student confidence and practical investigations

Early discussions with the teachers of the City High Year 12 Biology students indicated that 'recipe following' experimentation had been the most common experience for the students in their past science learning (Departmental meeting 27/11/92 and Diary notes 28/4/93). That is, practical work for most students had entailed careful following of detailed instructions developed by their teacher or text author. There was general agreement in this regard though there was some disagreement between the teachers over how much opportunity the students had had do open investigative work, with one teacher claiming that the opportunities for this at City High school was much less than that in her previous schools:

> *I am surprised that [the other teachers] seem to think that the students do a lot of open-ended work in the junior school here. From my experience in other schools I think that this opportunity is minimal and that is why the students are not very confident or able.*
> T1 Field notes 28/4/93

The other three teachers, however, felt that the students at City High had opportunities to carry out practical work of an open nature in the junior school (T2, T2 and T3, Departmental meeting, 29/4/93).

Some students had presented individual or small group Science Fair projects in Forms 3 - 5 but this was largely outside the domain of the classroom teacher. There was an acknowledgment that the teacher directed work at the lower levels of the school did not prepare students well for senior Biology, particularly Year 13 (Form 7) Biology, for example:

> *There is a huge jump between what we feed them in the sixth form and what we expect of them in the seventh.*
> T1 Departmental meeting 27/11/92

Because of the teachers' and researcher's felt concern that the students had not had a great deal of preparation for carrying out open investigations we, teachers and researcher, wished to find out if these students were confident regarding their ability to use scientific enquiry processes when they had the opportunity to personally direct these processes.

The data to help us answer this question were generated through a pre- and post-intervention survey approach. In the early stages of 1993, before the students had carried out any open investigations they completed a questionnaire to establish their felt (declared) confidence about aspects of carrying out of an investigation - see Appendix E. The survey was repeated at the end of the school year after the students had carried out a series of investigations linked to the research project.

Fourteen aspects of investigating were identified within the broad themes of focussing and planning, information gathering, processing and interpreting and reporting. The expected sophistication of the students with regard to their ability at carrying out an investigation was based on the statements at level 6 in the "Developing scientific skills and attitudes" learning strand in the *Draft New Zealand Curriculum Statement in Science* (Ministry of Education, 1992). The aspects were rewritten in language not expected to be difficult for Year 12 students and were trialed with students from another secondary school. The required response for each item was Very confident / Reasonably confident / Not very confident / Not confident at all, scored 4 / 3 / 2 / 1. The average ratings were then ranked.

7.2.1 Students' declared confidence

Seventy four students at City High completed both pre- and post- intervention surveys. Table 7.1 shows the average scores and ranking for the fourteen aspects surveyed and the changes of these from the pre- and post-intervention surveys. The "declared confidence" scales indicated that the students expressed greater confidence with the more mechanical aspects of carrying out an investigation and much less confidence with aspects of an investigation which required analysis and critical thinking. For instance, in the pre-intervention survey, the students indicated highest overall confidence at tasks such as 'taking measurements using appropriate measuring devices' (group mean 3.59) and 'selecting appropriate equipment to carry out an experiment' (group mean 3.34). The were much less confident with aspects such as 'identifying sources of error in their experimental method' (group mean 2.66), 'redesigning experiments when first results are unconvincing' (group mean 2.68) and knowing when it is 'appropriate to apply what' has been 'found out to other situations' (group mean 2.80). Aspects of investigating which they had been doing throughout their secondary school Science courses, such as analysing data (group mean 3.04) and making conclusions (group mean 3.02) gained overall scores in the "reasonably confident' range.

	Pre-score	Post-score	Change in score	Pre-rank	Post-rank	Change in rank
• I can make hypotheses (predictions).	2.93	3.18	+0.25	9	9	0
• I can do an investigation where there is more than one changing factor.	2.91	3.22	+0.31	10	7	+3
• I can make decisions about how many animals or plants to use when I am doing an investigation.	3.15	3.42	+0.27	5=	3	+2
• I can make decisions about how many times to repeat an experiment.	3.18	3.28	+0.10	4	6	-2
• I can select appropriate equipment to carry out an experiment.	3.34	3.20	-0.14	2	8	-6
• I can take measurements using appropriate measuring devices.	3.59	3.61	+0.02	1	1	0
• I can identify the sources of error in my experimental method.	2.66	2.85	+0.19	14	13	+1
• I can present data in an appropriate form.	3.31	3.49	+0.18	3	2	+1
• I can analyse data.	3.04	3.36	+0.32	7	5	+2
• I can make conclusions.	3.02	3.38	+0.36	8	4	+4
• I can justify my conclusions.	2.74	2.92	+0.18	12	11	+1
• I can use appropriate language and layout when presenting what I have found out.	3.15	3.07	-0.08	5=	10	-5
• I can re-design experiments when my first results are unconvincing.	2.68	2.81	+0.13	13	14	-1
• I can say when it is appropriate to apply what I have found out to other situations.	2.80	2.88	+0.08	11	12	-1

Table 7.1: Four classes combined pre- and post-intervention declared confidence scores 1993 (n = 74)

The data from the pre-intervention survey were enriched through discussion of the findings with the students involved, to provide further elaboration of their responses. Three of the four classes were involved in the discussions. The students indicated that they could not remember having to make decisions in the past regarding such aspects as numbers of animals or plants to use, the number of times an experiment could be repeated, and possible sources of error in a method. Rather, they indicated that in experimental work at Form 5 (Year 11) they had usually been following a method which had been given to them by their teacher (Field and diary notes 28/4/93 and 30/4/93).

There had been a major emphasis on Science Fair projects in City High, with preparation of a Science Fair project compulsory for all Form 3 (Year 9)and Form 4 (Year 10) students. A high percentage of the students completing this survey would thus have carried out investigations for Science Fair projects. However, Science Fair work as part of their science programme was not raised by the students until questioned about it by the researcher (Field and Diary notes, 30/4/93). The students indicated to the researcher that Science Fair work was much more demanding than classroom practical work, for example:

> *In a Science Fair project you are doing much more thinking for yourself. You are not getting fed information from the teachers on what the results should be. You are actually getting your own results and making decisions for yourself.*
> Year 12 student Field notes April 1993

After two terms of Year 12 Biology which included practical work which was exploratory, confirmatory and investigatory in nature (Woolnough and Allsop, 1985) the students were again asked to complete the identical confidence survey. The overall confidence of the seventy four students who completed both the pre- and post-intervention surveys was calculated and compared. A paired t-value test indicated a significantly different increase in the mean confidence for the pre- and post-intervention survey (DF 13; two -tail p = .0018). The students were declaring a greater confidence with respect to investigating after two terms of involvement in such activity.

However, such global statistical analysis masks notable changes of confidence on certain aspects but not on others. The students' declared confidence scores indicated a clear increase in confidence for aspects such as controlling factors, making hypotheses, increasing reliability of gathered data, analysing data and reaching conclusions. A smaller increase in confidence was declared for aspects such as identifying sources of error, presentation of data in an appropriate form, redesigning experiments when the first results were unconvincing, for making decisions regarding replication of experiments, justifying conclusions and application of findings to other situations. Their declared confidence scores indicated a clear lessening of confidence with regard to selecting appropriate equipment and using appropriate language when reporting. There was a minimal increase in the declared confidence score related to use of appropriate measurement devices.

The ranking of the various aspects of the investigative process also changed with greatest changes occurring for selection of appropriate equipment and use of appropriate language when reporting, with changes of -6 and -5 places (out of a possible 14) respectively. The two aspects which moved positively in the ranking related to controlling variables (+3) and making conclusions (+4).

These shifts in confidence were also indicated through an analysis of the percentages of students who declared increased confidence, the same level of confidence or a drop in confidence on each of the aspects of carrying out of an investigation - see Table 7.2. With three exceptions at least 50% of the students who were surveyed maintained their level of confidence with respect to the fourteen aspects of investigation. The three exceptions related to replication (47%), selection of appropriate equipment (49%) and making conclusions (46%). For making conclusions 44.5% declared an increase in confidence and for the other two students declared an increase in confidence (31% and 20% respectively) or a decrease in confidence (22% and 31% respectively). There were only two aspects where a greater percentage of students declared a loss in confidence than a gain. These aspects were the selection of equipment and the application of findings to new situations. For the aspect 'I can use appropriate language and layout when presenting what I have found out' the number reporting increased confidence almost matched that of those reporting a lesser confidence (22% and 24% respectively).

	% students increasing confidence	% students maintaining level of confidence	% students dropping in confidence
• I can make hypotheses (predictions).	30	63.5	6.5
• I can do an investigation where there is more than one changing factor.	30	58	12
• I can make decisions about how many animals or plants to use when I am doing an investigation.	34	57	9
• I can make decisions about how many times to repeat an experiment.	31	47	22
• I can select appropriate equipment to carry out an experiment.	20	49	31
• I can take measurements using appropriate measuring devices.	19	62	19
• I can identify the sources of error in my experimental method.	28	65	7
• I can present data in an appropriate form.	27	51	22
• I can analyse data.	40.5	53	6.5
• I can make conclusions.	44.5	46	7.5
• I can justify my conclusions.	34	50	16
• I can use appropriate language and layout when presenting what I have found out.	22	54	24
• I can re-design experiments when my first results are unconvincing.	28	56	16
• I can say when it is appropriate to apply what I have found out to other situations.	18	59	23

Table 7.2: Students' combined percentage change of confidence, 1993 (n = 74)
Note: percentages were converted to nearest whole or half numbers

The student responses on the two confidence surveys have also been analysed to identify the range of change in confidence for individual students. Shifts in confidence across the range from "very confident" to "not confident at all" were recorded for all fourteen aspects and then summed for each individual student. It was possible for a student who had indicated "not confident at all" for all fourteen aspects on the first survey and "very confident" on the second to have recorded a change of +42. However there were no recorded summed changes for an individual outside of the range -10 to + 10.

The mean change for females was +3.2, for males +0.8 and for all students was +2.1. There was thus a small overall lifting of felt confidence within the class, with a greater increase for female students than for male students. However for four individual students there was a notable drop in felt confidence of greater than or equal to 5 points. Students with notable changes in declared confidence (both positive and negative) between the pre- and post-intervention surveys were identified and invited to an interview with the researcher early in 1994.

Not all of the selected students who had large shifts in declared confidence were available for follow-up interview as some had changed schools or left school. In March of 1994 a small sample (n=6) of the 1993 students, now Year 13 students, were asked during a broad-ranging interview for possible reasons for the changes in declared confidence - both that which was noted overall for some students and on particular aspects of investigating for the class in general. These students indicated that they still did not have a great deal of confidence regarding the overall planning of investigations and that they would have liked more help, for example:

> *I reckon we just don't know how to plan ourselves properly, maybe. I reckon that we could get some [help].*
> 93T124 Interview March 1994

These six students were also very concerned to 'get it right' and they indicated that this concern caused them to be somewhat tentative in their approach. Their hesitancy in determining appropriate strategies and their naive understanding of the scientific endeavour is shown, for example, in the following:

> *S: Well, you want your experiments to prove your hypothesis right and I'm doing well. ... Well [its] in the textbook what actually does happen that scientists have proved and your experiments are just reaffirming it. If it proves wrong ... there are [experiments which are not just for reaffirming knowledge] that you can [do] if you want to but the things that we do have happened before .. You want to get it right, what it says in the book.*
> 93T118 Interview March 1994

Later, in the same interview, this student indicated that the students were also trying to please the teacher and that they had found it hard to think for themselves after having had the thinking done for them over the past four years. As one student explained this to me the others in the group were nodding:

From the third form we've ... we never actually think for ourselves and now it comes to the 7th form and all of a sudden we have to think for ourselves. Where do I start?
93T118 Interview March 1994

Not all students agreed that they had been required to think more for themselves during their Year 12 Biology course. In a different interview another student suggested that in Year 12 he had had to think less for himself because the teacher's instructions were more explicitly directive. When questioned further he changed his response to:

It was more, not really think less, just more absorb because there was so much theory to give you [that] there wasn't really enough time for practical examples, it was pretty much straight dictation, you write it down, you go home and learn it as best as possible ...
93T407 Interview March 1994

The difference in these responses may be simply due to differing students' expectations and perceptions but they could also to some extent be reflecting the different teaching styles of the four teachers in the 1993 study.

These six students were also directly asked about those aspects of investigating where the students' felt (declared) confidence regarding the planning, carrying out and reporting of investigations had decreased or increased. Some students attributed the loss of confidence regarding the use of appropriate language and layout to having been given, and required to learn:

... a lot of new words and you feel bombarded with them and you don't know where to use them.
93T124 Interview March 1994

In contrast to this, one of the other students argued that having practice with the use of new vocabulary during the year enabled them to become, as the year went by:

... more technical ... and so we learnt about that, and got more confident as we went along to do with that.
93T318 Interview March 1994

The six students who were interviewed intensely regarding the changes in student confidence over aspects of investigating, also argued that the indicated loss of confidence could have been caused to some extent by their being more realistic at the end of the year than they were at the beginning. For instance one student suggested the following as an explanation for the overall loss of confidence in the use of appropriate equipment:

I think that one would have been because during the year for some experiments the teacher said, "Right, [I've] got the chemicals, got the equipment, come up here, take them, go and do experiments. Then at the end of the year some people thought well the teacher has just given us the stuff. We weren't actually, really, realising what to use.
93T318 Interview March 1994

When asked to comment about those aspects where confidence increased, such as being able to carry out an investigation where there was more than one changing factor, students in both groups interviewed indicated that for them, in their particular class, frequent practice during their Year 12 year with such investigations had increased their confidence, for example:

We learnt more about .. how there are different factors affecting different things and so we ... got more confident as we went along to do with that.
93T318 Interview March 1994

However, although the four teachers planned the courses together and generally carried out a similar amount of practical work during the year one student's memories of his Year 12 year was one which was very theory bound. He indicated the need for a refresher course on designing practical experiments because:

I can't even remember how to write up the aim and the method and the equipment. That sort of stuff. You remember doing it in the third form and the fourth form and barely remember the fifth form but sixth form it just sort of wasn't there. It was just sort of flat out theory.
93T407 Interview March 1994

7.2.2 The teachers' response to this data

The four teachers associated with the research project in 1993 were also asked to identify possible reasons for some of the students' scores regarding confidence about carrying out of an investigation being significantly lower at the end of the year than at the beginning. Three of the teachers in the 1993 study, responding to a questionnaire, identified the following as conceivable causes:

- the students' initial inexperience at completing questionaries, for example:

The pupils, initially, were inexperienced in completing questionnaires of this nature. I feel that their judgment and scoring of their 'confidences' in the first instance was probably a little generous (perhaps to avoid embarrassment, even though it was in confidence).
93T1

- the students' perceptions of their own abilities had become more realistic over the course of the year, for example:

During the course of the programme they became more acutely aware of their own abilities as their experiences of what it was all about increased and their ignorance decreased. Thus in the second questionnaire they may have given a more informed and realistic appraisal of their abilities (having forgotten what they scored in the initial one - so they had become a different 'animal' for the second one. This would result in a smaller increase in confidence that perhaps we might have expected (a decrease even!).
93T1

• the students had realised that not all of their practical work had resulted in successful outcomes, for example:

At the start of the year they had had no (what they consider) failures, that is, experiments usually had an end 'result'. They may feel they 'own' the experiment if they formulate the hypothesis and method but this also means that they have to accept responsibility for their results or non-results.
93T2

• the students were more aware of the difficulties in planning and carrying out an investigation. In one class, the students had completed the survey not long after a particularly difficult investigation and this is reflected in the teacher's comments:

The 'transpiration' experiments were, for the most part, a disaster - mainly due to equipment failures. Therefore no results were recorded. Not a positive note to end the year on - the students filled in the questionnaire not long after this.
93T2

• the students were tired, for example:

For many, it was the end of a difficult year and they were tired.
93T3

7.2.3 The researcher's response to this data

Although the students' overall confidence at carrying out investigations grew during the year their apparent loss of confidence with some aspects points to areas where their teachers may have usefully given more support to their students as they constructed meaning for aspects of the process of investigating. The data could be interpreted to indicate that these teachers could have usefully, and directly, discussed with their students about the processes of scientific inquiry. As well as providing refresher courses on designing experiments, there could have been an emphasis on identification of potential of sources of error, on the value of redesigning experiments when first results are unconvincing, on appropriate presentation of data, on how to justify reached conclusions and how to decide when and how to apply findings to new situations. The students needed, and welcomed, plenty of opportunities to try out their developing understandings about investigating. An acknowledgment to students that experience with a new approach to practical work, with new equipment and with new communication requirements, may be accompanied by an initial loss of confidence may also have been of help to these students as they began to carry out investigations. The students may have needed encouragement to 'keep trying', to keep trying to solve design and equipment problems, and not to worry too much about 'getting it right' all at once.

7.3 Student response to investigative approaches to practical work

The previous section of this chapter has focussed on the students declared confidence with respect to investigating. The following section of this chapter focuses on the students' response to the introduction of this strategy to their Biology programme. Section 7.3 presents the students' perception of the relationship between investigative practical work and learning in Biology; the nature and importance of skill acquisition in open investigative practical work; and the role of the teacher during open investigative practical work.

The data forming the basis of this section of the thesis have been gathered from an end of year survey completed by 75 of the students involved in the 1993 research at the end of 1993 (see Appendix M), from interviews with 10 of the 1993 students when they were in Year 13 in 1994 and from interviews with all of the 1994 students towards the end of Term 2, 1994. Students were interviewed in small groups. These interviews did not follow a formally structured format but during the free-ranging discussions the following aspects of the project were explored:

- the students' preferences regarding open investigations versus investigations where the methodology had been carefully structured for the students by a teacher or text;
- the students' perceptions of the learning outcomes from open investigative practical work;

- ways in which teachers could help students to carry out open investigative practical work more independently;
- the students' understanding of the nature of science;
- how the students perceived learning in science to differ from that of learning in other subjects.

Data were also gathered through the completion of an end of intervention survey by 25 of the 1994 students at the end of Term 2, 1994 (see Appendix M) and from classroom observations by the researcher during 1993 and 1994 as recorded in the researcher's field notes.

7.3.1 Student perceptions of the relationship between investigative practical work and learning in Biology

The 1993 and 1994 student cohorts both indicated a positive relationship between engagement in investigative practical work and their learning in Biology. The responses which form the basis of this data analysis were generated from differently phrased questions. This arose because the questioning in the second year was deliberately more focussed on investigating rather than practical work in general. The responses from the students in each of the two years will therefore be treated separately before general findings are discussed.

The 1993 students' responses

In 1993 seventy five students from four classes responded to the question "How do you think doing practical work helps your learning in Biology?" Their responses can be divided into three major categories. The three response categories refer to cognitive aspects of studying Biology, to skill acquisition and to affective aspects of involvement. The frequency of these responses is summarised in Table 7.3.

Cognitive aspects of Biology	**% res**	**Skill acquisition.**	**% res**	**Affective aspects**	**% res**
• concept development	55	• scientific process understanding	27	• enjoyment	12
• visualisation of learning	41	• application of learned skills	9	• relevance	7
• personalisation of learning	32	• manipulative skill acquisition,	7	• confidence/ increased personal involvement	5
• nature of scientific enquiry	9			• realism	1

Table 7.3: Categorisation of responses to the 1993 survey question "How do you think doing practical work helps your learning in Biology?" showing percentage of students giving related response

The responses relating to cognitive aspects of studying Biology included emphasises on concept development as demonstrated by responses referring to 'understanding' and 'remembering', for example:

> *[Practical work] helps you to understand complex ideas which would be hard to grip if you were just reading from a text book. It also gives you a first hand view of the processes which happen in our world.*
> 93T11 End of year survey 1993

> *You remember more if you have done it yourself. Much more effective learning than just writing.*
> 93T204 End of year survey 1993

Visualisation responses indicated that the students valued personal involvement in events and that such involvement enabled learning, especially where remembered episodes were unusual (White, 1988). Many of these responses used a phrase such as 'helps understanding by seeing', for example:

> *[Practical work] helps understanding by seeing or witnessing what you have read in test books. It helps you to develop ideas and thoughts.*
> 93T203 End of year survey 1993

Responses relating to personalisation of learning were those where the students referred to being personally engaged in their learning, for example:

> *Practical work gives you a better understanding of the subject as it gets you involved with what is going on. It makes the subject easier to relate to.*
> 93T117 End of year survey 1993

Responses relating to the nature of scientific enquiry included a reference to an improved understanding of scientific enquiry processes, for example:

> *[Practical work] enables you to see for yourself how an experiment or investigation is carried out instead of just reading a book in class.*
> 93T101 End of year survey 1993

The students' responses to the question "How do you think doing practical work helps your learning in Biology?" also included some with an emphasis on skill acquisition. Some responses highlighted manipulative skill acquisition and an understanding of scientific processes, for example:

> *It makes you draw conclusions, helps you to understand your mistakes and create new experiments. You also learn to make hypotheses.*
> 93T210 End of year survey 1993

Other responses referred to the application of learned skills. Students often linked this to the repetition of all, or aspects of, an investigation, for example:

> *[Even] if the practical doesn't work out, I believe students will learn greatly, as more is learnt through perfecting a practical and carrying it out as opposed to [reading] a perfect solution given in a text book.*
> 93T222 End of year survey 1993

The students' responses to the question "How do you think doing practical work helps your learning in Biology?" also included some with an emphasis on affective aspects of learning, such as personal enjoyment, an appreciation of the relevance of studies in Biology an indication of appreciation of personal involvement, and a gain in confidence, for example:

> *Instead of sitting and listening to what's being read from a book, in practicals you learn to apply it and find it out by yourself, learning what to do and it is a lot more interesting.*
> 93T323 End of year survey 1993

There were no totally negative responses though one student did qualify her initial statement:

> *It helps understanding, but only if at the end of the experiment the correct results and set up of the experiment are given so that there is no confusion.*
> 93T110 End of year survey 1993

Another student mentioned the tedium of the perceived annual repetition of practical work such as testing leaves for starch, firstly in the third form, then in the fifth form and, 'hopefully finally', again in the sixth form.

It was apparent that the majority of the seventy-five students who completed the end of year survey in 1993 indicated a positive response to practical work in Biology. They perceived that engagement in practical work had increased their learning in the cognitive, skill and affective domains.

The 1994 students' responses

At the end of 1994 twenty-five students responded to differently phrased questions highlighting *investigative* practical work and conceptual development. The analysis and discussion of their responses has been separated from that of the 1993 students because the questions asked were phrased to emphasise investigative practical work rather than general practical work. The students were asked to indicate if they thought that doing *investigative* practical work in Biology helped them to learn the concepts (ideas) of Biology. They were also asked to explain their response.

The majority of the twenty-five responses were positive with only one student indicating negatively and three producing qualified positive, "Yes, but", responses. The positive responses could be grouped (in descending order of frequency of mention) as responses relating to procedural conceptualisation, responses referring to the visualisation of biological concepts, responses which refer to increased understanding of scientific concepts through personal involvement and responses which emphasised the improved learning of concepts through increased thinking.

Responses relating to procedural conceptualisation were given by twenty-eight percent of the students. These responses indicated that the students believed that participation in investigative practical work had increased their understanding of the processes of scientific inquiry, for example:

> *Practical work showed us the concepts of experimental design and practical applications.*
> 9427 End of year survey 1994

> *Yes, it taught me about having controls and changing factors.*
> 9406 End of intervention survey 1994

Responses referring to the visualisation of biological concepts were given by twenty percent of the students. Such responses indicated that the students believed that involvement in investigative practical work had increased their understanding of biological concepts through 'seeing Biology in action', for example:

> *Easier to understand theories when you see it happening in front of you.*
> 9432 End of intervention survey 1994

> *Yes by doing practical work we can see how things work so we understand them more.*
> 9403 End of intervention survey 1994

> *It gave us an insight as to what the text actually meant.*
> 9430 End of intervention survey 1994

Twelve percent of the responses referred to the enhancement of conceptual understanding which comes through personal involvement, for example:

> *Yes, because you were involved in the work, not just reading it, you had to use terms and concepts to do the experiments.*
> 9409 End of intervention survey 1994

> *Yes, it made me aware of biological factors and how things work.*
> 9408 End of intervention survey 1994

> *Yes, it gave a better understanding of why reactions do/don't happen.*
> 9410 End of intervention survey 1994

Eight percent of the students indicated that their personal involvement in investigative practical work enhanced their learning because they were more actively thinking about what they were doing, for example:

> *Doing things for yourself makes you think about it more.*
> 9423 End of intervention survey 1994

> *Yes, ...as I had to think more for myself instead of having a set task.*
> 9418 End of intervention survey 1994

The possibility of a student's increased metacognitive awareness during investigative practical work was emphasised by one 1994 student who sought out the researcher during an other-structured practical session which she did not really understand. The class were working through a practical designed to demonstrate the process of absorption in the gut. They had achieved a useful and accurate set of results but their analysis of their observations was limited as they appeared not to really understand why they were following the procedure which had been set down (Field notes, 21/7/94). This student said to me:

> *Mrs Haigh, if I haven't thought about it beforehand I don't learn anything.*
> 9428 Field notes 21/7/94

She confirmed this statement during an interview when she said (as a follow on to another student's comment about problem solving being better because 'you find out for yourself'):

> *Its not so boring and you've got to think, and when you think you know exactly what you are doing because it is in your head. You know you have made the idea up, you are working it out for yourself rather than just doing what someone has told you to.*
> 9428 Interview 8/8/94

The heartfelt emotion in her voice as recorded on the audio tape indicated that this student felt very strongly about the benefits of this type of practical work.

It is interesting to note that only one student who responded to the end of year 1994 survey suggested that he was gaining a better understanding of the nature of scientific enquiry through his personal involvement with practical investigations:

> *Science is very exact and any little change in an experiment could have a big impact on the results.*
> 9425 End of intervention survey 1994

The low frequency of this type of response was emphasised by the students' responses in interviews with the researcher. During these group interviews with the researcher at the end of 1994 the majority of these Year 12 students provided a list of topics when asked what science is. However, when probed, a few demonstrated that they may have been searching for a deeper understanding of the differences between the subjects that they were studying with comments such as:

> *[Science] is more to do with theory. There's a lot of things in science that we are not very sure of especially physics, things like English, its all set out but science isn't .....Its based on what people have thought, their own opinions ..... whereas History and Social Studies, that's all fact.*
> 9411 Interview

> *[Science is] more establishing a problem and trying to ... going about ... to solve it. In other subjects you are just learning straight from the thing and not seeing how its done.*
> 9425 Interview

The low response level of comment referring to the nature of science may have resulted from a lack of direct teaching in this regard. The researcher did not observe any teaching which directly addressed the nature of the science scientific endeavour but it must be acknowledged that not all of the Biology lessons with any one teacher over one year were observed.

There were 'uncertain' responses to the 1994 end of intervention survey question "How do you think doing investigative practical work helps your learning in Biology?" from twelve percent of the students. These responses appear to reflect the students felt lack of understanding of the topical area in which the investigation was based. One commented, for example:

> *It would have helped if I had had more of an understanding of the topic before conducting the investigations but yes, they helped.*
> 9411 End of intervention survey 1994

A single negative responder was concerned with inconclusive results and a lack of direction. He said:

> *No,* [it hasn't helped me learn Biology] *because sometimes the experiment didn't work, and I don't understand the purpose.*
> 9419 End of intervention survey 1994

In summary, students from both the 1993 and 1994 cohorts produced similar lists when asked to consider the outcomes from their engagement in practical work, whether it was labelled as specifically investigative in nature or not. They perceived that they had learned both declarative and procedural concepts and recognised the value of practical work as a means of both personalising and visualising their learning. A small number of the 1994 students whose focus question had specified investigative practical work rather than practical work in general also noted the impact of such work on their thinking - both in the requirement for an increased engagement in thinking and the learning outcomes related to thinking. These students recognised that they were more metacognitively aware of their own learning.

7.3.2 Student perceptions of the skills and attitudes required for participation in open investigative practical work

As part of the 1994 end of intervention survey, twenty-five students were asked to identify the skills and attitudes that they considered they needed in order to carry out investigative practical work. Their listed skills and attitudes included an understanding of relevant knowledge, science process skills and specific attitudes.

Understanding of relevant knowledge

Forty percent of the students indicated that it was necessary for them to have a knowledge of the relevant background theoretical information, or to be able to access this information. During group interviews the 1994 students had also often expressed a need to have the relevant background information and method of attack clearly identified for them before they began their planning of an investigation. Some wished to be directly told what they needed to know, whilst others felt it could be indicated generally and that they could be expected to take some responsibility for finding out the details. For example, a response from a student who had wanted greater direction:

> *Give us some steps to work through, don't just say find out this. Give us some basic guidelines like, find out what you need, do measurements, blah blah blah.*
> 9411 End of intervention survey 1994

and a response from a student who had recognised that his teacher was giving him cues as to direction without providing all the details:

> [I'm fairly confident about doing practical investigations], *it depends on different experiments, 'cos sometimes you don't quite know what substances to use, you are not quite sure. Sometimes when they ask you to make up an experiment they kind of obliquely put it so that you know exactly what you are looking for and what you are supposed to be testing.*
> 94 student Interview 1/8/94

This student and his working partner also had opinions as to the degree of help that they wanted from their teacher with respect to background information. They did not wish to be told previously explained information again, and believed that such information should simply be signalled but that new information should be covered in greater detail:

S1 *Yeah, what you should do is that the background knowledge that we should know should not be in the outline of what we are doing, because we already know that, stuff like that,*

S2 *The new stuff should be explained. We should be asked to call up our background knowledge.*
94 students Interview 1/8/94

Required process skills

In addition to acknowledging that recognition, or knowledge, of related theory was essential to their success at investigating, eighty-four percent of the students identified at least one scientific inquiry process skill as essential for carrying out open investigative practical work. The process skills which the students identified included thinking; an ability to recognise the problem; an ability to measure accurately; a knowledge of specific biological tests such as the Benedict's test for reducing sugars; and the ability to recognise appropriate equipment and to follow instructions.

Necessary attitudes

Sixty-four percent of the students listed at least one attitude which was necessary for successful investigating. Attitudes which the students listed included confidence, accuracy, patience, carefulness, being sensible, being positive, showing interest, working co-operatively, being open minded, being logical, being analytical, consistency, flexibility, persistence, willingness, determination and fairness. They also mentioned being prepared for failure. Open-mindedness (mentioned by twenty percent of the students), and care with techniques (patience, care and accuracy, for example, received a 32% response) were referred to most often. Statements included:

> *You need to be sensible, interested, patient, competent and co-operative in working with other people.*
> 9424 End of intervention survey 1994

> *You need a positive attitude, that things will eventually work, and as long as you are prepared to do a lot of thinking for yourself you should be all right.*
> 9423 End of intervention survey 1994

The students also identified that doing investigative practical work in biology during 1994 had helped them to develop these skills. The two students quoted above said:

... I had to co-operate with the people I was experimenting with. I needed patience in timing experiments and waiting for reactions to occur. Doing these experiments improved my competency and practical is far more interesting than doing work out of a book.
9424 End of intervention survey 1994

....you understand things better because you are actually thinking about things yourself and working through how things happen.
9423 End of intervention survey 1994

Another student also emphasised how doing open investigative practical work allowed her to think for herself and she recognised the positive outcomes of this approach:

Previously we have not been allowed nor encouraged to think for ourselves - instead [we have been] taught to rely on the teacher's explanation and textbook. So this allowed us to develop skills and attitudes by thinking for ourselves.
9430 End of intervention survey 1994

Other students recognised the positive value of learning from their mistakes and the requirement that they develop new skills:

We learnt from our mistakes so we could make our later investigations better.
9403 End of intervention survey 1994

... we used many different skills that we were unaware about and which we had not used before.
9421 End of intervention survey 1994

There was only one nil response to the question relating to the identification of required skills and attitudes.

In summary, within the group of twenty-five students of the 1994 cohort, there were students who were able to identify the value of a sound knowledge base, an understanding of science process skills and positive scientific attitudes to their learning in an investigative situation. Not all students identified aspects of all three domains. Some of the students' clearly identified a sound theoretical base as a skill that they required to help them investigate. They were thus not making the differentiation between knowledge and skills which is common in curriculum statements. Their belief in the importance of a sound theoretical base is supported by science educators such as Solomon, Duveen and Hall (1994) who state that, since observations are so theory bound, students should be taught the necessary background theory before they engage in an investigation.

The practice and learning of these students' may have been enhanced if they had been encouraged to discuss the theoretical concepts underpinning an investigation, if their teachers had cued scientific inquiry process skills as required and if they had been encouraged to develop attitudes such as open-mindedness, persistence and honesty.

7.3.2 Student perceptions of difficulties encountered during investigations

An indication of the sort of guidance that the students would have liked to have had from their teachers may be gained from their reference to those aspects of investigative work that they found easy or difficult.

When asked, in the 1994 end of intervention survey, about those aspects of investigative practical work that they had found "easy" and 'difficult', only twenty percent of the students who completed the questionnaire indicated that they had found all aspects of investigating easy, including planning. Thirty-six percent of the students indicated that it was easy to carry out the investigation once the planning stage had been completed. There was a low level 'easy' response for each of 'drawing conclusions', 'analysing results', 'measurement' and 'organising myself' (4%).

Particular features of the laboratory and lesson organisation were recognised to ease the investigative process for some students. Twelve percent of the students appreciated having necessary equipment easily available and sufficient time to carry out the investigations also eased the exercise for eight percent of students. Eight percent felt that working in groups facilitated their investigating and eight percent recognised the confidence which came from 'having to do it'. Other individual students indicated that they found carrying out of investigations easier as the year progressed and appreciated the similarity of some of the investigations:

> *They got easier as we learnt gradually how to think for ourselves and learned different methods.*
> 9430 survey

Another challenged the question and indicated that perceptions of ease were more related to self assurance:

> *Its not really whether it is easy or not, its whether you feel you are doing it right or not.*
> 9429 survey

There were also some aspects of investigating that the students deemed to be 'difficult'. For a majority of the 1994 students (60%) concerns about 'planning' (including references to framing an hypothesis) headed the list of those aspects of open investigations which they found difficult. A concern regarding their perceived lack of knowledge of required theoretical and process concepts, and required technical skills, was indicated by twenty-five percent of the students. A felt lack of security regarding the choice of the correct techniques was also referred to (4%), as was 'getting the experiments to work' (8%), measuring correctly (8%), writing conclusions, working as a team (4%), working by themselves (4%), and not having sufficient background information (16%).

7.3.3 The students' perceptions of the role of the teacher during open investigative practical work

In addition to indicating which aspects of investigative practical work they found easy or difficult, the students were also asked to identify specific teacher support that they would like to have had when they were investigating. They were asked to identify this at all three phases of the research project (1993, 1994 and 1995). Their responses were varied and sometimes contradictory. They indicated that their teachers could

- help them to identify and source useful background information
- allow them to learn through their mistakes
- leave them to design their own experimental procedures
- provide cues as to required "type" of answer and procedural approaches
- help them to develop investigative skills.

Each of these identified aspects of teacher support will be discussed in turn. Student responses from all three phases (1993 - 1995) of the research project will be drawn on to illustrate the identified aspects.

Helping the students to identify and source useful background information

In 1994, 25 students were asked in a survey to indicate what extra help they would like to have been given when they were doing investigations. The most frequent response, from fifty-two percent of the students, was that they would have liked to have had more of an indication of the area of knowledge that they should tap into when they were carrying out the investigation, for example:

> *[We needed] more background knowledge and a better understanding of how the experiment [related] to our theory work.*
> 9411 End of intervention survey 1994

Allowing students to learn through their mistakes

Although twenty percent of the students still wanted to be given an indication of expected results, or prepared answers, just as many indicated that they did not need much help and some affirmed the value of learning through mistake-making. One student said, for example:

> *We really needed to design experiments ourselves and analyse our mistakes though. It helped immensely.*
> 9427 End of intervention survey 1994

Allowing the students to design their own experimental procedures

At all stages of the research project students acknowledged the value of being left to think their own way through an investigation, to be able to design experiments to help provide answers for themselves. A student interviewed in 1995 explained very carefully that his personal involvement in the development of a method for an investigation had been crucial to his developing a greater depth to his learning. He was responding to another student who had indicated that if the investigation was 'hard' it was better to be given precise instructions, but that to think for himself was better than being given these instructions, with the following:

> *It depends on how hard they are but I think that the better way is to do them individually. It makes you think more, like, if you get a method its easier to follow it. You may get better results but you still won't learn much. Because, like, it makes you think, how to do it so, you know, before you even do the experiment you have to think about the results. What are they going to be? Are they going to be accurate, stuff like that. Yeah, it makes you think. That's about it.*
> Student from school 95S, Interview

Later in this same interview, the students in this 1995 class (95S) were discussing an investigation where their teacher had given them set instructions.

A small number of the students indicated that they had not followed these instructions but had designed their own method, finding this much more rewarding. When questioned regarding their confidence and freedom to do this, a student said:

> *Yes, it was much more fun than following instructions. It can be boring you know [following instructions].*
> Student 95S, Interview

Cueing the required type of answer and procedural approaches

Whilst recognising and valuing their growing confidence and ability with respect to investigating, the students also acknowledged the critical role of their teachers. They indicated that they expected their teachers to provide hints and to make knowledge links for them. One of the 1993 students, interviewed in 1994 when he was studying Year 13 Biology responded to a question regarding the required degree of teacher help with:

> *They can go about things in a roundabout way. Yes, hinting is good. We had some problems [description of some particular open investigations] and it was like that. They told you what to do but you had to take from it what you actually practised and what you saw, what the results determined. You were doing it, but you were told how to go about it but you were actually doing the work for yourself.*
>
> *R: So, one of the things that you would say teachers need to help you with is how to tackle an investigation?*
>
> *Yes, set out, layout and equipment, organise your information and know where to put it apart from that they can just leave it up to you.*
>
> *R: Would you rather do that then have [carefully structured practical work]?*
>
> *Yes. ... Otherwise it gets boring because its just like I have to do this next and I have to do that, whereas you can sit there and say 'I wonder what would happen if I tried this?', 'oh wow!' that happened and note it down.*
> 93T318 Interview

Whilst this student clearly valued some degree of independence, he went on to say that he would also have liked some indication of the 'type of result' he was looking for, to prevent a situation where some students might make quantitative measurements and others qualitative observations. He also indicated that he would have liked some indication of practical procedures and topic related theory before he tackled an investigation.

Helping the students to develop investigative skills

Many students also indicated that their teachers could give them more help regarding the strategies of investigation. Only twenty percent of the 1994 students indicated that they had enough experience and knowledge of investigative procedures to proceed on their own. In interviews the students also pointed to a preferred time for this help. The beginning of the school year was seen as the optimum time for a teacher to introduce information detailing investigative procedures. For some students the end of the year was not regarded as an appropriate time to teach about practical procedures as the students felt that they were unlikely to retain this information at this time due to pressure of remembering copious theoretical facts, for example:

> *Yes, [teach about practical procedures] towards the beginning of the year when you've got the most time because towards the end of the year you're really pressed for studying and you just don't really have a lot of time for practical stuff. If you introduce it near the end, when you're studying for exams, it usually just bounces off you, you don't take it in. ... You're probably in the state of mind that you're just concentrating on certain bits and if you hear something about something else you don't really tune in.*
> 93T318 Interview

Whilst such comments could be interpreted to indicate that this student viewed practical work to be of lesser importance than theory for high grade achievement, the remark signals a time in the school year when this student considered that there was value in teaching investigative procedures.

7.3.4 Overall summary of Section 7.3 findings

In summary, the 1993 and 1994 student cohorts reported a positive link between investigative practical work and learning in Biology. They indicated that being engaged in investigative practical work helped them to learn biological concepts, and helped them to remember biological knowledge as they were seeing biology in action. A number indicated that it helped them to understand more about the nature of scientific inquiry and scientific processes. It helped their manipulative skill acquisition and through this type of practical work they learnt to apply skills. In addition they found it enjoyable, relevant and realistic and felt that it helped them gain confidence as it increased their personal involvement.

They were clear as to which skills and attitudes helped them to carry out investigative practical work, listing an understanding of relevant knowledge, and an understanding of scientific process skills. They also identified confidence, accuracy, patience, carefulness, being sensible, being logical, being analytical, consistency, flexibility, persistence, willingness, determination, being prepared for failure, and fairness as essential attitudes for success at investigative work. Open-mindedness and care with techniques were mentioned most frequently.

A knowledge of relevant biological concepts and scientific process skills were seen by the students both as necessary for success, and an outcome from engagement in, open investigative practical work. The students perceived the role of the teacher as critical. The teachers could help the students to both construct meaning and to identify relevant past understandings. The teachers could help the students to source useful background knowledge, help them to develop investigative skills and provide some cues as to type of required answer and procedures to follow. However, in general, the students also wanted their teachers to leave them to learn through their mistakes and to allow them to design their own 'experiments'.

7.4 Student preference for open investigations

As well as indicating that participation in open investigative practical work helped their learning in biology, the students indicated a preference for this type of practical work. Students in 1993 and 1994 were asked during end-of-year surveys to indicate their preference for an open investigative approach to their practical Biology programme. The questions asked were differently phrased for each of these years and the generated data have been analysed separately. After the presentation of each of the two years' data, general findings will be discussed.

7.4.1 1993 student preferences for carrying out investigations

Seventy-five 1993 students responded to a question which asked them if they would have liked to have done more investigations similar to two named researcher designed semi-open investigations which they had all carried out.

Fifty-six responded in the affirmative (75%), twelve negatively (16%), four (5%) gave a qualified positive response and three did not answer the question. The students were asked to explain their answer.

The majority of the positive responses were linked to either affective and motivational reasons such as 'interesting', 'enjoyment' or 'fun' (mentioned by 41% of the students who affirmed a wish to carry out additional open investigations), for example:

> *I would have liked to have done more investigations 'cause it make things easy to learn and its a bit of fun at the same time, people will pay more attention to what's going on if its fun.*
> 93T215 End of year survey 1993

Other students recognised the increased personal engagement and the thinking required by the investigations (39%), for example:

> *[Yes, I would like to have done more investigations because] it is quite interesting, not only does it help in our Biology work but it can also help our logical thinking. It is fun.*
> 93T405 End of year survey 1993

> *[Yes, I would like to have done more investigations because] it extends our usual pattern of thinking and it helps us develop problem solving skills.*
> 93T308 End of year survey 1993

> *[Yes, I would like to have done more investigations because] it helps you understand the work and lets you experiment with your own ideas (work it out for yourself) rather than being told exactly what to do.*
> 93T325 End of year survey 1993

Twenty percent signalled that their involvement in such investigations had aided their memory of things biological, for example:

> *[Yes, I would like to have done more investigations because] they were what I call 'Fun learning" and I enjoyed them. I also remember just about everything we did in them.*
> 93T411 End of year survey 1993

> *[Yes, I would like to have done more investigations because]] doing experiments is very worthwhile. To me an experiment is more beneficial than writing because I can physically see results and how they occur. They improve my understanding of the issue.*
> 93T316 End of year survey 1993

> *[Yes, I would like to have done more investigations because] in performing these experiments you learn more than you could from reading out of a textbook.*
> 93T311 End of year survey 1993

Fourteen percent appreciated being able to apply biological knowledge or relate an investigation to the theory they were learning, for example:

[Yes, I would like to have done more investigations because] I enjoyed having to apply my concepts to the experiment and constantly having to think for yourself and apply your theories and practical ability even when it wasn't correct.
93T126 End of year survey 1993

[Yes, I would like to have done more investigations because] they are a lot more interesting and practical than classroom work and give you fundamental ideas on how to carry our investigations which are new to you. Also gives a basic idea of what future jobs may hold in store for you.
93T101 End of year survey 1993

Changes to regular classroom routines were appreciated by four percent of the students, for example:

[Yes, I would like to have done more investigations because] its more fun than copying notes from a book and its easier to understand the concepts involved because you can see how things work.
93T407 End of year survey 1993

[Yes, I would like to have done more investigations because] it meant we didn't get any homework that night and the class time was more fun.
93T102 End of year survey 1993

and another four percent focussed on the challenge and mystery:

[Yes, I would like to have done more investigation because] it is fun finding out what the problem was by ourselves instead of already knowing it before you start the experiment.
93T408 End of year survey 1993

[Yes] I wouldn't have objected to this, as these experiment's answers were never known to us students. It was a bit of an unsolved mystery, which I would liked to have known.
93T222 End of year survey 1993

[Yes, I would like to have done more investigation because] it makes you think about all the possible outcomes you can create. It gives us a challenge!
93T224 End of year survey 1993

There were some affirmative responses with added qualifiers. These responses mentioned that the students sometimes felt that they needed more class time to complete the investigation and also that they needed to know more information to help them reach answers, for example:

Although in the long term we all learned from these experiments it took too long to determine methods and then [convert] this to what we need to know in Biology. So, if there was more time, yes, these experiments would have been beneficial to have more of but taking into consideration the time frame we had this year it was impractical.
93T303 End of year survey 1993

Yes, but I should study the topic first and then do an experiment because all the ideas [for] experiments come from the things that you study.
93T127 End of year survey 1993

Only two of the seventy-five 1993 students rated investigations as boring. Four were concerned that the work disrupted their regular class work and that this was a concern when they were struggling to complete their course work, for example:

> *No! We already have a busy enough work load without more work being pushed upon us.*
> 93T320 End of year survey 1993

> *No. They cut into class and were at times boring as opposed to educational.*
> 93T203 End of year survey 1993

These responses may have been linked to a perception that this work was for the researcher's benefit rather than for them. Five students indicated that the degree of personal difficulty that they had experienced when investigating was sufficient for them to choose to do no more, for example:

> *No. Because it's hard for me to do things or to start an experiment by myself.*
> 93T221 End of year survey 1993

Overall, these students indicated a strong preference for investigative practical work.

7.4.2 1994 student preference for carrying out investigations

At the end of the 1994 year the case study students were interviewed by the researcher in small groups (3 - 6 students at a time) and asked to give a personal rating of their response to this kind of investigating and to explain their ratings.

The 1994 students had mixed responses regarding carrying out their own self-designed investigations compared to following the set instructions of a pre-structured investigation. Whilst recognising that thinking through the investigation increased their personal involvement and learning, they had concerns about 'getting the right answer'. In addition the students indicated that they lacked confidence in the early stages of the year but that practice and time overcame some of their early hesitancy. Their ambivalence comes through clearly in statements such as:

> *If you've got a set recipe then you know that your results should be like this and you know that this is the way you should be doing things, that's the advantage to it. But also the disadvantage is that you don't learn how to set up an experiment for yourself, you don't actually learn how to think logically.*
> 9415 interview

[I don't really like doing experiments] when you have got to make them up. I'm not too good at working out what you need or all that stuff, but once you do its quite good seeing the results.
9406 Interview

and, when discussing how difficult it was to learn how to do open investigative work:

S: It was [difficult] really, we didn't know how to make it up at the start but now we have learnt, you know, about variables and things like that and its OK. ... Just practice.
9408 Interview

At times the response from the student reflected the increased personal input required of the students. When a student was asked by the researcher if she liked to think for herself and to struggle with finding ways to attack an investigation the reply was:

You need to design the experiment yourself, so that you can carry it out, the individual thing, its not something that can be taught collectively. 'Cos if you design an experiment then you design it like, your things, your favourite things, to test, the things you especially like doing, you design it to your strengths, and you get good results.
9427 Interview

An inability to find a persuasive answer to their problem was not seen by all students as a problem and there was a recognition that a lack of clear cut answers was an acceptable outcome from this work, for example:

And now when we do an experiment we are not afraid to not get any results. We sometimes don't get results for our experiments but really that's not so bad. For the other ones you had to get a result for the experiment or you sort of failed the experiment really. Some of these ones it doesn't really matter. Well, it matters but not as much as before.
9428 Interview

However some students expressed concern regarding their insecurity over obtaining the "correct answer". The students' concern in this regard is best demonstrated by the following extract taken from a March, 1994 conversation between the researcher and four of the 1993 students when they had moved on to Year 13. This group of students were recognising that the more advanced Year 13 studies were requiring them to think through tasks, and make decisions for themselves, and that this approach was relatively new in their studies. (Individual students were not identified on the transcript.)

R: Now that's interesting, You've said that twice to me now. Once you said something about getting the right results and now you've said you don't want things to go wrong. .... Can you expand on that a little bit?

S: Well, you want your experiments to prove your hypothesis right ...

R: Do you think all scientists always do experiments which end up proving their hypotheses?

S: No ..... disprove it.

R: Or disprove it?

S: Yeah, well they do lots. When you're in school you just want it to go right.

R: You want it to go right. Who decides what's right?

S: Well, in the textbook. [They tell us] what actually does happen, what scientists have proved and your experiments are just reaffirming it. If it proves wrong ....

R: So experiments are for reaffirming knowledge that somebody else has already got?

S: No, there are things that you can do if you want to, but the things that we do tend to have happened before. You want to get it right, what it says in the book.

R: Why?

S: You want to please the teacher?

S: Yeah that's what we've been doing since 3rd form.

R: Pleasing the teacher?

S: Yeah.

S: And ever since 3rd form we never really had the opportunity to think for ourselves. Everything's already done for us and we just sort of throw it anywhere.

R: What you're saying interests me, so can you think through that again?

S: From 3rd form ... we never actually think for ourselves and now it comes to 7th form and all of a sudden we have to think for ourselves.

S: Where do I start?
Interview, 93 students, March 1994

This conversation is representative of a concern which was expressed by some of the students in both year cohorts. The wish to 'get the right answer' may have arisen from a felt need to please the teacher, it may be prompted by assessment pressures, or perhaps a feeling about the fixed nature of scientific facts. Some of the students had difficulty in accepting that, in an investigative problem solving situation what is required is a conclusion, or a decision, that is well supported by evidence rather than one 'correct' answer.

Overall the students indicated that they found carrying out open investigative work very motivating and that they learnt more when they were engaged in this type of practical work, for example:

S1: I like the stuff that we have been doing with you, doing it all ourselves, 'cos I think that you learn more if you do it all by yourself. 9408

S2: Yes, you learn more 9403

S1: Yes, you learn

S2: Yes, instead of just getting told what will happen or if the teacher says if we do this experiment this will happen, you get to do it. You want to learn about it, find out if you are right or not.

Interview 21/7/94

The frequency of this positive response to investigative practical work was tested by having the 1994 students rate their response to such work on a scale of 1 to 10. A rating of 1 indicated low preference/liking and a rating of 10 high preference/liking. The frequency of the students' responses and a sample of their accompanying statements are indicated in Table 7.4.

Score	Frequency	Sample Related comments
1	1	Because I'm not very good at thinking for myself, if you have to think for yourself you might get it wrong.
2	0	
3	1	Its rather confusing. Some of them are all right when you know the area of work you are concentrating on. When you don't know what to expect and you don't know how to do it its very confusing.
4	0	
5	3	Because some of the time you can do it and some of the time you would like to have the instructions. The textbook ones get pretty repetitive. Its a lot harder to do it yourself, because you don't know what to do and you've got to reason all the things and that's quite hard, I reckon.
6	3	The experiments don't work sometimes.
7	6	Because they're quite fun, but you just need more explanation of it, what you are doing, just the basic knowledge of it. I found them quite boring. I didn't really enjoy them very much but I suppose they helped, they got me thinking a bit more. ... I think its just me. I'm not an experimental type person. I wouldn't give it any higher because I don't like having to plan things on my own. I think maybe its a confidence thing, that you might mess up some where.
8	10	It is better for me to be able to bounce ideas off the teachers because the teachers know what is right.
9	2	Well, I think that as long as you have the background information I think it is really good. Instead of just getting told what will happen, or if the teacher says 'If we do this experiment, this will happen' you get to do it. You want to learn about it, find out if you are right or not
10	2	We didn't know how to make it up at the start, but now we have learnt, you know about variables and things like that and its OK. [I like doing experiments where] I'm not getting told what to do 'cos [being told] doesn't make it very interesting. You can do your own thing, see if its going to work.

Table 7.4: Student responses when asked to rank open investigative practical work from 1 (low preference) to 10 (high preference) [n=28]

Ninety-three percent of the students ranked their involvement in investigative practical work at higher than the mid point of 'five'. This data confirmed the qualitative data which had been gathered from the students and which had indicated a high level acceptance of an investigative approach to practical work by the 1994 student group.

7.5 Key findings from this section of the research

The data which has been discussed in this chapter focussed on the affective domain. The students' confidence with investigating and their response to this type of practical work in their Biology programme has been explored.

The students in the four Biology classes at City High in 1993 declared an overall increased confidence with investigating after experiencing a practical programme which included a number of open investigative tasks. However there was a reported loss of confidence with regard to some aspects of investigating.

Specific findings from the pre- and post-intervention survey data and student comments suggest that the students believed that their confidence regarding investigating could be enhanced if they were given the opportunity to reflect on the process of scientific inquiry and their own practice in this regard; if the making of linkages between prior knowledge and present situations was explicitly encouraged by their teacher; if the teachers acknowledged the value of failure to reach expected outcomes in understanding the processes of science; if their teachers facilitated 'refresher' courses on all aspects of designing, carrying out and reporting on the findings of practical investigations; and if their teachers facilitated whole class discussions regarding the application of the findings of an investigation.

The confidence with which a student approached an investigative task was likely to be strongly influenced by their perception of the difficulty of the task and their personal assessment of their knowledge base, their ability to generate ideas and their ability to carry out scientific inquiry.

The students beginning a study of Biology at Year 12 brought with them the practical skills that they had developed and practised in junior secondary school Science. Much of the practical work at the junior Science level for the City High students had been teacher-directed with students following set instructions. The students attitudes to practical work had also been shaped by their past experiences. If these students were easily to make the transition to open work in Year 12 Biology then the findings indicated that many of the students required confidence boosting guidance regarding what was expected of them, support while they were engaged in open investigations, and feedback regarding their techniques and findings.

The findings from the 1993 phase of the research informed the second and third phases of the research project as the researcher and teachers searched for strategies by which feedback and assistance regarding the process of practical investigation could be given to students. We, the teachers and researcher, were also concerned to identify the means by which students could be encouraged to reflect on the process of investigation. How could students be helped to recognise when they did not have persuasive answers to the set questions and be encouraged to plan again and/or repeat experiments? How could the students' transferral of cognition and manipulative skills from one practical situation to another be increased? Classroom strategies and possible focussing questions for teachers to use were developed during 1994 and used in the teachers' guide material for the 1995 phase of the research.

Aspects of investigating which were identified as being linked with a decreasing student confidence were particularly addressed. Strategies which addressed these areas included discussion as to the nature of scientific inquiry; whole class discussion and planning of an approach to solving a particular "problem"; analysis of "recipe" style investigations from texts, with discussion as to why the planner may have chosen to carry out the investigation in that particular manner; breaking down the investigation into its particular phases and concentrating discussion on one aspect only; whole group listing of possible variables, with identification of the independent and dependent variables and those that need to be kept constant; asking many questions of the students as they carry out their investigations; having students plan an investigation and then compare their's to a given 'method' (text or teacher supplied); asking students to plan their investigations separately and then share their ideas in small groups so that they develop a group plan; having students critically analyse others' plans; having students evaluate their own work on completion of the investigation; and emphasising the benefits of, and encouraging, co-operative learning practices.

A listing of the types of questions that could be asked by the teachers to boost the confidence of students who were working on investigations, was compiled after analysis of the researcher's field notes and during teacher-researcher discussions. The questions referred students to past experiences; helped students to switch into the relevant knowledge base; helped students to decide the approach they will take; helped students to make decisions about the recording of the data; helped students to identify the significance of their observations/gathered data; helped students make decisions regarding the reporting of their findings; helped the students become more precise in their thinking; and encouraged the students to reflect on the overall process of investigating. The questions are listed in fulll in Appendix N.

As well as identifying those aspects of investigating where the students felt confidence was high or not, the data analysis in this chapter focused on the students' general response to the introduction of contextually situated, open investigative practical work to their Biology programmes. In general the students from the 1993 and 1994 cohorts were positive about the introduction of open investigative practical work into their Biology programme. They recognised an increased personal involvement and the majority gave affective/motivational reasons for their greater involvement. Some also acknowledged a greater depth of thinking and an increased understanding and learning of biological concepts arising from this involvement. They valued the opportunity to make their own decisions and to test their own ideas. They recognised that their increased engagement influenced their learning of both declarative and procedural concepts in a positive manner. However, despite these perceived positive outcomes the students were aware that this change in approach could be difficult and demanding for many students and they indicated some ways that teachers could facilitate positive outcomes.

The students in the research project indicated that they would welcome help to identify and source useful background information; that they appreciated teachers who managed and organised the classroom equipment and student dynamics in ways that facilitated their working; that they wanted teachers who allowed them to learn through their own mistakes; that they needed teachers who left them to design their own experimental procedures and who let them test their own ideas, yet who provided cues as to required "type" of answer and procedural approaches and who could help them to develop their investigative skills.

7.6 Summary

This chapter has traced the students' confidence when working in an investigative mode and the students' response to the introduction of open investigations to practical work in Biology. Changing levels of confidence as a result of experience with investigative practical work were noted and strategies for facilitating students' investigative work were introduced. The chapter also presented the students' perception of the relationship between investigative practical work and learning in Biology; the importance of skill acquisition in open investigative practical work; the role of the teacher during open investigative practical work and the students' overall response to this curriculum innovation. The students' definite preference for open investigations compared with following practical work with pre-set instructions was indicated.

Chapters 6 and 7 considered the students' approaches and responses to the introduction of an investigative approach to practical work to a Year 12 Biology programme. A complex interaction of cognitive and affective responses occurred. Chapters 8 - 10 explore this complexity from the teachers' standpoint in order to provide additional information for answering the research questions 2, 3, and 4.

Chapter 8: The teachers' response I: 1993 - 1994 at City High

8.1 Introduction

The phasing in of a new curriculum for a school subject frequently introduces change, both to the subject matter to be covered by students studying that subject and the manner in which it is to be taught. By 1993 the final curriculum document for the teaching of Science in New Zealand schools was close to being published and the draft document for Biology at senior secondary levels in New Zealand was available for comment. Both of these documents placed greater emphasis on students carrying out scientific investigations than had been the case in previous syllabuses and prescriptions. Students were also expected to become more self-directed and metacognitively engaged in their learning.

How did the teachers' respond to this curriculum innovation and how did they value it? Did they see benefit in the proposed changes with respect to student learning? Which aspects of the proposed approach caused particular difficulty for the teachers? Did any of the consequential changes to expected classroom roles and relationships present special challenges to the teachers? Did the City High teachers identify any personal professional development from their involvement in the research project linked to this innovation? This chapter documents the four City High senior Biology teachers' responses to the 1993 and 1994 phases of the research project.

The setting for this phase of the research is described in Section 8.2. The impact of the intervention is discussed in section 8.3 in terms of cognitive and skill gains and affective value. Strategies used by the teachers to maximise their students' learning in this aspect of Biology are explored in section 8.4. Concerns raised regarding the demonstrated ability of students' investigative skill gains in formal examinations are presented in section 8.5. Section 8.6 and 8.7 cover pedagogy and resource related concerns arising from the introduction of partially-open practical investigations and teacher change arising from the introduction of partially-open practical investigations is discussed in section 8.8.

8.2 The context for this phase of the research

The four Biology teachers at City High introduced partially-open investigations into their practical programmes during Term 1 of 1993 and during 1993 they and their students carried out three investigations as part of the formal research project - refer to Section 5.3 page 102. During 1994 one of the teachers (T3) and her students participated in a greatly increased programme of open investigative practical work. (See Chapter 5 and Appendix B for details of the investigations.) Data were gathered as the students and teachers were engaged in these investigations. In addition, data were gathered relating to other aspects of the Biology class work. This included information relating to the regular assessment programme for practical work. A practical project which required the students to plan and carry out experiments to answer contextually placed biological questions formed part of the formal assessment programme in 1993 and during 1994 a series of assessments covered aspects of practical investigation. Questions relating to the planning of investigations were included in the mid-year formal examination.

The data has been analysed to give the teachers' perceptions of the impact of these interventions on their students' learning. The challenges experienced by the teachers as the programme was introduced and assessed are also considered.

8.3 The perceived impact of this intervention

The introduction of a more open and contextual approach to practical work was seen by these four teachers as a very positive innovation. In addition to providing students with the opportunities to practise and develop expertise in essential skills such as numeracy and co-operative skills (Ministry of Education, 1993a), the teachers indicated that there was affective and cognitive gains from having their students engage in open investigative practical work. The teachers' perceptions of essential skill gains, motivational and cognitive values are described next.

8.3.1 Essential skill development arising from an open investigative approach

The four teachers indicated that as their students carried out the investigations they were creative and learning how to work co-operatively (Graves and Graves, 1990), a skill that they indicated was not part of the students' repertoire originally (see section 8.4), for example:

> *It [investigating] allows originality and creativity. Initially individually and then another skill that it develops, which I think is important as well, is the working in groups and communicating and co-ordinating activities in the group.*
> T1 Interview 2/7/93

One of the teachers also noted that as long as the students were given the opportunity to appraise their investigations and to assess what they had done then the students learnt to evaluate their work more honestly and began to think more critically (T1 Interview 2/7/93). Two of the teachers also thought that the students were also learning to take more responsibility for their actions and becoming increasingly independent (T4 Interview 11/8/94, T1 Interview 8/12/94) with consequent improvement in their general behaviour, for example:

> *Even the slow kids, and there are slow kids in that class, are motivated, are working well. They get involved and you know, their whole behaviour at the moment is good. They are clearing up at the end and they are responsible for their actions and I think its partially to do with the feeling that they are contributing.*
> T1 Interview 2/7/93

8.3.2 Perceived affective and motivational value of an open investigative approach

The four teachers indicated that the students were very positive towards practical work when it was presented in the form of investigations, for example:

The motivation as I expected is there, better motivation into getting up and getting started and getting on with something, they get excited about it. I think it's more purposeful, in that they can see that it is something that is allied to real life, so it is worthwhile doing and it's not just for the sake of here's another experiment, this is the double period, we do an experiment sort of thing.
T1 Interview 2/7/93

The introduction of open investigative practical work provided opportunities for the four teachers to give positive feedback and they noted that previously reluctant learners were often the first to become engaged in the task, for example:

Also it gives us far more opportunity to give the pupils a bit of positive reinforcement ... to congratulate them on little things which may not have otherwise arisen. And I have noticed some of the kids in my class who are a bit reluctant getting up and getting started. ... they are now some of the first ones to get on the move, so its lifted them a bit, which has pleased me.
T1 Interview 2/7/93

Some of the ones who have lacked confidence in the past are really excited and contributing.
T4 Field notes 28/5/93

8.3.3 The perceived cognitive gains from an open investigative approach

All four teachers noted that engagement in open investigations required students to think more deeply about the work that they were doing. In addition, the teaching-learning strategies that were employed both encouraged the students to think about the decisions they were making and granted the time for this to happen. This was seen as a very positive outcome of the project and was recognised as a change in her teaching approach by at least one of the teachers (T3). T3 had perceived her students' enjoyment of learning episodes which required thinking, discussion and self-direction as encouragement for her to continue with the project. When asked if she received positive or negative feedback from her students when they were doing [one of the investigations] she replied:

Well, they, I think they really enjoyed it. I think they enjoyed the novelty of being able to sit and discuss. Because they certainly didn't moan and complain and they, you know the days that you were there, the Friday and they were sort of discussing what they would do, they were really keen on the Monday to put it into practice.
Interview 2/7/93

However she was not sure how placing investigations into contextual situations affected the students. She preferred to think that they were more creative in their thinking but she had not put that hypothesis to the test:

> *I don't know. I mean I haven't really assessed that [the gains accruing from placing investigations into contextual situations] either. I suppose again I would like to think that it's given them an element of lateral thinking ability. I haven't tested that.*
> T3 Interview 2/7/93

In comparison, she (T3) had also noticed that when students were carrying out other practical work which required them to follow a series of set instructions they did not engage closely with the task:

> *And they are really likely to go through the text book one never really thinking about any of the things that could have influenced the result ... because they have not really been asked to think about them, or challenged to think about them.*
> T3 Interview 28/7/94

There were other comments from the teachers which indicated that they were recognising their students' increasing cognitive involvement during self-directed practical work. Even though these teachers regularly encouraged their students to think carefully about a question (as for example as noted in T2 Classroom transcript 10/3/93, T1 Field notes 19/3/93, T1 Interview 2/7/93, T4 Field notes 30/4/93) they indicated that these students had largely been 'spoon fed up until the sixth form' (T1 Interview 17/3/93). They therefore found it encouraging to notice their students' flexibility of thinking when they were planning and carrying out self designed investigations. They were 'heartened' to observe that the students were able to make changes to their original plans during the course of an experiment (T4 Interview 2/7/93). They observed that when their students were working in this mode they were not so easily defeated if they obtained unexpected results or if the chosen equipment proved to be inappropriate for the task, for example:

> *... there is not so much sitting down and just saying its not working. ... they are actually thinking of other ways to make things happen. Because they start off singly and then they pool their ideas, everybody has their own ideas, they own the ideas and therefore they work on them better.*
> T2 Interview 2/7/93

Overall, although there were some perceived negative indications related to the additional class time required for thinking, T3 in particular acknowledged that if educators want 'thinking people, and scientists should be thinking people' then educators should include more situations in Year 12 Biology classes which require students to think and to test their ideas (T3 Interview 2/7/93). There was an acceptance that students were going to need to be able to think, to associate ideas, in their future lives and that a teaching approach which included open investigative practical work was going to help their students to learn to do this (T3 Interview 1/12/94).

The perceived positive gains from encouraging deeper student thinking during practical work had a spin off into their teaching of more theoretical aspects of Biology. By December 1994, T3 had acknowledged that she was also encouraging increased student cognitive engagement during her theory teaching. After indicating that she was using far fewer prepared notes ("I haven't been as conscious of using piles of overhead transparencies that I used in the past.") she described her increasingly questioning teaching approach:

> *... Some reading in the text and then some discussion of the text and then [some] minutes to answer some questions and then discuss those and sort of , why did you write that answer? What were you thinking about when you wrote that? Because nobody else in this room has come up with that sort of answer. And it makes all of them then think about maybe a different aspect of this problem, that they haven't considered before.*
> T3 Interview 1/12/94

As a result of her involvement in the research project, T1 also indicated that she now had a different understanding of her students' thinking and that this had brought about a change in her teaching. She noted that she was now:

> *more aware that pupils may not be thinking what I think they are thinking - I am now more rigorous in my questioning in pursuit of details and accuracy of responses.*
> T1 Notes December 1993 (her emphases)

This increase in thinking and personal involvement was seen by the teachers to be linked with gains in both declarative and procedural conceptual understanding. Although the research project did not include carefully controlled pre- and post-intervention matched group testing for gains in understanding of biological concepts and processes, these four experienced teachers considered that their students had improved their understanding of both the processes of science and biological concepts as a result of their involvement in the project. In response to a question regarding her students' learning of biological concepts, Teacher 3 indicated that this had improved as a result of carrying out open investigations:

> *Well, I think that has been a spin off as well, because having gone through the mental exercise of thinking about the problem, they must have used past information, background knowledge. They must have relied upon some past information in order to go through the process of analysing the problem and working out a way of dealing with it. It would have required them to use what information they had.*
>
> *... and the more they think about it and discuss it, the better they in fact understand it. In fact I'm convinced that if you can sort of verbalise an idea, you actually understand it better than if you keep it to yourself.*
> T3 Interview 1/12/94

Two other teachers (T2 and T4) also perceived that their students general biological understanding had improved as a result of a more open investigative approach. The gain in understanding of both procedural and theoretical knowledge and the linked nature of this learning was indicated by T4 during 1993 (Interview 2/7/93) and again in her response to the 1995 trial where she listed specific curriculum knowledge as one of the cognitive outcomes of this type of practical work (T4 Questionnaire 1995). T2 suggested that the contextualisation of the problems helped the students to make the links between the practical and the theoretical and thus strengthened the learning (T2 Interview 2/7/93).

However the greatest cognitive gain as perceived by the teachers seemed to be the increase in the students' problem solving abilities. As noted above the teachers indicated, during interviews with the researcher, their students' growing understanding of the processes of science as they engaged in the project's investigations. This learning appeared to the teachers to be carried by the students into the following year and applied when they were carrying out their individual animal and plant studies. For example, T1, commenting on her Form 7 students' investigative ability the year following the initial Year 12 intervention stated that:

> *I really feel that most of them were able to start more confidently and get on with it.*
> T1 Interview 8/12/94

This perception was reiterated by T3 who noted at the end of 1994 that:

> *The quality of [Form 7 individual plant and animal] work was far superior to anything we've had before.*
> T3 Interview 1/12/94

A similar improvement was also noted by T3 at the end of 1995 (T3 Interview 12/12/95) and T4, who commented in May of 1995 that she had found her 1994 Form 7 students were able to make a quicker start and sounder effort in their Form 7 individual plant and animal studies.

Another valued learning related outcome, which was understood by one of the teachers to flow from this approach to practical work, was the increased awareness that the students had of their own knowledge base. When students were designing their own investigations they became more aware of the considerable knowledge they already had regarding an issue or topic (T3 Interview 1/12/94).

Another gain that these four teachers noted for the students was an increase in student engagement with a task when they were investigating. This greater engagement was perceived to enable better learning in situations which may be seen as presenting problems for learners. Such an instance could be the multiplicity of learning outcomes which can happen when students are carrying out open investigations. This occurrence was not seen by the teachers as negating the intended outcomes from a learning episode. Instead, by their very nature multiplicity of outcomes was perceived as encouraging deeper understanding of procedural and theoretical concepts, for example:

> *I don't think unwanted outcomes are a disadvantage at all. They actually help with the process of learning how to do investigative work. ... I can't see why its a problem because a discussion period at the end of the investigation should resolve a lot of those questions.*
> T3 Interview 1/12/94

8.4 Supporting students as they are investigating

For maximum cognitive gain the teachers reported that they had to scaffold the students' efforts. They had to constantly reassure their students regarding the path they were following. They had to cue students to make appropriate connections between past knowledge and current experience. They found it necessary to stage the introduction of openness. They had to encourage precision of measuring and reporting. Each of these is discussed in turn.

8.4.1 Reassurance and encouragement

The teachers thought that cognitive gains for students did not come easily or without the constant encouragement and reassurance from the teachers. The teachers had to teach the students how to design their investigations (T1 Field notes 12/3/93, T3 Interview 28/7/94, T3 Classroom transcript 28/7/94; T4 Interview 11/8/94). Two teachers explicitly stated that they had to teach students how to identify and manipulate variables (T3 Interview 1/12/94, T4 Interview 12/3/93, 2/7/93 and 12/3/94). One teacher noted that her students had difficulty in anticipating experimental outcomes (T3 Interview 2/7/93) and/or were not able to identify the significance of the data they had gathered (T3 Interview 28/8/94). Another noted that the students possessed a poorly developed critical skill, often writing down meaningless and nonsensical results without questioning them (T2 Interview 2/7/93).

One teacher also found it necessary to reassure students of the similarity of this work to that gone before (T4 Interview 2/7/93). Two found it necessary to insist that the students critically evaluated their results (T3 Classroom transcript 20/6/94; T4 Interview 11/8/94). Two also noted the positive value of feedback to the students once the investigation was completed, for example:

> *I think my lesson plus your lesson* [researcher feedback session] *was a great learning experience for them, because if we had given them the recipe from the book there and simply done that experiment and handed out the mortars and pestles and sand, I honestly feel they would have gone through the motions of the experiment, got the results and two days later there would probably be very little of what we had done left in their heads. But I bet you if we went back to test that little situation they would probably remember quite well.*
> T1 Interview 2/7/93

> *And the feedback to them was valuable because even though they are learning by problem solving, they need to know they've been on the right track and ... they've done a good method.*
> T4 Interview 2/7/93

8.4.2 Cueing connections for students

The teachers often found themselves having to cue students so that they would make appropriate connections between past knowledge and experiences and the current situation. This comment was frequently commented on by Teacher 3 (T3 Interviews 2/7/93, 28/7/94 1/12/94). The issue of transferability of knowledge from one learning situation to another was raised by the teachers often over the two years of the project at City High. They noted an apparently poor transference of information from theory to practical situations and from one practical situation to another, and thus accepted the need to trigger their students' memories, and were actively encouraging this connection making in their classrooms. Examples of such cueing were found in interview transcripts (for example, T1 2/7/93; T2 2/7/93 and 8/12/94; T3 2/7/93 and 1/12/94; T4 2/7/93 and 11/8/94) classroom transcripts (for example T2 10/3/93) field notes (for example, T2 17/3/93 and 2/6/93) and the researcher's diary notes. Expressing amazement that working within an investigative or problem-solving mode appeared to be like learning a new language for her sixth formers, T3 indicated that she had thought that much of the required knowledge would be so basic and fundamental it wouldn't be strange to her students. That it appeared to be so made her think about the teaching and learning in her other classes as well as the research linked class and to question whether all knowledge was similarly pigeonholed:

> *Is everything so compartmentalised? It's literally period by period learning, where you just don't transport anything. And it alarms me especially with maths* [when Biology requires mathematical process knowledge].
> T3 Interview 2/7/93

The teachers had noted their students' low level use of previous learning during regular practical work as well as during investigative sessions, and suggested that making connections between theory and practical was even more poorly done if the students were not engaged in decision making regarding the methodology of the investigation. Discussing her students poor practical work strategies when following a set-instruction practical which did not give the students clear, nor easily understood results, T3 explained that:

They didn't know what they were doing ... or why they were doing the testing. [They] really hadn't put two and two together at all. And it wasn't until they were actually questioned about it that it was quite clear that none of them had actually figured out what was going on. ... The theory had been covered, but they hadn't assimilated it. And they hadn't made any connection between what they had learnt, or what they had written some notes about and what this investigation was all about. It's quite weird. And the theory had been covered on the previous lesson, that particular bit of theory. ... It would have been better if they had been asked to design a way of testing what your intestines do to starch.
T3 Interview 28/7/94

Field notes taken by the researcher on that day (21/7/94) also point to the students' early confusion and the difficulty that they had in understanding either why they were carrying out the practical exercise in given way or the significance of the observed results. The majority of the students did not link this enzyme related practical exercise with the theory of enzymes structure and function they had recently been studying.

There was a tension experienced by the teachers between giving cues to students and their wish that the students would be creative in their approach, for example:

I think the idea really is to get them to think for themselves. Because if you spoon feed, you say you are going to need five test tubes and ten beakers, what are we doing it for?
T3 Interview 2/7/93

I try to keep direct information to a minimum. Often they will ask me a question and I simply look at them and they will then come up with the answer. And I say, good, away you go. So they have thought of it. But I think it's maybe a confidence thing, in some cases. ... I think the whole system would fall apart if we gave them too many cues and made it too, it would just become teacher directed again, wouldn't it?
T1 Interview 2/7/93

Some judicious cueing however was seen as a means of increasing students' creativity since a lack of understanding of suitable practical techniques may have been limiting the students' ideas during the planning stages of an investigation (T4 Interview 11/8/94).

8.4.3 Staging the introduction of openness

All the teachers found it necessary to stage the introduction of the openness, giving students increasing freedom of choice as their understanding of scientific procedures increased and cueing the students less as they progressed through the year (T1 Interview 2/7/93, T2 Interview 2/7/93, T3

Interview 1/12/94, T4 Interview 2/7/93; teachers and researcher at a departmental meeting 8/10/93). T4 noted her students' increasing confidence regarding their ability to make design decisions that developed when students were required to make these decisions for themselves:

> *T4: I've noticed that they don't ask me [what to do next] any more. Occasionally they will say to me, this is what we want to do, do you think we've got it right, do you think we are following the right method? Or I want to measure it, what is the best measuring thing? And usually I won't tell them, I'll suggest that, well you've got this and you've got this, and you've got this, how accurate do you want to be? So they have to figure it out for themselves.*
>
> *R: So the ... ownership of the problem ... has made them more independent of you?*
>
> *T4: Imm. Most of them. I wouldn't say everybody, all the time, but most of them all the time, there's a bit more confidence.*
> Interview 11/8/94

The teachers here were noting that the students' dependence on them decreased as the students had more experience with the investigative approach. They were acknowledging the value of a considerable amount of scaffolding of students (Ninio and Bruner, 1978) in the early stages of the year and a diminishing requirement for this as the year progressed.

8.4.4 Encouraging precision of measurement and reporting

Related to both cueing and the staged introduction of openness was the necessity to remind students of the need for taking precise measurements when they were gathering data. T4, in particular, perhaps from her long association with the Science Fair movement was very aware of the requirement for precision and that students frequently did not plan for quantifiable data and therefore needed encouragement to do so (T4 Interview 12/3/93; T4 Field notes 28/5/93; T4 Interview 2/7/93). Another noted that her students had become increasingly aware of the requirement for measurement precision as the research project proceeded:

> *I think they are much more precise about what they are going to do about [the independent variable]. They realise now that when they say a little or a lot, they've actually got to do some measuring. So they have started to think about that.*
> T2 Interview 2/7/93

A closely related issue concerns precision of student's verbal and written responses. One teacher noted that as a result of being involved in the research project she now:

> *... aim[s] to help pupils express themselves more clearly and accurately - both orally and in writing, as I realise that, when left to their own devices, their descriptions are often vague and lacking in details.*
> T1 Notes December 1993

8.5 A cautionary note regarding cognitive gains

The four teachers did sound a cautionary note regarding the student's learning of procedural concepts. They believed that their students' better understanding of investigative procedures did not necessarily show up in the 1993 or 1994 mid-year examination results. Although the teachers did not carry out any statistical testing, it was their belief that students from research linked classes were not gaining significantly higher marks, in the sections of the examination most closely related to the investigative work being done during the research, than the students who were not linked to the research (T2 and T4 as reported in T4 Interview 2/7/93; T4 Interview 11/8/94). However, the teachers had not restricted their teaching of investigative approaches to the research linked classes and thus no conclusions can be drawn from these reflections. It is possible that this lack of improved procedural ability as demonstrated by the students in the examination was linked to the students' poor transference of knowledge and skills and to there not being two distinct groups (experimental and control). All four of the teachers queried their students' ability to transfer knowledge and skills to a new situation, for example:

> *I think [transference of knowledge] varies according to the student. From the work I've observed I think that some kids will bring, will actually relate what they are doing to things they have done previously and others won't at all.*
> T3 Interview 2/7/93

The requirements of the examination for individual response when planning and the need for a quick response may also have impacted on the students' results. The examination format gave students a limited amount of time to complete the planning exercise session during the examination.

Five percent only of the examination marks were linked to the planning task thus approximately 10 minutes only were available to the students to complete their planning. In addition individual responses were required. Thus the students' first ideas were more likely to be presented since they were unable to be tested through discussion with others or pre-trialed and refined.

In summary, the teachers who worked with students carrying out investigations in 1993 and 1993 indicated that they perceived the key outcomes for their students were essential skill development and that there were affective and cognitive gains from open investigative work. In order to maximise the learning of their students they found that they needed to offer reassurance and encouragement, to cue connections between theoretical and procedural knowledge, to stage the introduction of openness and to encourage their students to become more precise when measuring and reporting. They also indicated some difficulties with the introduction of such a programme. These aspects will be considered in following sections of this chapter.

8.6 Pedagogy related concerns

Although the four teachers were generally very positive about the introduction of increasing openness into their Year 12 Biology practical programme, they did express some concerns which were both pedagogy and resource related. The pedagogical issues were primarily student and assessment focused. In addition, there was some concern for less experienced teachers being required to use this teaching strategy. The frequently mentioned resource issues were time and equipment related. Each of these concerns is discussed in turn.

8.6.1 Concerns for students who did not succeed when they were carrying out open investigations

All four teachers were, firstly, concerned about some students' inability to succeed in a less structured environment. This concern was evident from discussions with the teachers both at the start of the project (T4 Field notes 13/3/93) and at the end of the two year's of involvement, for example:

> *Pupils using these open ended experiments who do not do well, their confidence begins to be eroded, and then they regress and they lack initiative and ask repeatedly for help ... they'll actually go backwards because they lose any confidence they had, because they are exposed so much more in this type of experiment.*
> T1 Interview 8/12/94

The possibility that more able students are better able to work in an open manner was suggested, for example:

> *I feel that it's a method that actually works better with more able pupils. I feel that the less able pupils get much of the information from other groups - they are basically incapable of thinking laterally or of engineering something within the time constraints, that they either have to be told by the teacher or given an awful lot of prompting by the teacher. ... At least they are doing something - making progress with the problem. Even if it's looking at another group. It's [difficult to tell what they were learning] because it wasn't clear whether they actually knew what they were doing.*
> T1 Interview 8/12/94

Instances of students who performed 'well' in written examinations but whose problem solving skills were poor and visa versa, were noted. Whilst such disparities raised concerns, the opportunities to comment positively on at least one aspect of learning in Biology that were provided when both content and process were tested was seen as a positive feature of the inclusion of the assessment of practical exercises into their Biology assessment plan.

8.6.2 Concerns for students who do not have sound co-operative learning skills

A second area of concern related to group work. The teachers believed that their students did not bring sound co-operative learning skills with them into Year 12. These students, who had worked in groups formed for the convenient organisation of equipment throughout their science studies, did not appear to these teachers or the researcher (for example, Field notes, 7/4/94) to have adequate co-operative skills to optimise their investigative procedures, for example:

> *Well, that was another thing that ... I have actually thought of as interesting, that the delegation of jobs is not done very well in a group. I mean I remember working in groups doing university work, if you weren't told to do something you just sat and watched and there are lots that fall into that category. They are happy to just sit and do nothing and have somebody else who seems to know what they are doing, take over and that often slows it down.*
> T3 Interview 2/7/93

The teachers noted that often one student would dominate the group and it was observed that this was not necessarily the student with the most appropriate ideas (T3 Interview 2/7/93). One of the teachers admitted that her involvement in the project had forced her to review her understanding of students working in groups (T2 Interview 8/12/94). Previously she had expected her students to work positively and productively when in groups but she had come to realise that this was not always the case and had had to adjust her teaching in this regard, making her requirements much more explicit and not leaving the development of co-operative learning skills to chance (see also section 8.7.1). Students who had had most of their education in Asian countries and were recent immigrants to New Zealand were perceived by one teacher as having particular difficulties both at group formation time and when working within groups (T2 Interview 2/7/93). Teachers 2 and 3, in particular, noted that they had had to consider the size, nature and dynamics of groups and to teach about delegation/sharing of duties and group responsibility (T2 Notes December 94; T3 Interview 2/7/93).

8.6.3 Concerns regarding assessment

The third pedagogical concern of these teachers related to assessment of open investigative practical work at City High during 1993 - 1994. Assessment of investigative practical work presented the teachers in the Biology department at City High with considerable difficulties. They acknowledged that assessment decisions sometimes led to disagreement with other staff members about issues such as the amount and validity of the assessment tasks which had been set (T3 Interview 1/12/94, T4 Interview 11/8/94). In particular, in 1994, there was a concern that too much assessment had been scheduled, that it was repetitive (T1 Interview 8/12/94) and that some of the assessment strategies that had been used were invalid in that they did not measure what had been intended, or that incorrect biological concepts were being accepted as a correct answer if the students' stated procedures were satisfactory (T2 Interview 8/12/94). Possible sources of these assessment concerns were differences in the four teachers' declared attitudes regarding assessment of practical work, the central focus of assessment practices at City High and changes that resulted to assessment practice resulting from the school's involvement in the research project. These will be addressed in turn.

Differences in the teachers' declared attitudes regarding assessment of practical work

A possible source of this concern focussed on assessment could be the teachers' widely differing views regarding the ease of assessing practical problem-solving investigations. When asked at the end of 1994 to respond to a survey statement '[Open investigative practical work] is difficult to assess' the teachers' responses ranged from 'Strongly agree' (T1) to 'Strongly disagree'(T3) (End of intervention survey 1994, see Appendix G for survey structure and Appendix O for details of their responses to other questions in this survey). T1 moved from 'Agree' to 'Strongly agree'; T2 ticked 'Strongly disagree' both pre-intervention and post-intervention; T3 moved from 'Disagree' to Strongly disagree" and T4, who had left the school by the time the post- intervention was administered, disagreed with this statement in the pre-intervention survey. This was the widest disparity of all their responses except for 'It is hard to develop or find suitable problems' which covered the same range. The disparity with respect to aspects of assessment is particularly interesting because assessment of practical work became an issue for these teachers in 1994. They engaged in considerable discussion regarding the assessment of investigative practical work during the year, in particular at the times of common assessment testing and the mid-year examination.

The central focus of assessment practices at City High

Concern about assessment practices were significant for the teachers at City High as they were linked to general school expectations of high standards of student outcomes. The years 1993 to 1994 were also a time of great assessment change in New Zealand education. Questions regarding the assessment of practical Biology skills and the impact of the introduction of a more open approach to Biology practical work were raised throughout the research period. Initial concerns were expressed when the teachers and the researcher met for the first time to discuss and negotiate the intervention in November 1992. At this meeting there was discussion about how the proposed practical approach linked with the project work by which they traditionally assessed their students' practical skills in the middle term. This project work had formed the basis of their practical assessment programme. They were also concerned whether any changes to their programme would require consequential changes to their overall Biology assessment schedule which had been submitted to the New Zealand Qualifications Authority.

Assessment concerns continued to be important over the two years of the research project. In July of 1993, T1 was indicating that she was 'more than happy to have [this approach to practical work] continue' (T1 Interview 2/7/93) as long as it did not upset the assessment programme that the department had in place:

> *You know, because we've got to, we've got to keep a weather eye on how much we are doing and how, to make sure that their assessment programme stays in place. And if we can work it around that, that will be good.*
> T1 Interview 2/7/93

Another major concern repeatedly stated by these teachers was a perceived tension between teaching Biology from an investigative stance and the necessity to prepare their students for internal and external examinations with their greater emphasis on theoretical understanding and recall. This concern was more frequently expressed by two of the teachers (T1 and T2) who referred to this tension throughout the period of their closest involvement in 1993 and again at the end of 1994 when they were interviewed by the researcher, for example:

In an ideal world we would produce scientists and I have got this terrible dilemma, you know, do you produce a scientist who can cope with tertiary education, or do you produce a pupil who gets a great mark in bursary? You know, its a terrible position to be in. It would be lovely to be able to teach everything in an open ended manner.
T1 Interview 2/7/93

T1 raised this dilemma at a departmental meeting in April 1993 in reply to a comment from another teacher that their emphasis on examinations had produced students who were not very creative but instead were 'desperate for the right answers' (T2 Departmental meeting 28/4/93). The other members of the teaching team indicated agreement when challenged with the idea that they appeared to be producing students who could simply pass exams rather than producing scientists.

Overall, assessment requirements, linked with available time, were also frequently mentioned by these teachers as constraints on their freedom to introduce a greater amount of open investigative practical work into their programmes. Acknowledging that students often need time to revisit an investigation these teachers indicated that their teaching schedule was not sufficiently flexible to allow time for students to do this. The lack of flexibility was perceived to be linked both with the demands of an internal assessment programme and school and national examination schedules:

I do less practical work than I used to and I think that is terrible. And that's partly to do with internal assessment. I mark less practical work than I used to. I used to take their books in the whole time. Their books used to be going backwards and forwards. But now you concentrate on things for [assessment] and the kids do it too, and the kids say to you 'Is this going to be assessed.' So that's a real downer I think. Actually the interest has been taken out of biology because now the kids want to know if things are being assessed. And to do the kids justice, you've actually got to do what is being assessed.
T2 Interview 12/3/93

... they felt frustrated I think at the end of both of them [two investigations] because they hadn't got much out of them. And because the exams were coming up I really didn't go back and go over them, with them.
T2 Interview 2/7/93

Several members of the team questioned how well, if at all, the department assessed student's practical skills. In July of the first year of the intervention, one teacher stated that they did not assess the students on their practical skills in the laboratory (T3 Interview 2/7/93), therefore her students' low confidence regarding their practical ability may have arisen from the low frequency of their exposure to practical tests and hence lack of feedback in this regard.

Another teacher carefully detailed during an interview how the specific practical project work was assessed (T4 Interview 12/3/93). Throughout the year this teacher pondered the best means of grouping students for the assessed project work so as to allow every student to participate and thus make it easier for the teacher to assess an individual's contribution and achievement. In an attempt to overcome the problem of individual assessment of students working in a group situation Teacher 4 explained how she had:

> *... muddled them up totally, so that they were working with people that probably they had never worked with before. And initially there was a little bit of [resentment] and they thought, well this is for assessment, we've got to get on with it. And they did, they co-operated very well indeed.*
> T4 Interview 11/8/94

Changes to assessment practices resulting from involvement in the research project

In addition to concerns arising from the four teachers' differing views of assessment and the central focus of assessment practices at City High, concerns also arose as assessment practice changed due to their involvement in the research project. Involvement in the research project encouraged the teachers to review their assessment practices and to make changes to these. In 1993 T4 was in charge of the Year 12 Biology assessment programme. Explaining the departmental procedures for assessment of practical work, she indicated that students were expected to complete a practical investigation for their Year 12 Biology project and that aspects of this project were marked as the students progressed through the investigation. The students were marked firstly on their original plan, had this returned to them, were permitted to make adjustments to the plan following suggestions made by the teachers, were assessed for their practical skills as they carried out the experiment and were finally given a mark for the submitted written report. In 1992 the team had provided the students with project starter statements from the TAPS 3 scheme (Bryce *et al* 1991) but had discovered that the given starter statements did not lead to comparably sized projects and that some students had been disadvantaged as a result (T4 Interview 12/3/97). In 1993 they presented the students with starter statements similar to those from the TAPS 3 scheme but selected more carefully for comparability of demand and time and rewritten by T4 to be more directed. In addition, the teachers had provided technical assistance sheets where necessary and all students were required to use ready-formatted worksheets to facilitate the marking (a change of procedure indicated by T4 during a departmental meeting in April 1993).

As a result of the difficulties they had encountered in 1993 regarding the individual assessment of students engaged in group practical work, the department decided to make changes to their procedures for assessment of Biology practical work in 1994. In 1994 T3 was in charge of the assessment programme for the six Year 12 Biology classes and she organised this different approach. In an attempt to overcome the difficulties which they had encountered in assessing a large scale group-completed practical project, they designed a different assessment programme for the practical aspects of their course. Instead of concentrating their marking of practical work at one time around the investigative project, the assessment was broken into smaller chunks and spread throughout the year. They marked the students' abilities at planning an investigation, data gathering, and analysing and reporting at different times during the year and across several different partially-structured investigative situations.

There were different responses to these changed 1994 procedures from the four City High teachers. After an early common assessment task T3 commented to the researcher that 'the other [three] teachers did not like marking the problem solving assignment - they didn't know what to look for and they felt that their classes had been disadvantaged [compared with the research intervention class]' (T3 18/4/94). However, T3 also noted during this discussion that her non-intervention class had performed better that her intervention class and wondered if this was caused by the intervention class being more aware of what was expected and thus more tentative in their answering.

Whilst T4 indicated that, from a time spent perspective, she preferred the breakdown of the assessment into smaller chunks (T4 Interview 11/8/94), she also queried the value of some of the actual assessment tasks from a perspective of content validity. She had noted informally to the researcher (Field notes 1/8/94) that she had a concern that the marking schedule had enabled students to gain marks for an experimental design which could not lead to valid conclusions. Reporting that another of the teachers had shared a similar concern with her, she presented the assessment task to her students in a particular way to help her identify what the students had done to generate the data they were analysing:

> *What I did with mine, is that I ... said to them that you will be assessed on your table and your graph and there will be two questions. And then on [T2]'s suggestion, I said to them, now it's not going to be marked, but I want you to just briefly indicate your method. And just from a quick glance at that I could see [which students' work would lead to valid conclusions].*
> T4 Interview 11/8/94

T3, who had set the task evaluated above, discussed the other teacher's responses with the researcher indicating that T2 in particular had complained that 'students were given marks for something that was patently incorrect' (Field notes 18/8/94). There were two outcomes from this debate. Firstly, one of the other teachers (T2) was asked to set the next assessment task and secondly the teachers moved to expect all the students to carry out a more rigorous evaluation of their used practical methods through requiring the students in future assessments to evaluate their collected data and to suggest possible reasons for any unexpected results.

The ongoing debate about procedures and purposes for assessing practical work, the validity of the tasks and concerns regarding the assessment of group work led to further changes in 1995.

During 1995 the biology teachers at City High incorporated some of each of the previous two years' assessment strategies into their assessment schedule (T3 Interview 12/12/95). They used a TAPS (Bryce *et al*, 1991) practical skills test which generated 5% of the year's assessment marks. They set two planning tasks which generated another 5% of the marks (after giving all the students one of the research generated investigative scenarios as a practice run) and finally had the students carry out a complete investigation which involved rising dough. This assessment task required the students to develop an initial plan individually and this was marked for each student. The students were then grouped, with students who had selected the same independent variable working together. The groups were permitted to modify their plan in order to produce a plan on which all members of the group were agreed, and then the students, as a group, carried out the plan. The students were then required to tabulate and graph their results, reach a conclusion and finally evaluate their method and findings with the group members being assessed as individuals at each stage of the investigation.

These four teachers were clearly concerned with assessment practice at all stages of the research project and this resulted in their making changes to their Year 12 Biology assessment schedule. However, there remained some unresolved issues relating to the assessment of practical work. The issues raised by the teachers regarding the practicality and validity of the individual assessment of students who are working in a group situation remained to the fore of the debate throughout the two years. In the early stages of the research project T2 indicated that she could grade aspects such as group co-operation and individual effort:

> *I think you could do things like the group co-operation, I mean I think you could easily tick that off. And how much each person, whether they are participating or not, or wether they sat back and let someone else do it.*
> T2 Interview 2/7/93

However, she did acknowledge the difficulty of allocating a grade at the end of the exercise when 'it's been such a changing, evolving experiment' (T2 Interview 2/7/93). The same teacher indicated at the end of the second year of the research project that she felt, based on many years of her Science Fair involvement, that students could assess themselves easily in a group situation. She believed that a situation where all students in a group received the same group mark even if they had not equally participated was most unfair and that students should be encouraged to indicate the relative participation of the members of their group. Her later comments indicated, however, that she may not have actually followed this procedure:

> *There is a sheet I've seen, which you can give the kids to say who in the group worked. And I think really a group, they can assess themselves. Its very hard for us from the outside to assess their co-operation I think but they are quite good at it. They are very quick to tell you who didn't pull their weight.*
>
> *We get over that, they do [the practical in groups] but we assess them individually, we take in their individual work and mark their graph ... because you, for internal assessment in the sixth form, they don't want to share their mark with their peers.*
> T2 Interview 8/12/94

Other assessment issues which troubled the teachers related to the organisation of the marking during the practical work. They felt that it was difficult to carefully observe each of their students during the practical session, particularly when there were approximately 30 Year 12 students carrying out an investigation in the room at any one time (T3 Interview 2/7/93). They indicated that it was difficult to find the time to allocate to the students for repeat assessments (T3 Interview 1/12/94 and 12/12/95). They stressed the need for clarity of instructions to students (T4 Interview 11/8/94). They also struggled to define the role of the teacher during assessed practical work in consideration of reliability issues and the perceived need to obtain a 'nice spread' of marks (T1 Interview 17/3/97, T4 Interview 11/8/94).

In summary, assessment of investigative practical work gave the teachers in the Biology department at City High appreciable difficulty. In this school which had a high expectation of student achievement, investigation related assessment decisions had sometimes led to disagreement between the Biology teachers. In particular, in 1994, there was a concern that too much assessment of investigative practical work had been scheduled and that it was repetitive. There was a concern that this over emphasis on assessment would create barriers to the introduction of this more open approach to practical work in Biology. There was also a lack of agreement as to whether the investigation linked assessment strategies were valid measures of this work.

The debate about assessment practices had led the teachers into considerations of the aims of the biology programmes and to wider debates about how well regular practical work was assessed. Involvement in the research project encouraged the teachers to review their overall assessment practices and to make ongoing changes to these. However there were unresolved issues such as those relating to the individual assessment of students who were working in groups.

Pedagogy related concerns have been identified as relating to students' ability to work in a unstructured environment, the students' ability to work in co-operative groups and aspects of assessment. In addition, the teachers expressed concerns relating to beginning teachers using this strategy.

> *I think it's going to be quite hard for new teachers coming up, with big classes like we have, to be able to cope, cause it is chaos at times. But organised chaos, I mean we at least know where the gear is and what should be used and what should be expected. But I think the young teachers, it might be a bit daunting.*
> T2 Interview 8/12/94

The concerns expressed so far have been pedagogically related. Another source of concern which arose for these teachers when they were introducing an investigative approach to Year 12 Biology students centred around the availability of resources. These concerns will be addressed next.

8.7 Resource related concerns

Resource concerns centred firstly on a possible lack of readily available equipment and ideas and secondly on the increase of time that working in an investigative mode was perceived to require.

8.7.1 Availability of equipment and ideas

Availability of equipment was a significant issue and questions were raised by the teachers relating to this. The issue was one of students not being able to make good design choices because they lacked technical familiarity with possible equipment. Linked with this there was the concern over the lack of readily available equipment for the students to use when early notification of need was not always able to be given to the school science technician. In an attempt to overcome both of these constraints the teachers found that they tended to cue the students to use certain equipment which they had already ensured would be available in the laboratory. But they admitted that this was problematic for them, since clearly identifying possible equipment could act to restrict creativity of design (for example, T2 Interview 2/7/93). Additionally, clearly indicating to the students that it may be better to use alternative equipment was seen as possibly casting doubts as to feasibility or appropriateness of design, and thus limiting student decision-making, for example:

> *You [may] even say broadly, well all the equipment is available in the room. So anything you want to use is here, so don't try and think of something fancy, that needs to be brought from the chemistry lab, because anything you meed is actually in the room, and you know, make a blanket statement like that. Or, if you know in advance that there will be something that some of them might want, that might not be available, you might have to say, most of the equipment that you will think of using will be here, there may be the odd piece that you will need to see me about. But that sort of begs the question, well what sort of piece? Does that fuel in their minds ideas that its a bit too simplistic if we stick to what's in the room? I don't know, does a statement like that make them stop and think, well do I have to think of something fancy to make a success of this?*
> T3 Interview 2/7/93

Lack of readily available equipment or limited amounts of particular pieces of equipment was perceived to restrict the range of investigative practical work that the teachers were able to choose for their students (T4 Interview 2/7/93 and 11/8/94).

Another limitation identified by two teachers related to the design of contextually situated open investigative situations for their students. They recognised that teacher creativity and time were required to develop investigative contexts that were of appropriate standard, curriculum linked and relatively comparable with regard to the demand on the students (T1 Interview 2/7/93; T2 Interview 2/7/93).

8.7.2 Time resources

Another limited resource for teachers and learners is time. Having students design their own investigations requires more time than directing them to follow set instructions, especially if the students are required to continue with their investigation until they reach conclusive and valid findings. The teachers indicated that if all practical work was approached in an investigative manner then 'you could not get through the course' (T1 Departmental meeting 8/10/93) and the course coverage could become compromised. In addition, usual time constraints such as the length of a school period was a factor in non-achievement of sound results with students getting 'a bit sort of pressured and start[ing] to make careless mistakes' (T3 Interview 1/12/94). Although the teachers did not require their students to repeat an investigation during 1993 and 1994, Teacher 3 indicated that this could be the next step for them, particularly when the investigation is being assessed in a high stakes situation such as a practical examination (T3 Interview 1/12/94).

The four teachers valued the investigative approach sufficiently to suggest a change of overall teaching strategy which could act to counteract the longer time spent covering work in an investigative mode. One suggested that the time normally spent in class while students made notes from a text or overhead transparency could be used for investigative practical work if the students made these notes for homework (T3 Interview 28/7/94).

The teachers had indicated definite areas of concern regarding the introduction of a more open investigative approach to Year 12 Biology practical work. They also noted that they had changed their approaches to teaching Year 12 Biology as a result of their involvement in the research project. These changes will be discussed next.

8.8 Teacher change arising from the introduction of partially-open practical investigations

The four teachers indicated that they had changed their approach to teaching of Year 12 Biology as a result of new understandings formed during their involvement in the research project. Bell and Gilbert (1996) have indicated that feedback, support and reflection are three factors which contribute to professional development of teachers. All three factors were reported as being significant in the teacher development associated with this research project. These changes arose partly from the teachers' own ongoing reflections on their practice and partly through the feedback they received from being part of a research project. As teacher 1 commented 'The fact that you've been doing this has catalysed us into thinking more consciously about what we are doing.' (T1 Interview 2/7/93). The changes could also be linked to feedback from their students and support and feedback from other teachers in their school. The role of personal reflection (8.8.1), student feedback (8.8.2) and collegial support and feedback (8.8.3) will be discussed in turn.

8.8.1 Personal reflection on their practice

The teachers' reflections centred around their changing understandings of the role of practical work in school Biology courses; the role of the teacher during practical work; their estimation of students' prior knowledge and abilities; and the role of thinking in student learning. They also articulated how they were extending these new understandings and consequent teaching strategies into their teaching at other school levels.

The role of practical work in school Biology courses

Throughout the research project this team of teachers had begun to question the role of practical work in Year 12 Biology, for example:

> *We have to perhaps look at why we give practicals. You know, do we give it just because we want to illustrate a point? And most of the practicals in the past have been like that. ... Not to enable the students to be able to design something of their own and understand variables.*
> T4 Interview 11/8/94

There was a developing realisation that practical work, rather than serving a simple illustrative purpose, could also serve to help students understand scientific processes, and gain confidence about carrying these out.

The role of the teacher during practical work

One teacher changed her understanding of the role of the teacher during practical work:

> *I think its the perspective that I take on practicals that's changed. My perspective is now more that I would rather they worked it out than I do. ... I think I ask more questions, which would be a prompting sort of thing. But I enjoy it more.*
> T3 Interview 28/7/94

This teacher had found that working with students who were making decisions for themselves had both educative gains for the students and was personally rewarding.

The teachers' estimation of students' prior knowledge and abilities

As a team the teachers had realised that in the past they had overestimated their students' prior knowledge and abilities (Departmental meeting 8/10/93; T4 Interview 2/7/93; T1 and T2 Interview 8/12/94). The teachers shared that their understanding of their students' prior knowledge and ability had been challenged. T1 identified her increasing awareness that her previous assumptions regarding her students' knowledge and experience had been often wide of the mark, as a significant factor influencing her changed teaching approaches. Linked to this was her greater awareness that her students may not have been thinking along the same lines as she was and therefore she had become more rigorous in her questioning 'in pursuit of details and accuracy in responses' (T1 Notes December 1993).

Three of the teachers (T1, T2 and T3) also identified that they had previously overestimated their students' co-operative learning and group dynamics skills. They had realised that it was necessary to address this directly rather than assuming that the students had the necessary skills to work productively in groups, for example:

> *... certainly the group work made me think how kids react in groups. They don't do it very well, in the sixth form. And I had this assumption because they worked in groups all the time, they knew how to do it but they didn't. ... And so I've tried to start it in third form now and telling them, telling the students how to do group discussions and how to carry out a problem so that's been a very good spin off I think.*
> T2 Interview 8/12/94

The role of thinking in student learning

Two of the teachers (T3 and T4) articulated that they were now requiring their students to make more decisions for themselves than was previously the case and that they were moving to have their students develop increasing confidence and independence (T3 Notes December 1993; T4 Interview 11/8/94). This had not been a sudden change but arose from less 'spoon-feeding' and more encouragement of thinking and study skills (T4

1/12/94). One teacher identified that direct note-giving featured less frequently in her lessons:

> *I haven't been as conscious of using piles of overhead transparencies that I used in the past.*
> T3 Interview 1/12/94

Two teachers indicated that they were now more frequently using questioning to steer the students in certain directions rather than allowing the students to 'free load' (T1 Interview 2/7/93), for example:

> *I think we tended to mollycoddle them far too much in the past. ... They are learning a whole lot of little skills if we let them, rather directing too much.*
> T1 Interview 2/7/93

> *I do see myself as a [source] of information, but I see myself more now as one who tries to get the students to produce some of the information by themselves, by questioning. ... I think it's actually a two way thing, especially with problem solving. There's far less that I have to do and I can be more, I think, more of a help than I might have been before. ... I don't think in fact, if I really sort of think about [it], that I asked many questions before. I don't think that was what I was doing, you know two years ago. So that would be another change that my .. that I've had to undergo, or have undergone.*
> T3 Interview 1/12/94

The spread of new teaching strategies

Another consequence arising from their personal reflections on their practice, was that all four teachers acknowledged that they were also building an investigative approach into their programmes at other levels of the school. They were using teaching strategies that they had developed during the project with other classes (T1 Interview 8/12/94; T2 Interview 8/12/94; T3 Classroom transcript 29/7/94; T4 Departmental meeting 28/4/93).

The changes to the four teachers' practice were also stimulated by their students' response to open investigative practical work and discussion with other teachers.

8.8.2 Student related feedback

As well as identifying that the students' increased metacognitive engagement was permitting greater student learning (for example, T3 Interview 1/12/94) all of the teachers noted their students' obvious enjoyment (T1 Interview 8/12/94; T2 Notes, December 1993; T3 Interview

1/12/94; T4 Interview 11/8/94), increased motivation (T4 2/7/93), ability to do practical work (T4 Interview 2/7/93) and positive student engagement during open investigations:

> *Yes* [it has been the students' response that has brought about that change] *because I see them as in fact enjoying that type of learning and they take a more active part in it because they are forced to associate a lot of ideas rather than just behave a bit like a sponge. And I think that's an extreme advantage because they are always going to have to do that and the earlier the better.*
> T3 Interview 1/12/94

> *I have chatted to them about* [their enjoyment] *while we've been doing* [open investigations]. .. *I have more time to talk to them, when it's their experiment, rather than them looking upon it as my practical and keep running up to me and saying, oh what do you want us to do next? It's , OK well its ours, you know, we've got a hand in this and this concept of ownership keeps coming out. One of the groups I spoke to would be my slowest. They are um, one of the girls is particularly limited, she's in the seventh form, but this is her first year at sixth form. And she says, oh, she said, yes, this is good because it is ours, we've done it, we've thought it through. But ah, some of the others, you know, oh how are we going to do this, you know, this is really important to me. They just get stuck in and they do it.*
> T4 Interview 11/8/94

T3 also reported receiving powerful feedback which encouraged her to continue with open investigations when her students were carrying out a practical exercise which did not encompass openness. She had asked her students to carry out an investigation which required them to follow set instructions. She noted that they experienced wide-ranging difficulties in this situation (T3 Interview 1/12/94) which she identified as arising from their lack of cognitive engagement with the problem. Researcher field notes for this session support her observations and comments (Field notes, 21/7/94).

Student-sourced feedback also included a perceived change in the students' expectations of learning in Biology. In early discussions, T4 had indicated that it was her experience that Year 12 Biology students expected to be given the facts (Interview 12/3/93), but this expectation had changed to such an extent that she had now observed that the students were keen to be involved in decision making and to 'own' their work (similarly T2 Interview 2/7/93). She (T3) had become enthusiastic about seeing 'kids work so well'. It was this positive student response which encouraged her to continue with a similar programme in future years (Interview T3 11/8/94 and survey questionnaire 1995).

8.8.3 Collegial feedback and support

As well as student-sourced encouragement for change the teachers identified the importance of talking with other teachers (T1 and T2 Interview 8/12/94) and the support of the school community at large, ranging from the principal who often discussed the project with the teachers and researcher to the knowledge that the school's parents had, in 1994, in response to a school commissioned survey, expressed an expectation that the school would introduce more problem-solving to the curriculum.

The teachers also indicated that they had begun sharing ideas with the school's chemistry and physics teachers as they had also started to incorporate problem-solving approaches into their programmes, for example:

> *We sit down and talk, and some of the same problems we've talked about have come up there.*
> T2 Interview 8/12/94

This discussion was seen as being valuable for all participants.

8.9 Summary

In this chapter, the focus has been on four teachers' responses to the introduction of open investigative work to a Year 12 Biology programme. The 1993 - 1994 City High teachers' perceptions of the students' knowledge and skills gains arising from the introduction of partially-open practical investigations have been addressed. These four teachers at City High reported affective and cognitive gains from open investigative practical work in a Year 12 Biology programme. They indicated that they could identify their students' knowledge and skills gains but described considerable difficulties with the introduction and assessment of such a programme. Pedagogy and resource related concerns arising from intervention were likewise raised. Teacher change arising from intervention was identified and the stimuli and support for this change were sourced.

Knowledge and skills gains by the students that were identified by the teachers included working co-operatively and creatively. The teachers perceived that the students gained work independence and learnt to evaluate their work critically and honestly. They felt that the students approached investigative work very positively and many previously reluctant workers were quick to become involved. Students were perceived to be thinking more deeply about their work and to be more cognitively engaged in their practical work. In turn the students' preparedness to think about and question their work encouraged their teachers to use an increased questioning approach to the more theoretical aspects of the Year 12 Biology course. The teachers claimed that this increase in student engagement was linked to gains in declarative and procedural conceptual understanding. However, in order to maximise these cognitive gains the teachers had to offer reassurance and encouragement. They had to present their students with cues to past knowledge and experience in order to help them make appropriate connections. Similarly they often found it necessary to stage the introduction of degrees of openness, scaffolding the students as they took their initial tentative investigative steps.

The four City High teachers also expressed some concerns regarding the introduction of openness into a Year 12 Biology practical programme. They were concerned for students who did not have positive experiences in the less structured environment and for students who did not bring sound co-operative learning skills to their biology learning. They expressed dilemmas regarding the assessment of investigative open work, especially within a perceived requirement to formally assess all aspects of students' work. This requirement was seen as acting as a constraint on the introduction of an even greater amount of investigative practical work into the programme. Changes to assessment schedules were ongoing throughout the two year intervention period and on into the following year. The teachers were also concerned about time and resource (equipment and ideas) limitations and for beginning teachers who may not possess the teaching expertise required to incorporate open investigative practical work into a biology programme.

All four of the teachers who participated in the research project indicated that they had changed their approach to Year 12 Biology teaching as a result of this involvement. Feedback, support and personal reflection all contributed to the professional changes identified by these teachers. Feedback to the teachers came from their students and their colleagues. The positive response from their students was both articulated and demonstrated by an obvious increase in the students' enjoyment of practical work. Collegial feedback and support was wide-ranging, from the school's principal to the other members of the science team. The teachers also acknowledged that their involvement in a research project and the requirement to discuss the project's outcomes with the researcher encouraged a greater degree of conscious professional reflection about aspects of their teaching such as the role of practical work, the role of a teacher during practical work, and their estimation of student ability. Their new understandings were extended into their teaching at other school levels.

The following chapter presents a case study of one of these four teachers, T3, following her experience and teacher development in greater detail.

Chapter 9: The teachers' response II: Kaye - a case study

9.1 Introduction

This case study chapter illustrates the changes that one of the teachers from City High made to her practice when she participated in this research project. The teacher's professional development experiences fit Bell and Gilbert's (1996) model of the three types of teacher development - social, personal and professional. Aspects of the Concerns-Based Adoption model (Hall and Loucks, 1979) for teachers involved with curriculum innovation (awareness, informational, personal, management, consequençe, collaboration, and refocussing) are also identified in the teacher's professional development over the time of the research project. However the sequential nature suggested by Hall and Loucks is not clearly identified, a situation also recognised by Bell and Gilbert's (1996) model.

Kaye (94T - "Kaye" is her self-selected pseudonym) was closely associated with the research project for two years (1993 and 1994). Kaye was selected for case study in detail because she was the teacher of the class which was intensively followed by the researcher in 1994. This class was chosen for the 1994 refocussed and intensive phase of the research because their timetabled Year 12 Biology classes were scheduled at a time when the researcher's own teaching timetable enabled her to visit the school. The interactions of the researcher and this teacher were therefore more frequent and occurred over a longer period of time (November 1992 until December 1995) than the researcher's interactions with the other teachers at City High.

This chapter describes Kaye's personal response to the introduction of open investigative practical work to her Year 12 Biology teaching repertoire. Section 9.2 briefly outlines the context for the data gathering and report. Section 9.3 indicates how her initial indifference for participating turned into enthusiasm as she noted an educative value for this teaching strategy for her students learning in, and of, Biology. Sections 9.4 - 9.6 trace the changes to her teaching practice which resulted from this involvement. Her concerns are noted and the difficulties she had which related to the introduction of this teaching approach are indicated. Section 9.7 describes how Kaye's involvement in the research project changed her views regarding the aims of practical work within science education. The teacher development experienced by Kaye is placed within Bell and Gilbert's 1996 model in section 9.8 and the overall findings of this case study are discussed in section 9.9.

9.2 Setting the context

When the intensive period of intervention began at City High School in February of 1993, Kaye had been teaching at the school for 3 years. Prior to this she had taught in secondary and tertiary education Biology departments and then spent a period of ten years caring for her children during which time she was out of the classroom. She had completed one year of Year 12 Biology teaching at City High before the research project began. She was not known by the researcher before the start of the project.

Early interview transcripts show that Kaye was critical of aspects of the Year 12 Biology syllabus. She favoured the teaching of genetics but did not like the ecology section. She had a preference for a practical approach to teaching Biology (94T Interview 12/3/93). On her return to secondary teaching, she had hoped that she would be able to incorporate the experimental approaches she had developed during her time in a tertiary institution into senior secondary biology courses. However she had found that differences between secondary and tertiary institutions, such as tighter time constraints imposed by the secondary system timetable, presented some difficulties:

> *I thought I had all these experiments that could be done but of course it wasn't applicable. They were often [designed for] two hour long sessions and even with a double period with interval between them wasn't enough to run the experiments so I had to give up on a lot of that stuff. It was a bit of a shame because I thought that I had this wealth of stuff I would be able to use, but it wasn't actually possible to apply it.*
> 94T Interview 12/3/93

She acknowledged that in the time she had been away from teaching whilst child rearing there had been a change in the content of school Biology courses so that much of the material 'in the textbook was in fact modifications of what I had been doing there [a tertiary institute].' (94T Interview 12/3/9) She had however continued to search for interesting practical work, particularly in aspects of Year 12 Biology which she perceived to be traditionally taught from a more theoretical framework, such as much of ecology.

9.3 From awareness to refocussing: Kaye's changing attitudes to the research project

Hall and Loucks (1979) proposed a model of teacher development which occurred when teachers were involved with the implementation of a curriculum innovation. They suggested that teachers move through seven sequential phases from initial *awareness* but little involvement, through an *information seeking* phase followed by *personal* alignment to, and *management* of, the innovation. Once the innovation has been successfully managed they believed that the teachers increasingly focus on the innovation's *consequences* for the student, become more *collaboratively* rather than personally involved and finally reach a stage of *refocussing* where they may think of additional alternatives which might work even better. Whilst Kaye did clearly experience these aspects of development they were not identifiable as being sequential and certain aspects were more iterative in nature. The Hall and Loucks' framework is now used for analysis of Kaye's involvement in aspects of the research project.

9.3.1 Awareness, personal and informational phases

Kaye became enthusiastic about the proposed curriculum intervention of the research project during 1993 but her initial 1992 response had been tentative. At the first departmental meeting in November of 1992 during discussion of the research parameters and approaches, the other three teachers' comments indicated that they were keen to be involved and looking forward to the introduction of open investigative studies in their

Year 12 Biology classes but Kaye's responses were infrequent and quiet (Departmental meeting transcript 27/11/92). In an after-class discussion with the researcher early in 1994 and soon after decisions had been taken that it would be her class which would be involved with the research in 1994, she indicated that in 1993 she was involved only because the other departmental members and the researcher wished it. However, by 1994 she was involved because she wanted to be (Diary notes 28/2/94). This feeling was confirmed by Kaye during an interview with the researcher in December 1994. Reflecting on her initial level of enthusiasm she said:

> *I must admit I was put in the position of being required to do it, and so I don't know how reluctant I was at the time. I thought, well, perhaps this could or could not be interesting, I'll just go along with it and see how it works. And over that year there weren't that many of them [investigations], but each, as each one took place, I saw the effect it was having and the satisfaction it was giving the students, that this year I actually tried to spill it over even further into other classes, and found it was producing just the same responses, even you know in the fourth form.*
> 94T Interview 1/12/94

After two months of the intervention Kaye was still somewhat ambivalent towards this investigative approach to practical work. She demonstrated this ambivalence in a March 1993 departmental meeting when she was still somewhat hesitant about being involved in the project However, whilst being tentative about her involvement she was also stating that she would like to try the approach with her Year 10 science students (94T Departmental meeting 28/3/93).

Kaye's initial lack of enthusiasm was not because she did not understand the project or was apprehensive about the direction of the project. She indicated that her understanding of the project was that the approach to be taken largely required changes in teaching and learning strategies rather than the introduction of additional theoretical Biology into the year's programme:

> *Another teacher: Will we need to alter any of the course outlines, or anything we give to students?*
>
> *94T I don't think so 'cos it [course outline] is really all theoretical and it's strategies that we are using.*
> Departmental meeting 27/11/92

9.3.2 Considering the consequences for her students

Kaye's considerable concern for her students may have been the source of some of her initial reluctance regarding the research project. She was concerned about the ethics of advantaging one group of students compared with another group. This concern arose because only four of a possible six Year 12 Biology classes were directly involved in the research intervention in 1993:

> *The only thing would be if it gave one group some sort of discerning ability that the others didn't have and then you tested that, you probably couldn't do that.*
> 94T Departmental meeting 27/11/92

However, she immediately argued against the validity of her concern by indicating that class groups differ considerably even if they have been selected as equivalent:

> *So I suppose what you might find is that this method is going to suit one particular group more than it does another particular group. They could well have been chosen as a homogeneous lot and yet what you have sitting in front of you is much more willing than the group in the next room.*
> 94T Departmental meeting 27/11/92

In addition to her concerns that all of her students should benefit from any positive outcomes of the research project Kaye also noted the outcomes of her students' involvement. This aspect of her development and the effect of her changing perceptions of the value of her students' involvement are discussed in section 9.4.

9.3.3 Management and collaboration phases

Once Kaye had gained information regarding the nature of the proposed curriculum change and reassurance that her students' learning would not be adversely affected by the change, Kaye quickly moved into collaborating with the researcher and the other teachers to introduce the new approach to her students. She was actively engaged in leading the students' group planning exercises in Term 1 of 1993 (Diary notes 30/4/93). In 1994 she introduced an investigative or problem-solving approach to most aspects of her Biology teaching with her new class very early in the year (Diary notes

17/3/94). This was additional to those teaching sessions which were directly related to the research project.

It was a feature of all of the teachers who participated in the research project to work collaboratively with the researcher (Johnston, 1990). All of the teachers were encouraged by the researcher to be involved in defining the research problem, selecting samples and in measuring, analysing, interpreting and applying understandings derived from earlier findings. Kaye was thus involved collaboratively at all stages of the research, interacting closely with the researcher and with the other three teachers. Her involvement naturally increased during 1994 when she was the teacher most closely involved with that phase of the research. Working collaboratively was not a new feature of the department. Even though the four teachers taught in widely physically separated classrooms in the school, the majority of their departmental decisions were either made jointly during meetings or a decision to delegate was jointly made. The methods used during the research project for gathering data and communicating findings reinforced and contributed to the open and wide ranging debate during the departmental meetings. The sharing of information regarding the research project thus occurred easily and frequently.

9.3.4 Refocussing

After two years of the research intervention, Kaye had moved quickly from an awareness of the project, to considering consequences for her students, to the initial management of changing classroom practice and into refocussing and redefining this practice. A remaining, and significant, concern regarding the introduction of an open investigative approach to practical work was the comparatively longer time required for practical work when students were postulating their own hypotheses and designing their own methods for testing these. Even then she noted that students became more adept and took less time over the initial planning stages as they became more experienced. She became more skilled at helping the students to identify the contributing variables in an experimental situation (Interview notes 1/12/94). By the end of 1994 her practice included the use of many focussing and cuing questions which she felt eased the students into the investigation.

Another concern for Kaye was the assessment of this investigative practical work. Her endeavours to develop valid and reliable means for this have been documented in Chapter 8 where she is represented as Teacher 3.

The teacher change that Kaye was experiencing brought with it changes in her perception of what it means to learn Biology. Kaye changed her understanding of what is involved in doing investigations, how students learn to do investigations and the barriers to their learning in this area. She had reconstructed her understanding of what it means for a student to be learning Biology and placed increasing emphasis on students' thinking, She had also changed her perceptions of what it means to be a teacher of Biology and had altered her teaching approaches to match these new understandings. In addition as a result of her involvement in the research project she had changed her perceptions regarding the role of practical work in school Biology programmes. Practical work now had a different role to play in her students' learning of Biology with a practical investigative lesson requiring different learning objectives. These changes in her understanding will be considered in turn.

9.4 Reconstructing her understanding of student learning

Kaye suggested that being involved in the research project had influenced her views of student learning. She had become more aware that students':

> *... existing knowledge appears to be pigeon-holed, therefore they find it difficult to relate some past experience or knowledge to the current work, they actually have to dig down inside as though they've actually sort of closed it off in that little compartments. Their previous learning in a lot of ways doesn't seem to influence their problem-solving very much at all unless it is dug out before you begin.*
> 94T Interview 2/7/93

During 1994, Kaye gave one of her classes a practical exercise designed to determine the role of the small intestinal wall in the process of digestion. The students were following a practical exercise from their set text (Relph *et* *al*, 1986, p 135, number 9) where the method had been designed for them thus requiring them to follow a series of set instructions. In addition some of the equipment had been pre-set-up so as to save class time. Field notes (21/7/94) of this lesson indicate that the students stated that they knew what they were doing, but not why. The students asked both teacher and researcher a number of basic questions relating to the method such as 'Do we need twenty test-tubes?', 'Do we need a large beaker?' and "What do we do with this?' The researcher and teacher responded not with direct answers but with further questions encouraging the students to think further (Field notes 21/7/94 and follow-up interview notes 28/7/94). One group spoken to by the researcher had not considered that concepts of absorption, semi-permeable membranes or even the digestive process were related to the practical work they were carrying out. They had not formed any hypotheses or predictions. They admitted that having some background information and knowing what the practical related to would have helped, them to understand it. One student commented that 'Having to work it out for yourself helps you to learn it.' (Field notes 21/7/94). The group this student was working with had gathered an excellent series of results but their analysis of their observations were limited because they had a limited understanding of the background information (Field notes 21/7/94). The behaviour of the students during this practical session challenged Kaye to admit that these students had not 'assimilated [the theory]', that 'they hadn't made any connection between what they had learned, or what they had written some notes about and what this investigation was all about.' (94T Interview 28/7/94). She commented that, if the alternative to having students design an investigation for themselves was to have to spend a period explaining the text book method, then the students might as well work it out for themselves:

> *... [it would] have been better if they had been asked to design a way of testing what your intestines do to starch. ... Its the thinking about it which irons out a lot of those questions. ... Its like the old story, if you can get up and explain something to someone, you've understood it yourself. And maybe the brain, their brains actually have to be forced into that position.*
> 94T Interview 28/7/94

Kaye was critically reflective regarding the effect of an investigative approach on other aspects of her students' learning. She expressed concern about whether we [researcher and teachers] had found ways of determining if this approach affects student learning in areas wider than the immediate investigative situation, and questioned whether there was any transference of learning from one investigative situation to another. She also questioned whether we had evidence that the investigative approach is carried over to Biology class work that is not so obviously related to the project and into other science subjects:

> *[Students] don't do it any other time unless [they] are told [they] have got to think. But that could be something that one could encourage much earlier on, so that, you know, maybe third and fourth formers could start doing that and then by the time they are in the sixth form, they are so used to having to think as to the problem solving technique that it won't be so foreign to them. Its really, this is like learning a whole new language I think.*
> 94T Interview 2/7/93

In her comments she was emphasising the role that teachers play in encouraging students to think in ways which are wider, more creative and different from that they are used to.

Placing an increasing emphasis on focussed student thinking

Kaye indicated during interviews with the researcher and during departmental meetings that she had a particular interest in having her students think about what they are learning. She used different strategies to help students with different learning styles to engage in their learning. She indicated, for instance, that she liked to use strategies such as video viewing in her lessons to help students who learn visually to make the links in their understandings (Interview 12/3/93). She also noted that, being aware of the difficulties that students have with confusion of definitions of terms in general and scientific use, she was careful that her students and she had a shared understanding of the definitions of terms that she was using (citing as an example the term 'population' in interview on 12/3/97). However, comments by Kaye such as 'I think that the students enjoyed the novelty of being able to sit and discuss.' (Interview 2/7/93) indicate that she may not have commonly given her Biology students time to sit and discuss their work prior to her association with this project.

It was this increased emphasis on student thinking that was perceived by Kaye to be at the heart of the research project rather than any improvement of their practical laboratory skills. She argued that her students were definitely more accomplished at hypothesis making, and at identification of variables, but she questioned that they were actually any better at carrying out the practical aspects of the investigation:

> *They are better at thinking about the problem and thinking about ways of tackling it. I don't know whether they've actually got better at the practical aspects of an investigation, you know, the technique of investigation. But I don't think that was the objective. I think the objective was to get them thinking.* [R: What about their understanding of things biological?] *Well, I think that has been a spin off as well, because having gone through the mental exercise of thinking about the problem, they must have used past information, background information ... to analyse the problem and work out a way of dealing with it, ... and the more they think about it and discuss it the better they, in fact, understand it.*
> 94T Interview 1/12/94

Her reflective comments, some months after observing her 1994 class carry out a exercise where they were given set instructions to follow (see extracts from field notes below relating to this 21/7/94 exercise), supported her contention that increased student metacognition was a focus of this research project:

> *I remember the day during the year when, on short notice they had to do an investigation straight out of the book. And fumbled for two periods with it and at the end of it really hadn't a clue about what they were doing or why. And it appeared that they had not thought it out, because they hadn't had to think about the situation before they launched into it, they hadn't in fact even worked out what they were doing or why. Because they hadn't, they didn't need to, it was just there .*
> 94T Interview 1/12/94

It is clear that Kaye had come to believe that students need to have a sense of ownership of the investigative approach that they were to take and that this required the students to work out for themselves what they were doing and why. She thus believed that focussed thinking and debate was an important part of the decision-making that makes up investigation.

However, whilst Kay valued the increased emphasis on student thinking which resulted from an investigative approach she was concerned about the impact of the extra time requirement on a Year 12 Biology syllabus which she considered to be overfull already:

But I do wonder about the time element that is required to devote to having them think for themselves over a big expanse of syllabus. Perhaps one should look at more chopping out bits of the syllabus that don't really lend themselves to this. If we want thinking people and scientists should be thinking people, then maybe the answer is to aim for a lot more of that .. in that direction and encourage that and forget techniques of using a microscope which could be learnt at a job anyway. You don't need [endless] periods of how to use a microscope.
94T Interview 2/7/93

9.5 Changing her teaching in response to her new understandings about students' learning

Kaye responded quickly as the results of the various phases of the research became available and were discussed with the teachers, changing her teaching strategies to meet newly identified needs of her students. The results of the first survey were discussed with the teachers at a meeting on the 28 April 1993. Responding to the first survey where the students had indicated that they were not confident about identifying and controlling variables within an experimental situation (refer page 194). Kaye indicated that she had already begun to take this finding into consideration in her teaching:

I am asking them about looking at investigations and changing the factor or more than one. I am doing that currently with the enzyme work. Its amazing how many of them can't work out that there is more than one factor that may change and why. I've been looking at the bottom end of this [survey results] now. Mmm, like this morning, what were they doing? They had strange results that had come out of the experiment that they spent two periods doing on Monday. I said "You've got to stop and think. What have you changed, you have such strange results? I said "Had they actually measured them [quantities] out?" No, they hadn't and "Had they left them in the water baths for long enough?". No they hadn't and they had mixed them all up and given them a shake. They had introduced a whole heap of other things, and they had to work out all the things they had done and what had affected the outcome.
94T Departmental meeting 28/4/93

She was concerned to help her students - to gather them quickly into the task so that they did not waste time - frequently giving cues to students with regard to equipment to be used and helping her students to focus their thinking. Having to do this challenged both her self-acknowledged role as a teacher and also her espoused emphasis on having students think for themselves:

There seemed to be a heap [of cues that I had to give to the students]. And I think that I could have avoided all of that if I had given them a list of possible equipment. I remember having to say, you know, 'You've done this before'. I didn't want to have to say that, but I mean for some of them there was no option .. so maybe right at the start. If it is something that they have done before, one maybe should say, hint, this is something, work of this nature you have done in the past, recent past, or within the last year. Maybe even that's too big, you know, maybe they can't think back. If they can't think back to yesterday, how on earth are they going to know what they did in the fifth form..... I'm certainly guilty of giving heaps of cues ... but I didn't want to. I didn't want to be in that position, and I found I had to. ... I couldn't be more in favour of having them think for themselves. ... [But] with some of them it just a blank wall. And all you do is hint, hint, hint. With some of them you can hint and actually get all the answers coming back. The one hint has in fact sorted out a whole number of problems.
94T Interview 2/7/93

Although Kaye encouraged her students to work in groups she noted that 'the delegation of jobs is not done very well in a group' and that there are often several students that are happy to just sit and do nothing and be led by one person even though that approach often slows down the process and outcome of practical work:

They are watching one test tube when they could have in fact set up four, if they had worked cooperatively.
94T Interview 2/7/93

Her observations in this regard led her to suggest that groups should be regularly mixed up in order to improve the working and thinking habits of all the students - a view that was new to her way of working with students in the laboratory:

So, and this is very very different, that's why I would have thought perhaps the idea would be not to have them always working in the same group, so that they don't become dependent on someone who does think and plan and then never have to be forced to do it themselves.
94T Interview 2/7/93

9.5.1 Redefining the role of questioning in her teaching

Kaye frequently used questioning in her teaching. In one eight minute introduction to a "note taking" session which had been organised to ensure that students had notes about aspects they were to be examined on, she used a total of 40 questions. Three of these questions were repeated. However, Kaye did not expect open verbal student response to all of her questions. Students responded out loud to only 17 of these 40 questions and in three cases the questions were answered simultaneously by several students. Students responded openly to all three of the repeated questions. At the end of the eight minutes of this teacher-led and dominated discussion the class moved into formal note-taking from a pre-prepared overhead transparency (Field notes 12/9/94). In a December 1994 discussion focusing on this data Kaye indicated that she felt that her teaching style had undergone considerable change in this regard. She felt that her early 1993 lessons would not have shown the same pattern or emphasis on questioning. By the first term of 1994, data gathered from lesson transcripts and field notes were indicating that Kaye had adopted questioning as her preferred teaching strategy for both theoretical development and practical lessons (for example, Classroom transcript 21/4/94, and Field notes 21/3/94, 7/4/94). At one stage, as a result of researcher feedback, she became very conscious of her shift to increased questioning and queried whether she should be teaching in this manner (Diary notes 14/4/94). However, by December 1994 she acknowledged that using questioning to encourage her students to think more deeply about Biology and Science matters had become very much part of her teaching style and that her students had adapted to this change very readily:

> *I think I may have been at some stage, conscious of it ... and I sort of thought, oh I really am doing too many, too much questioning. And I don't think I even think about it now. And I am sure I am doing it in the junior classes without even thinking about it.*
>
> *.. they've adapted quite readily. They may not have realised it was happening. I mean with the junior classes, it probably just developed through the year, I don't think it was an overnight thing.*
> 94T Interview 1/12/94

9.5.2 Renegotiating what it means to be a teacher of Biology

Kaye indicated early in the research project that she considered that as a teacher she should be a facilitator and role model, with statements such as:

> *I know from last year when they did their practical investigation, a girl in my class who got I think the best value out of her investigation, was one who worked on her own. Admittedly, she did get quite a lot of help from me, but I didn't detail what she was going to do, I tried to channel her and I was able to do that with her just sitting across a table. She didn't actually complete her experiment, she got sick in the middle of it, but she launched herself into this in a really very professional way, I felt. I may have moulded her, I don't know...*
> 94T Interview 2/7/93

Kaye' involvement in this research had affected her teaching. She indicated in a written response to a set question "How do you think being involved in this research has affected you teaching?", completed in December 1993, that she found herself encouraging investigative approaches to learning at lower form levels. She was giving fewer hints and fewer 'recipe style' practicals. She was having students identify factors that could be tested in a 'fair' way. And she was certain that she would be using more of this style of investigation in a Year 12 Biology course. In an interview in July 1994, when she was thinking about how to shift practical tasks from a 'students following set instructions' situation to an investigative approach which was student initiated, she commented that having a book 'recipe' available was the easy option that need not be taken as long as time was available for students to design the investigations for themselves. Her changing understandings were also having an impact on her overall approach to teaching Biology:

> 94T: *... if time is not critical, then a lot of [practicals] can be done that [in a student initiated investigative manner] way, and then I suppose more and more the homework would become note taking at home. And one's time in class would become more and more that sort of work.*
>
> R: *Have you noticed that happening in your class this year?*
>
> 94T: *Well, no, well I have been setting more work for homework as in writing notes, but I've also found myself having to say ..'So in this period, this is the work that has to be covered. It can't be done off the board, so its going to be those three pages, and you are responsible for making your notes. So you've got this period, plus whatever is left over for homework.' And I have found myself doing it more this time [year] that the first time [first year of research project]. ... Actually I think that it's a bit boring standing there going through loads and loads of theory, and two periods in a row in a double period is hard work, and boring for them, and its not terribly interesting for me. I would rather have the double periods used, you know, doing the practical work. And if that means giving up the period before as well, to think about working it out, I think I would be happier with the three periods like that. And since they actually prepare nothing in the homework for their lab, because they've done it the period before, then I don't think it's unfair to give them, in effect, one more period as homework [writing notes].*
> 94T Interview 28/7/94

As well as being a facilitator and a role model, when Kaye was working with students who were carrying out investigations she was also acting as a mediator, mediating the interaction between the teacher and student's thinking. As noted earlier she was using increasingly probing questioning in this regard. She had also begun to cue her students to help them make links between previous and current situations. This represented a change in her practice. She indicated to the researcher that once she:

> *... expected that they would be able to use some previous knowledge or laboratory experience, and put it into a new context, with little difficulty. I think that was what I thought.*
> 94T Interview 2/7/98

However she had moved to a recognition that students need help to make links with past experiences when they are in new situations:

> *They do need help in ways of looking at a situation, because for many they have never done that before.*
> 94T Interview 1/12/94

Kaye was, thus, increasingly recognising the importance of the interaction between the teacher and the student for enhanced student learning.

When asked again in July of 1994 to indicate if involvement in the research project had changed her teaching, she indicated that it was the perspective that she took to practicals which had changed, that she would now much rather the students worked out their own approaches than that she did the work for them. She thought that she asked 'more questions, which would be a prompting sort of thing' (T4 Interview 28/7/94) and that she enjoyed her teaching more when she was working with students in this manner. She also noted positive side effects from working in this way in that it helped students better understand the nature of the scientific endeavour and that it helped students to think more widely:

> *I actually like the idea of them having to work out all the facets of the problem, identify them. And it makes them think, I think, globally rather than channelled like a text book recipe would.*
> 94T Interview 28/7/94

9.5.3 The students' influence on her changing teaching style

As well as responding to the unfolding research findings Kaye was responding to her students' responses both to the investigative approach to practical work that she was introducing into the Biology programme and to the overall changes in her teaching approach. The response of Kaye's students to this curriculum innovation was important to her. She noted that the students complained less about homework which required note-making, than they did if class time was used for note-making. She responded to her students' comments by lessening the amount of class time spent note-making and thus freeing time to spend on investigative practical work and class discussion. By the end of 1994 she was reporting that 'in fact I haven't really used a lot of my notes this year. I haven't been as conscious of using the piles of overhead transparencies that I used in the past.' (94T Interview 1/12/94) and that she was encouraging considerably more class discussion of text material:

> *... some reading of the text and then some discussion and ten minutes to write some answers and then discuss those. Why did you write that answer? What were you thinking about when you wrote that? Because nobody else in this room has come up with that sort of answer. And it makes all of them think about maybe a different aspect of this problem, that they haven't considered before.*
> 94T Interview 1/12/94

Kaye did not indicate that her lessened use of prepared notes had any negative influence on her students' learning as indicated in their examination grades. Rather she felt that her students' learning had been enhanced as a result of their thinking more for themselves:

> *... The more they think about it and discuss it, the better they in fact understand it. In fact, I'm convinced that if you can sort of verbalise an idea, you actually understand it better, than if you just keep it to yourself."*
> T4 Interview 1/12/94

9.5.4 The ripple effect of her changed teaching approach

These new approaches to teaching, that Kaye was using with the students who were participating in the research project, were not confined to her teaching of this class but were being introduced to her other classes as well. During 1994 Kaye had two Year 12 Biology classes. One was linked to the researcher who visited the classroom twice a week and the other was not observed by the researcher. A measure of the effect of her involvement with the research project on her practice as a teacher can be seen in the way in which it influenced her teaching approaches with other. By the end of July 1994 she was indicating to the researcher that she was using investigative strategies with both Year 12 classes as a matter of course:

> *I'm not now finding myself telling [the non research related class] that this is one that the other class has done. I don't tell them that any more. As far as they are concerned [the investigations are] just part of the course now.*
> 94T Interview 28/7/94

She also indicated in this interview that the students in the research class considered that all the investigations they carried out, both those specifically research related and others, were regular parts of the course. Her own attitude towards these investigations was matter-of-fact. By July 1994 she clearly believed that involvement in the research project was not requiring the students to do additional work. She was carrying this approach over to her non-research related Year 12 Biology class as well as in the research situation, giving her students the option of choosing to follow a pre-structured method or of designing their own approach:

> *Well, I don't think they think they are doing extra. I mean the starch one is a classic example. In my other class, I said, now look we've got two options here. "You can do the one in the book or we can invent our own. How many of you would like to do the one in the book? And a couple of hands went up. I said, how many of you would like to try something that's a little bit different? They said, yes we'll have that.*
> 94T Interview 28/7/94

In addition to introducing an open investigative approach to her two Year 12 Biology classes Kaye had also introduced an open investigative approach to her junior Science classes. Here, too, she was concerned as to how to help her students make the links between the practical situation and related background theoretical knowledge upon which the students could usefully draw. She realised that it could be part of her role as a teacher to be more explicit in this regard - that she would need to lead the students into becoming more aware of their learning and the processes they were going through when they were engaged in problem solving. During an interview on 28 July 1994 she noted:

> *I don't really think that [linking of theory and practical situations] is done much at all. I tried this sort of stuff with the fourth form, you know, and giving them a problem, think about ways of solving it, but I don't really sort of stop and ask them 'What are you using to, what information are you using to help you solve this? That would be the next step then.*
> 94T Interview 28/7/94

Immediately following this reflection she decided to try this metacognitive approach with her Year 10 Science class and organised to tape this lesson so that the researcher could listen in and see how this approach operated at this year level. Analysis of this tape showed that she was encouraging the students in this class to think globally and creatively about the set problem.

The students were working around the topic of "Pollution", specifically designing a test for polluted water involving water samples and detergent. They were asked to consider what would influence the amount of froth produced during this test. She did not ask this question however until they had completed a whole class discussion regarding the causes of water pollution. The students were encouraged to list possible causative factors and then she summarised the ideas gleaned from a whole class discussion. She then asked the very direct questions:

> *In what ways does any information you've learnt in science help you to work out a problem like this? What sort of things does your brain need to do, to help you produce a list like this? What did you have to do while you were sitting there?*
> Classroom transcript of Kaye with a Year 10 Science class 29/7/94

During the conversation with her students immediately following these questions she led her students to the realisation that in this situation, new to all but one student, they had used knowledge that they had previously stored in their memories and that they had been required to retrieve this information and recognise its applicability to the problem they were currently facing. As demonstrated in this transcript Kaye was now increasingly using strategies to increase her students' metacognition - a change in her teaching approach deriving from her involvement in the research project. She was increasingly concerned that her students recognised that they were learning and how they were learning. This change in her approach was confirmed by Kaye during an interview in December of 1994. She still saw provision of information as an important part of her role as a teacher but identified her now increasingly questioning approach as one which helped the students to learn:

> *... because they are forced to associate a lot of ideas, rather than just behave like a sponge. And I think that's an extreme advantage because they are always going to have to do that and the earlier they can do that the better. .. and that would be, I think, the most impact [being involved in this research project] has had on me. I came here having lectured and I didn't really do a lot of, I suppose you'd call it interactive teaching. I didn't do that, I then, I thought well I was an imparter of information and this is much more enjoyable.*
> 94T Interview 1/1/2/94

Kaye's involvement in this research project had thus had a considerable impact on her teaching approaches. From being a presenter of biological information who saw herself as a facilitator and role model she had increasingly come to mediate her students' thinking. She was questioning her students more frequently, challenging them to think for themselves and to become aware of their own thinking.

9.6 Kaye's changed views of the role of practical work in learning Biology

Initially Kaye saw the role of practical work in Year 12 Biology as largely illustrative with perhaps a small role to play in developing students practical skills:

> *As a way of illustrating a point in the text. It then becomes easier for recall .... possibly looking at some skills but by the time they reach [Year 12] their practical skills should be good enough. ... It should be more that you try to illustrate something that's a fundamental principle.*
> 94T Interview 12/3/93

By the end of 1994, however, she had added motivational and exploratory reasons and recognised the value of developing scientific enquiry skills. In response to a query regarding the reasons for including practical work in school Science programmes she said:

> *Well, for one, for fun. And two, to learn, to reinforce theory. Or even to be an entry into an idea in science. And to learn how to plan an investigation and then carry it out. But I like to think that there's an element of enjoyment in it as well.*
> 94T Interview 1/12/94

At the start of the research project Kaye indicated that she considered that Year 12 Biology students should have the skills necessary to carry out any practical work required of them:

> [discussing a role for practical work] *Possibly looking at some skills but by the time they reach [Year 12] their practical skills should be good enough. They shouldn't be the point of the exercise. They probably need some background [before they do practical work] although maybe not in every situation. No. But one assumes that they know some practical skills before they come in but one perhaps assumes that they have some background knowledge as well. I would tend to use it that way.*
> 94T Interview 12/3/93

In support of this argument, she claimed that there were opportunities for students in Years 9 to 11 Science to identify and work with variables during experimental situations. As an example she referred to deliberately given opportunities for Year 11 students to design their own experimental methods during photosynthesis practicals:

> *I can't help thinking that the photosynthesis [practical exercise] doesn't [give set instructions]. The lab manual in fact doesn't tell you how to investigate the variables, the other factors. You have got to come up with your own plan. It might be one of the few examples but there is one that I can think of. And then, if there is time, you could investigate the other ones, apart from the one that is given in the book.*
> 94T Departmental meeting 28/4/93

However, her comments and opinions about Year 12 students' practical skills abilities had changed by the end of the first year of the research intervention. At this stage she was acknowledging that some students did not have all the cognitive skills necessary to approach investigative work and that teachers had to help students work through the investigative processes involved. She noted that she had earlier expected that '[the students] would be able to use some previous knowledge and skills or lab experience and put it into a new context, with little difficulty' (94T Interview 2/7/93) but found, however, that many of the students could not do this. She also expressed concern about the students' apparent inability to anticipate outcomes even if they had recently carried out a similar experiment - that students were unable to relate a new experience to past experiences and to draw upon the past to help them solve the new. She emphasised her growing understanding that the teacher needs to facilitate the link-making both in regards to conceptual ideas and the use of particular materials and equipment:

> *You had to sit down beside them and say, 'Well, you haven't thought of all these things, you haven't even got them on paper yet. How are you going to collect this gas?' and you know, those sorts of things. They are just, I don't think they've ever had to do this, none of them have ever had to sit down and write a list, so they are really in an unknown area.*
> 94T Interview 2/7/93

She was surprised that so many skills and understandings that she had taken for granted as basic to practical work were not well understood by the students. For her, this feature of her students' work emphasised their compartmentalisation of their learning (94T Interview 2/7/93). Her students' inability to draw upon past experiences was considered by Kaye to influence their overall learning in the area of open investigative practical work, for example:

> *Some have learnt a lot but the majority have not. Some have learnt to think and the rest haven't. ... I think that it is because they are not able to think that way. It is not something you just pick up like that. I think that it all hinges on [helping kids pick up the processes in a staged manner]. I am becoming more and more convinced that even in the fifth form they don't have a clue what they are doing.*
> 94T Departmental meeting 8/10/93

By the end of 1994 Kaye had changed her view of the general aims of practical work within science education and now placed greater emphasis on student metacognition and cognitive skills rather than manipulative skills. When questioned about this at the end of 1994 Kaye indicated that she would like her students to be thinking more like scientists both as they carried out practical work and as they prepared reports of this work. She had been encouraged by the level of participation of her students and the high standard of their work. At the end of the 1995 school year she reported that her Year 13 students who had participated in the investigative project in 1994 had shown an 'unbelievable difference' in their ability to carry out the individual plant and animal studies which make up part of the Year 13 Biology course. With regards to their ability to hypothesise, make predictions, carry out their investigations and write reports, some of the students had done 'brilliantly'. She also noted that two of her 1994 students who had had to repeat Year 12 Biology had shown considerable leadership skills during experimental work the following year (94T Interview 12/12/95). Such informal feedback was important for Kaye and encouraged her to continue to incorporate open investigative practical work in her Science and Biology teaching.

9.7 Summary

This case study chapter has described one teacher's personal response to the introduction of open investigative practical work to her Year 12 Biology programme. It has traced her reflection of the consequences of her involvement and the changes to her teaching practice which resulted from this involvement. It indicated how her initial tentative involvement turned into enthusiasm as she noted the educative value of this teaching strategy for her students' learning in, and of, Biology. Kaye's concerns, and the difficulties she had, relating to the introduction of this teaching approach were noted.

During the two year span of Kaye's intensive involvement with the research project she experienced all three of the types of development identified by Bell and Gilbert (1996). During that time she had, firstly, renegotiated and reconstructed 'what it means to be a teacher' of science (*ibid* p15) - social development. Secondly, she had evaluated and accepted for herself these new meanings - personal development. In doing so, she had, thirdly, reasoned and articulated her underlying beliefs about student learning in science - professional development. This change had taken place in the context of a long term involvement in the research project rather than as the result of any one phase of her involvement in the research intervention.

Not all aspects of the professional development Concerns-Based Adoption model developed by Hall and Loucks (1979) for teachers involved with curriculum innovation were clearly demonstrated by Kaye's individual professional development during the time of this research project. The headings of Hall and Loucks' model are useful categories for analysing the ongoing professional development of teachers who are engaged in implementing a curriculum innovation. However, whilst Hall and Loucks suggest that their named stages are sequential, Kaye's experiences as described in this chapter suggest that a teacher may move through some of these stages very quickly and that the stages may be iterative in nature rather than linear. It may have been Hall and Loucks' (1979) intention that the iterative nature of much professional development is captured by their final refocussing phase. However, for Kaye the consequences of what she was trialing, and the trial itself, was an early developed and ongoing concern. For example, rather than considering consequences for her students some time after the introduction of the innovation, Kaye was very aware of possible consequences for her students from the earliest stage of the project and this concern was an important ongoing feature of her engagement in the project. She had also stated ethical concerns about the effect of the research intervention on her students at an early stage in the research project .

Additionally, although the layout of the City High buildings was such that the four Biology teachers taught in four different school blocks, collaboration between the Biology teachers at City High was a feature of their working relationships from the beginning of the project rather than at a later stage as indicated by the Hall-Loucks' model.

By following Kaye's experiences in detail over two years of the research project I had been able to signpost some areas which could be addressed in teacher development programmes relating to the introduction of increased openness into investigative practical work. Teachers could be challenged to debate and refine their understandings of the role of science education and the purpose of practical work within this. They could consider in more depth what is involved in doing investigative practical work. They could consider what it means to be a learner of Biology and the significance of enhancing cognitive as well as manipulative skills for achievement in Biology. They could be helped to develop expertise in teaching approaches which matched these understandings. It also appeared that it would be of value for teachers to be challenged to consider what it means for them to be a teacher of Biology, and to reflect on their expectations of their students and their views about learning.

By the end of 1994 I was interested in finding out if the curriculum materials that had been developed during the two years of the research project at City High could be used by other teachers, in other schools, and when the researcher was not present. In addition, the data which had been gathered during 1993 and 1994 had informed the development of a teacher resource pack which could be used by others wishing to introduce investigative practical work in to their Science and Biology programmes (see Appendix A). This material was sent to teachers working in other schools for use and trial during 1995. The experiences and responses of these 1995 teachers are discussed in the next chapter.

Chapter 10: The teachers' response III: the 1995 trial

10.1 Introduction

By the end of 1994, the partially-open investigative approach to practical work which forms the basis of this study had been formally trialed in five Year 12 classrooms at City High. A teaching pack containing classroom material and associated teachers' guide material had been developed in consultation with the four teachers (see Appendix A). I was interested in finding out whether this classroom material could be used by teachers and students in other schools when the researcher was not present in the classroom and where the student demography was different from that of City High, with its upper socio-economic decile, urban, co-educational setting. Additionally, I wanted a wider data base from which to find out if the introduction of a partially-open investigative approach to practical work in Biology challenged teachers' previously held meanings for teaching and learning in Biology.

In addition to the testing of the developed investigative material (see Chapter 5 and Appendix B) in a greater number of classrooms, the extension of the 1993 - 1994 phase of the research into a wider range of school types and a greater number of teachers served to strengthen the validity and reliability of the qualitative methods used in this research project by the gathering of data from multiple sources.

This chapter documents the trialing of the package of materials developed in the first two phases of the research. The participating schools and teachers are introduced in section 10.2. Methods used for data gathering and processing are covered in section 10.3. The challenges faced by the teachers and students to their constructed concepts of teaching and learning in and of Biology when open investigative practical work was presented to these Year 12 Biology students is outlined in section 10.4. Section 10.5 summarises the positive features, reservations and overall value that the teachers ascribed to the introduction of more openness to their Biology teaching programme. This chapter also reports on the teachers' response to the 1995 trial. The positive features of such an approach as declared by the teachers and their reservations are examined.

10.2. Methodology related to the 1995 trial

The researcher - practitioner relationship for this phase of the research was first developed as a result of a conference presentation by the researcher in 1994. After this conference presentation a group of teachers expressed interest in the ongoing trial of the developing material. The researcher-practitioner relationship was maintained throughout the third phase of the research, and the write up of findings, mostly by mail or telephone and a small number of personal meetings. The developing data analysis was sent to the teachers for their comment and there was an opportunity for the teachers to meet again with the researcher at a conference 21 months after the initial presentation - see Section 5.4.2 for information regarding the 1995 teachers for Phase III of the research.

Material sent to schools

In January of 1995, chairpersons of the schools' Board of Trustees, principals and science head of departments were sent a letter outlining the nature of the trial and were asked to give consent. The teachers concerned were sent a package of the trial materials and a description of the ethical considerations binding the trial. The guidelines included a general introduction to the role and nature of investigative practical work; guidance for teachers facilitating investigative practical work; investigative task sheets workbooks and evaluation for students; accompanying assessment schedules and teachers' guides; and schedules for the teachers to use when reporting back to the researcher.

10.3 Data gathering and processing for this phase of the research

The majority of the findings reported in this chapter were derived from teacher response to a questionnaire included in the investigation teaching pack (see Appendix H). There were fourteen written reports returned to the researcher at the end of the 1995 trial. These came from teachers in boys (1), girls (6) and co-educational (7) schools. Eleven of these schools were situated in large urban areas and three in rural townships. Two of the teachers were also interviewed by the researcher. Whilst there may have been joint discussion and preparation of reports in schools where more than one teacher was involved in the project, all of the returned questionnaires were completed by individuals. The teacher is identified by the school code, for example, 95S.

The questions in the questionnaire focused on elucidating aspects of change accompanying curriculum innovation and were developed after analysis of findings from the 1993 - 1994 phases of the project. It was expected that the teachers and students would be engaged in the social process of reconstruction of the meanings for 'teaching' and 'learning' in, and of, Biology, and the questions were phrased to elicit the changing understanding and development of these concepts. Nine only of the teachers responded fully to the questions in the questionnaire, thus indicated numbers of teachers will not always sum to fourteen. Data gathered during interviews with two of the teachers and telephone conversations with others have also informed the analysis presented below.

10.4 Challenging held perceptions relating to teaching Biology

Whenever teachers are involved in the trial of new teaching strategies it is expected that they will experience a challenge to their constructed definitions of teaching and learning in, and of the subject they are teaching. These teachers were introducing a greater degree of openness into the practical work in their Biology programmes and there was a recorded change in their understanding of why they taught Biology as a result of this change in teaching approach.

In the questionnaire the teachers were asked to explain why they taught Biology. This question was included to contribute to base line information about the teachers. Reasons given included the development of their students' science process skills (7 comments), the opportunity to share their own enthusiasm and knowledge (5 comments), helping students to get a particular view of the world and to help students live in that world (4 comments), and to encourage students to undertake further tertiary studies in Biology (1 comment). The reasons given by the teachers for teaching Biology thus related largely to helping their students learn about declarative and procedural concepts and the application of biology to the students' world.

10.4.1 Challenging the teachers' definitions of "Biology teacher" through the introduction of investigative practical work to a Year 12 Biology course

Seven of the teachers indicated in their questionnaire responses that being involved in this trial of investigative material had changed their view of themselves as a teacher of Biology, seeing new roles and activities for themselves - a professional development outcome that was also indicated by teachers in the LISP Teacher Development Project (Bell and Gilbert, 1996). The teachers in the 1995 trial were viewing student learning in a new light; were more aware of the need to fully utilise as many English Second Language skills and activities as possible to assist student learning; were focusing more on student thinking; had changed from a 'chalk and talk' approach to a more facilitative approach which allowed students to engage in self-directed study; and had gained confidence in themselves as teachers. One teacher who had also participated in the original research project in 1993 and peripherally for part of 1994, wrote:

> *The initial involvement (two years ago now) began the change but being more involved this year has enabled me to view student learning in a new light. I feel far more able to accurately assess student progress - to distinguish actual from expected student learning outcomes. Involvement in this trial has given me the confidence to participate in 6 Biology unit standards trial in 1996.*
> 95U

Whilst no change of view of themselves as a teacher of biology was indicated by five teachers, three of these five teachers did indicate that they had valued the opportunity to provide a challenge for students and that their involvement motivated them to utilise a teaching strategy other than 'recipe' style practical work:

> *This programme has replaced similar experiments I would normally do with a 'recipe' hence it is another teaching strategy to use which is particularly good for preparing the students for independent practical investigations as part of their Sixth Form Certificate assessment.*
> *95P*

No, [I have not changed my view of myself as a Biology teacher but] it provided me with a new way of providing experience to challenge and involve students. And reinforced my own gut feeling that it is the experiences that students have that most influence the way they think. I committed continuing time to some of the investigations because the students became so involved - it seemed to me more constructive use of time than 'getting on with the syllabus.
95C

Even though teacher 95C indicated that she did not think that her involvement had changed her view of herself as a teacher of biology, in answer to another question regarding the teacher's role in the student change process she said:

I think that having these scenarios available meant that I put them in open situations and pushed them into thinking/planning themselves. I found it quite sobering that this felt like an exciting new idea ... (to me!)
95C - emphasis hers

One of the teachers commented that she had trained as a teacher in another country where she was expected to teach up to fifty students in one class. This work, which represented considerable change from her own traditional didactic schooling and her previous experiences as a teacher, became another means of helping her to shift to the more student-centred approach which she had encountered in New Zealand (95M).

The trial teachers who responded in writing and interview to the researcher also noted a change in the teaching strategies and approaches that they were using with their students. They reported that they had to provide help for students who were making a change to open investigative practical work in ways which were not necessary, or did not have the same significance, when the students were following set instructions during practical work. The teachers listed the following methods which they had used to help their students with investigating:

- explaining the process of investigation, including having a practice runs(s) with other investigation(s) (3 related comments)
- using the planning sheet (provided in the investigation pack) (1)
- providing a 'questions to think about' sheet (2)
- offering alternatives and suggestions without answering questions directly (3)
- being constructively critical (1)

- requiring students to give an oral presentation including self-criticism and evaluation and opening these to whole class discussion with the aim of improving a follow up investigation (2)
- initiating a great deal of discussion - whole class, group and individual (1)
- providing time to repeat practical investigations (1)
- encouraging students to have confidence in their own ability to make decisions (2)
- thorough marking of practical assignments and class discussion of these (2)
- altering student groupings throughout the year (1) [Altering student groupings allowed students to 'learn more about working with others and their expectations' (95K).]

All but the last three of these were indicated in the teacher's guide which had been sent to the teachers, and it is possible that the teachers consulted the guide when answering this question. However, as listed, their comments reinforce the findings of the earlier phases of the research.

10.4.2 Challenging the meaning of being a "learner in, and of, Biology" through the introduction of investigative practical work to a Year 12 Biology course

In response to the question "What do you think learning in biology involves?" the teachers listed conceptual involvement (5 responses); essential skills development (7) - communication (4), manipulative skill development (2) and independent thinking (2) as well as co-operative team building (3); a range of scientific process and practical skill development (7); and the identification of the relevance and application of biology (3). Three teachers focused on the affective domain, mentioning student interest, involvement and application. Whilst aspects of 'knowledge - skills - attitudes' were reported they were not all mentioned by all the teachers. However, many of the responses included a combination of these comments, for example, a response which focused on some of the cognitive, performance and disposition attributes required for students to work scientifically listed:

> *Being observant of what is around; Wondering why - an inquiring mind; Understanding concepts and how they relate; Thinking for oneself; Background research - library, textbooks; A co-operative team approach; Building on prior knowledge or experiences; Planning carefully.*
> 95R

One which focused on the students' affective involvement noted that:

It starts with 'sparking an interest' in knowing why something happens. Students wishing to know more.
95A

One teacher responded by stating that she thought learning in Biology should involve the opportunity to focus on 'reflection and repetition (modification) of original tasks' (95S) - a response which has direct implications for students who are engaged in open investigative practical work.

The teachers noted that because of the introduction of open investigative work the students, too, had had to rethink their ideas about the meaning of "learning in Biology" - both in regard to the process and the learning which resulted from the process. Nine of the fourteen teachers responded in full to the question "Have your students had to change their views about the 'rules of the game' of the biology classroom this year?". All of these teachers indicated that the students had been required to make changes to their approach to learning and classroom behaviour, being required to take an increased responsibility for their learning; two teachers indicated that a small number of students were not able to make the change and one noted that she did not think that the students were aware that there had been changed requirements. The teachers reported that when the students were first introduced to open investigative work many were initially anxious, being hesitant to get started, but that they gained confidence as the year progressed, becoming less irritated and being prepared to take on the challenge. At first, the students found it difficult to make decisions for themselves as they wanted their work to be 'perfect' but 'by the third investigation they were actively involved and looking for ideas' (95B).

The students' views of "learning in and of Biology" had also changed. In their questionnaire responses the teachers indicated that they felt that their students had come into their Year 12 Biology classes at the start of the year confident about doing structured practical work (2); expecting to be assessed through a range of activities such as essays, tests and exams (3); and anticipating that their teachers would tell them what they needed to know (1), for example:

I think largely, that they thought of Biology as a somewhat 'soft option' that they would not find too difficult.
95C

The majority expected me to provide all the notes and they would occasionally do some practical work - recipe style and waited for me to tell then the answers.
95R

One teacher thought that the students were expecting Year 12 Biology to be 'similar to the Biology they had previously experienced' in Year 11 Science (95D). Another teacher reported that her students had talked to previous years' Year 12 Biology students and had therefore expected an emphasis on project work, dissections and human biology (95U).

However these student views about learning in Biology had been challenged by the introduction of investigative practical work. Nine teachers provided written or verbal feedback to the researcher regarding the question about changed student expectations as a result of their involvement in investigative practical work. All nine indicated that their students' expectations of practical work in a Year 12 Biology class had changed as a result of their involvement with practical work which demanded that they design their own experiments to test self-generated hypotheses and predictions. The introduction of partially-open investigative practical work had not been expected and therefore challenged these students to rethink their expectations about practical work, for example:

Many students quickly find Biology is more difficult and 'different' from what they thought. A small group can't make the adjustment and don't achieve a lot over the year. Many do learn that they must 'think for themselves' if they wish to succeed at open investigative work. There was some initial annoyance by very good students that I hadn't explained what was required fully enough!
95A

Even if the students had not recognised much change in the way in which they were interacting with each other and their teachers during practical work, eight of the teachers reported that most were changing, for example:

I am not sure that they were aware of any change themselves - they gained some confidence in group work (co-operative model), formulating hypotheses and isolating one factor to test. The evaluations helped them accept that they were in charge and they often expressed satisfaction.
95C

Five indicated a change in the depth and amount of their students' thinking, and noted that they needed to encourage their students in this area, for example:

> *[The students] found that they were more actively involved in the thinking process and planning process in practical work and hence investigations. They found that they had to analyse their own data and present criticisms.*
> 95K

> *"I have changed my approach to teaching - [now] putting the emphasis on the students thinking for themselves.*
> 95R

Four teachers reported that as the year progressed their students had thought through the investigation material more deeply and discussed it more fully in groups before carrying out the practical work. One teacher noted that her students tended to 'trust a group decision making process before their own' and then gain confidence when they realised that its 'their decisions that make [up] the group decision' (95H). Six of the teachers noted that their students took more responsibility for their own learning and became more consultative rather than demanding of the teacher (see, for example, quote from 95K above). The requirement on the students to evaluate their investigations on completion 'helped them to accept that they were in charge. They often expressed satisfaction.' (95C). One teacher indicated long term implications from her students' involvement in this project because many of her students had opted to study [Year 13] Biology because they 'enjoyed the unpredictability of Biology' (95H).

For one class of students (in school 95S) an investigative approach was presented to them from the first day of the year as the practical approach for Year 12 Biology. It was not until May that they were given a practical exercise where they were expected to follow set instructions. When they were questioned by the researcher about this experience the students in this small class of ten indicated that they had thought that personal experimental designing was expected of all Year 12 Biology students. They claimed that they felt more responsibility if they had planned the investigation themselves and that they learnt more when they thought about, planned and did the investigations themselves. In fact when they were given set instructions one group changed them:

> [Researcher: You felt that you were able to do that?]
>
> *Student: Yes, it was much more fun than following the instructions. It can be boring you know [following instructions].*
> Students in 95S' Year 12 Biology class

Their teacher commented that these students definitely had had to change their views about the "rules of the game!" Early in the year:

> *... they expected that I would provide all work (theory notes, practical details, investigations* et cetera*) in a non-interactive format that simply gave them all the answers on a plate. They expected that they would simply do the work and just 'know' how to answer any exam question - they were frequently unable to apply their knowledge when not challenged with thought provoking activities.*
> 95S

All of the nine teachers had to address this change in their students expectations of the teacher and subject which had occurred after investigative practical work had been introduced, for example:

> *Students began to be more consultative - they would come up with plans but want to talk them through more. We did a lot of 'problem solving' discussion, brainstorming, practice investigations with a careful look at individual plans. Discussion, discussion, discussion - was very important. One by one discussion of individual work with me asking questions.*
> 95A
>
> *I needed to provide an explanation of what open investigations were about and why. I feel that I expected too much of the students initially and next year would give quite a bit of guidance in the first topic and gradually reduce my input.*
> 95R

One indicated that, as she marked all investigation linked assignments carefully and went over them in class when she returned them to her students, she used this opportunity to help her students understand what investigating was about (95B). Others introduced investigations in a dummy run (3 responses). Another regrouped the students differently each time to allow for peer assistance and asked the students to give oral presentations of their work (95K). Encouragement of students to enjoy Biology and to have confidence in their own ability was also noted (95H). Opportunities to reflect on, or repeat, practical investigations and to discuss the experience were also considered to be very important in helping students to achieve expected learning outcomes (6 responses).

In summary, the introduction of a new and unexpected approach to learning in Biology was perceived as presenting challenges to these teachers and their students. The students had had their expectations of Biology and, in particular, practical work in Biology, challenged. They had to learn different ways of working, together and with their teachers. The teachers had changed their views of themselves as teachers and had reported that they were now focussing more on the process of their students' learning as well as their knowledge construction.

10.5 Reflection on the 1995 trial

The teachers in the trial were asked to reflect on the use of an investigative approach to practical work in Year 12 Biology. Eleven of the fourteen teachers who responded had carried out a programme of investigative practical work based on the pack of investigative materials developed during earlier stages of the research project. Eight of the eleven teachers had devised additional and similar investigations for their students with one devising five to six new investigations, one three to four new ones and the rest one or two additional investigations. The teachers were asked to indicate whether they would carry out a similar programme with their students in future years, what aspects they were most enthusiastic about and what reservations they had regarding this approach to practical work.

Overall, all of the teachers who responded to the reflection section of the questionnaire, indicated that there were positive learning outcomes arising from the introduction of this approach. They perceived that their students had increased their biological understanding and had become more confident as learners. For example, comments from two teachers indicated that:

> *[There are] certainly increases in depth and breadth of understanding. As well, [the students] appreciate that their knowledge is the tip of an iceberg.*
> 95K

Students may take two or three attempts to satisfactorily complete such tasks, but with each attempt students become much more confident in their skills and judgements and can see their mistakes, or how to eliminate unnecessary effort.
95S

These eleven teachers listed a number of positive features about investigative practical work. All but two (95B and 95C) also had some reservations. These identified positive features and reservations will be illustrated by the teachers comments and discussed.

10.5.1 The positive features

The reasons listed by the teachers for continued inclusion of investigative practical work in Year 12 biology were both cognitive and affective. Aspects of open investigative practical work as a teaching strategy that the teachers were most enthusiastic about included cognitive aspects such as:

- the encouragement for students to think and plan creatively:

Yes [I would carry out a similar programme in future years] because it is one of the few subjects at school where students can think for themselves and be creative in their ideas.
95R

- the opportunity for wide discussion, for example:

... its very open to all sorts of interpretation and lots of new ideas appear in discussion.
95H

... the opportunity for discussion] in groups, using the two planning sheets - the student planning sheet (individually at first) then the other sheet ... in groups, was great. The students really got involved in this, discussing, hypothesising etc and came up with some good ideas.
95T

- the opportunity to develop skills which support ongoing learning in Biology, for example:

I value the cross over of skills into the [Year 13 Biology] individual study.
95C

The teachers also reported significant knowledge outcomes as a result of the students' involvement in this investigative work. Such knowledge outcomes ranged from an emphasis on their students' improved understanding of 'scientific method' (2 comments), their developing investigative techniques and research skills (13) to the reinforcement of declarative concepts from engagement in related practical work (3). One teacher reflected the underpinning of a co-constructivist (McNaughton, 1995) view of learning as she reported that her students would:

> *... learn to be independent thinkers having to share their ideas with their group, consider other peoples ideas and interact with group members to come to a consensus. They will have to decide upon a division of labour within the group and learn from each other. They will be carrying out the scientific method in its fullest sense and at the end of it evaluate their findings with the others in the group.*
> 95P

Essential skill and affective aspects of learning which were reported as being supported by an investigative approach included:

- the opportunity, even necessity, for increased student responsibility, control, involvement and ownership of learning, for example:

> *I feel that students have more motivation and willingness to participate if they have 'owned' the experiment and are able to choose what they do.*
> 95D

- the student's positive reaction and increased motivation (particularly for students at the "higher end of the ability scale"), for example:

> *My students really enjoyed all the open investigative scenarios they used, and in my opinion did/learned more real biology last year. ... For my own unsophisticated students the gains in satisfaction, real learning and increasing self confidence seemed so obvious.*
> 95C

- the allowance for both individual work and group dynamics, for example:

> *Allows for individual work in a small class and group dynamics.*
> 95U

> *Seeing the [students] actively involved, working as a group, asking lots of questions in their groups, comparing what they're doing with other groups.*
> 95P

Three teachers commented on the development of positive work habits such as a 'desire to complete their work totally' (95S).

10.5.2 The reservations

There were also some reservations regarding the use of this teaching strategy from this group of teachers who trialed the material in 1995. Two teachers indicated no reservations but for the others there were concerns which largely related to demands on available class time. The length of time required for student completion of the exercise formed the basis of eight of the 'reservations' comments, for example:

> *... the students enjoy doing a thorough job but it is time consuming.*
> 95K

One teacher noted that when the students were spending longer doing practical work they had less class time for learning about Biology subject matter. However, she valued the investigative approach sufficiently to say that she felt that adjustments to their programme were necessary:

> *[Being involved with this project] provided a new way of providing experiences to challenge and involve students. And reinforced my own gut feeling that it is the <u>experiences</u> that students have that most influence the way they think. I committed continuing time to some of the investigations because the students became so involved - it seemed to me a more constructive use of time than 'getting on with the syllabus.' ... I recognise the tension between 'process' and the 'body of knowledge' the students need to acquire. I come back to the conviction that my students learned more, and increased their confidence in their ability to 'do biology' when making their own decisions.*
> 95C

Two of the teachers indicated the considerable time required for teacher/technician preparation as a concern, for example:

> *preparation for investigations can take time - buying what is needed.*
> 95A

Additional class-time required through being part of a trial concerned one teacher though this lessened during the year as students became 'trained' (95U).

'Anxious, insecure and resentful students' were mentioned by one teacher (95R) but she believed that this may be overcome if she were to introduce investigations more carefully and if investigative tasks were part of junior Science. Other single comments mentioned the tension between the emphasis on process and the body of knowledge in biology (95C); the mechanics of having to mark students' write- ups (95P); that this strategy was not applicable to low level students (95D); that management of the class was more difficult with excited students (95M) and that at the end of the year the investigations were not greeted with such enthusiasm (95P). One teacher referred to the class discussion required during setting up and reporting of findings and commented that an 'experienced, confident teacher would enjoy the process more' since they may have fewer management problems with large numbers of less than co-operative students (95A).

Overall, the positive gains of increased engagement of students in their learning and a perception that students' learning of declarative and procedural concepts was enhanced when they were engaged in investigative practical work, were countered by some organisational, affective and learning outcome concerns. However, even given that there are a number of reservations to counter the perceived positive features arising from introducing an investigative approach into a Year 12 Biology programme it is interesting to note that all of the eleven teachers who answered the question "Would you carry out a similar programme with your students in future years?" were very positive with regards to the overall project and were certain that they would use the material again. The reasons given for this included the higher level of student involvement (4 responses), and the changes that had resulted in their teaching (5 responses). Two teachers indicated that they would be including investigative practical work into Year 12 Biology programmes because this approach enabled students to engage in 'real life biology' (95B), for example:

> *Its interesting to watch them at first when they lack confidence and then as they gain knowledge and confidence to succeed. I think that they understand biology and its relevance to real life more now.*
> 95H

All of the eleven teachers also indicated that they would be continuing to introduce investigations into their Year 12 Biology programmes because they perceived that their students had become increasingly confident and independent learners. Three indicated that they would be making major changes to their programmes in future (95A, 95C and 95P) with one listing herself as an 'enthusiastic convert' (95C). There was an indication that the introduction of this approach to practical work had changed some of the teachers' views of practical work. One indicated that she would repeat the investigations in the future because they were 'real biology' (95B, her quotes). Another indicated that at her school the Year 12 Biology teachers were considering changing their assessment tasks to include an investigation:

We are considering replacing our 20% Sixth Form Certificate assessment on an independent project with something along these lines to get away from the recipe-like approach a lot of the students fall back on.
95P

One teacher who was the sole Biology teacher at her urban school claimed that being involved in the project made her feel more 'mainstreamed' which could be interpreted to mean that she felt that she was now teaching Biology as she perceived it was taught by other teachers or it may indicate that she valued the opportunity to be part of a project alongside other teachers. Another so enjoyed her involvement that she talked about an extension of this approach to her highly receptive science department (95A). One indicated that she felt 'far more flexible, understanding of and accepting of change' as a result of her involvement in the trial, so that she is now reacting favourably to other innovations such as trials of new assessment procedures (95U). One had become so enthusiastic about the approach that she asked for permission to share it with teachers at neighbouring schools (95U). Some of the teachers had spent time developing additional investigations for use with their Year 12 Biology classes. None indicated that they would continue to introduce investigative practical work simply because the curriculum required them to do so.

10.6 Summary

This chapter has considered the challenges to teachers' previously held meanings for teaching and learning in, and of, Biology when partially-open investigative practical work was introduced to Year 12 Biology classrooms. The teachers in the 1995 trial indicated that they had changed their views of themselves as teachers of Biology. They had become more facilitative than didactic and were focussing more on encouraging their students to be actively engaged in classroom programmes. They had developed, and were using, a wider range of teaching strategies. They had also noted that their students had had to redefine for themselves what it meant to be a learner in, and of, Biology and that some of their students had difficulty with this aspect of changing programme requirements.

This chapter also reported on the teachers' response to the 1995 trial. The positive features of such an approach as declared by the teachers, and their reservations, were examined. The necessity for increased student responsibility and control of their own learning was identified as a positive feature as was an increase in student thinking, opportunities for individual and group work, the imperative for lots of discussion and the opportunity to develop skills which could be used in later studies. The teachers also indicated that they had perceived significant cognitive outcomes such as improved student understanding of research skills and the students' increased understanding of declarative concepts. The reservations that the teachers had regarding this approach to practical work centred around demands on time for completion of the investigations, equipment provision and marking. They also indicated increased classroom management demands especially when lower ability students were carrying out an investigation.

It is clear that these teachers had found multiple solutions to their 'problem' - that of the curriculum required introduction of openness to the Year 12 Biology teaching-learning programme. They had identified ways by which they could help their students to cope with the demands of this approach. They had also indicated that the value of this approach was such that they would continue to use it with future Year 12 Biology classes and junior Science classes.

The introduction of partially -open investigative practical work to Year 12 Biology programmes was expected to be multi-dimensional, involving the use of new materials and/or new teaching approaches and possibly requiring an alteration of beliefs (Fullan, 1991) on the part of the students and their teachers. The findings from this 1995 phase of the research study indicate that such a change was required of both the teacher and the student body when an investigative practical work was introduced. Roles, previously understood either implicitly or explicitly by the participants had been renegotiated so that teachers and students had common expectations of learning in Biology. Intended goals had become visible in the classroom. If this had not taken place then changes in expressed goals would not have necessarily resulted in changes in the classroom (Penick and Bonnstetter, 1993).

Chapters 8 -10 of this thesis have considered the impact of the introduction of partially-open investigative practical work to Year 12 Biology classrooms from the teachers' standpoint. The teachers have identified and described cognitive challenges and gains, and affective value for, the introduction of openness into Year 12 Biology practical work. Chapters 6 - 7 traced these cognitive and affective aspects from the students' viewpoint. Chapter 6 considered how the students approached investigative work - how they hypothesised, planned, gathered data and evaluated their own work. In contrast, Chapter 7 considered the students' response to investigative practical work. The findings from these data analysis chapters will now be placed together as the answers to the research questions and implications from the research findings for classroom practice, teacher development and future research are addressed in Chapter 11.

Chapter 11: Discussion

11.1 Introduction

The phasing in of a new national curriculum for a school subject frequently introduces change, both to the subject matter to be covered by students studying that subject, and the manner in which it is to be taught. By 1993, when this research began, the final curriculum document for the teaching of Science in New Zealand schools was close to being published and the draft document for Biology at senior secondary levels in New Zealand was available for comment. Both of these documents placed greater emphasis on students carrying out scientific investigations than had been the case in previous syllabuses and prescriptions.

The official New Zealand curriculum for Biology states that learning in Biology should enable individual students' 'ideas, experiences, interests, enthusiasm, values and culture' to be 'acknowledged and enhanced by actively involving students in investigations which are relevant and meaningful in their world' (Ministry of Education, 1994, p6). Additionally, the curriculum document claims that it is through this process that:

> students can develop biological knowledge and scientific skills and attitudes which will increase their confidence to explore and evaluate ideas and theories with an open mind.
> (*ibid*, p 6)

A connected emphasis is the important role that teachers play in this process, especially in 'removing barriers to achievement so that the participation of students in the learning process is fostered and enhanced' (*ibid* p 7).

This research project followed students and teachers who were engaged in biological investigation. It also looked at the match between the expected outcomes of the national curriculum and the perceived learning outcomes of the Biology classroom. The research explored ways in which open-ended investigative practical work was considered by teachers, and students, to promote learning of biology and identified some of the perceived difficulties associated with this teaching approach. It sought to identify means by which teachers can maximise the learning opportunities for students as they carry out investigations in Biology.

The research questions for this thesis were selected because, whilst there was, in the early nineties, an increasing emphasis on investigative approaches to learning in Science and Biology in New Zealand schools, there was little detailed analysis of this approach in practice in the New Zealand based science education research literature.

The research questions that were developed for this thesis were:

1. In what ways can the students' abilities at carrying out open investigative practical work be enhanced?

2. In what ways can Biology teachers be supported to introduce openness into Year 12 Biology practical programmes?

3. What are the perceived benefits accruing from introducing investigative activities into classroom programmes in Science/Biology?

4. What are the perceived constraints regarding the introduction of investigative activities into school Science/Biology?

This chapter presents a summary of the general findings of the research project (Section 11.2) and answers the four research questions (Section 11.3). It identifies benefits which the participating teachers perceived as accruing from introducing investigative activities into Year 12 Biology programmes and notes some perceived constraints regarding this introduction. Consequent changes to classroom expectations, roles and procedures will be specified and means of helping teachers and students to cope with such changes will be suggested. Adherence to a co-constructivist pedagogy will be presented as a way of enhancing students' learning during open investigative practical work. The apparent simplicity of curriculum expectations can be challenged by observed classroom practice (Section 11.4) and a model is developed to emphasise the complexity of teacher and student acts and decision-making which occurs when investigating takes place in school Biology programmes (Section 11.5). Links between this study and other research are considered in Section 11.6 and suggestions as to future directions for research in this field are offered in Section 11.7. Section 11.8 presents implications for classroom practice and teacher development arising from this study and concluding remarks appear in Section 11.9.

11.2 Summary of general findings

The study covered three years of classroom intervention (1993 - 1995). During those three years, data were collected as Year 12 Biology students in five classes in the case study school, and students in fourteen other schools in New Zealand, were introduced to a more open approach to practical work in school Biology. A summary of the findings of the study as they relate to students as investigators and their teachers' response is given below.

11.2.1 Students as investigators

The Year 12 Biology students who participated in this study were followed as they planned and carried out partially open investigations. They were also asked to appraise their findings and to evaluate themselves as investigators.

The majority of the sixteen to eighteen year old students in this study had a limited understanding of the role of hypotheses in scientific inquiry and did not find hypothesis generation easy (see Section 6.2). The students did not often, of themselves, write more than simple descriptive and predictive hypotheses (Wenham, 1993). Nor were many of the students able to generate testable predictions from their stated hypotheses. Their hypothesis generation abilities appeared to be both context and task format dependent.

The students' understanding of the inherent requirements of gathering reliable and valid scientific evidence and their ability to evaluate their own expertise at scientific inquiry was also very variable. The students did not always demonstrate sound procedural approaches when planning an investigation (see Section 6.3). Nor did they readily identify declarative concepts underlying an investigation. Although these students knew about the principles of fair testing they did not always demonstrate consistent application of these principles. When planning and gathering data these students had a poor understanding of experimental protocols relating to sample size and replication. They had difficulty identifying and manipulating variables and did not always specify required measurements with sufficient precision.

Many of the students demonstrated only a limited understanding of concepts of evidence. Some of the students claimed validity on grounds which the scientific community would not find acceptable (see Section 6.4). However, there were those who questioned the validity of their results more critically, following scientifically accepted criteria.

The students welcomed opportunities to try out their developing understandings about investigating. Their overall confidence at carrying out investigations grew during the year (see Section 7.2) but, after experience at investigating, they declared a small loss of confidence with some aspects of designing experiments, such as selecting appropriate equipment and recording their findings. Some students accepted the opportunity for personal involvement, self direction and responsibility very quickly, whilst others needed support and encouragement from their teachers for much longer periods of time. Strategies designed to increase students' confidence and to facilitate students' investigative work have been developed and are listed in Appendix N.

The majority of the students indicated a positive response to investigative practical work in Biology (see Sections 7.3 and 7.4). They perceived that engagement in practical work had increased their learning in the cognitive, skill and affective domains. They perceived that they had learned both declarative and procedural concepts and recognised the value of practical work as a means of both personalising and visualising their learning. A small number of the students also recognised that they were more metacognitively aware of their own learning as a result of their involvement in investigative practical work. In addition they indicated that they found it enjoyable, relevant and realistic and felt that such work helped them gain confidence as it increased their personal involvement. The students perceived the role of the teacher as critical.

11.2.2 The teachers' response

The participating teachers reported affective and cognitive gains for their students from open investigative practical work in a Year 12 Biology programme (see Sections 8.3 and 10.5). Student knowledge and skills gains identified by the teachers included working co-operatively, creatively, independently, critically and honestly. Students were perceived to be thinking more deeply about their work and to be more cognitively engaged in their practical work. The teachers perceived that this increase in student engagement positively influenced their students' declarative and procedural conceptual understanding.

However, in order to maximise these cognitive gains the teachers had to support their students as they investigated (see Section 8.4). They perceived that they needed to offer reassurance and encouragement and to present their students with cues to past knowledge and experience in order to help them make appropriate connections. Similarly, they often found it necessary to stage the introduction of degrees of openness, scaffolding the students as they took their initial tentative investigative steps.

The teachers also expressed some concerns regarding the introduction of openness into a Year 12 Biology practical programme (see Sections 8.6, 8.7 and 10.5). They were concerned for students who did not have positive experiences in the less structured environment and for students who did not bring sound co-operative learning skills to their biology learning. They expressed dilemmas regarding the assessment of investigative open work, especially within a perceived requirement to formally assess all aspects of students' work. The teachers were also concerned about time and resource (equipment and ideas) limitations (see Section 8.7).

The teachers who participated in the research project indicated that they had changed their approach to Year 12 Biology teaching as a result of this involvement (see Sections 8.8 and 10.4). They had become more facilitative than didactic and were focussing more on encouraging their students to be actively engaged in classroom programmes. They had developed, and were using, a wider range of teaching strategies. Feedback, support and personal reflection all contributed to the professional changes identified by these teachers. The teachers also noted that their students had had to redefine for themselves what it meant to be a learner in, and of, Biology and that some of their students had difficulty with this aspect of changing programme requirements.

11.3 Answering the research questions

This section addresses the four research questions directly. The answers to the questions frequently overlap. The closely linked questions 3 and 4 are addressed first as the answers to these questions also inform the other two questions. The two questions (1 and 2) relating to the enhancement of students' ability as they carry out investigative work and support for teachers who are introducing investigative practical work, are addressed together as the closely interwoven student - teacher relationship has been identified as a very important feature of an investigative biology classroom.

11.3.1 Perceived benefits accruing from introducing investigative activities into Year 12 Biology programmes

An open investigative practical approach was stated by the teacher participants of the 1993 and 1994 case study and the wider 1995 trial to be motivating by encouraging the personal involvement and commitment of students to their work (see Sections 8.3 and 10.5). They noted an increase in positive student engagement in their learning. Such an approach was seen to promote students' confidence regarding their ability to make useful and valuable decisions. Students were perceived to be more metacognitively aware, such that they were taking on increased responsibility, control and ownership of their learning. Investigative approaches were understood to help students to develop practical skills and identified as contributing to students' development of co-operative learning skills. When engaged in investigative practical work students were encouraged to take personal responsibility for their actions and became more resilient and determined when faced with "failure". Involvement in investigating was seen to encourage flexibility of thinking in the students. The teachers believed that carrying out these partially open investigations led students to a better understanding of biological concepts and helped students to a better understanding of the nature of scientific inquiry.

The students' positive response to investigative practical work also encouraged the teachers to include it in their programmes (see Sections 7.3, 7.4, 8.8 and 9.5). In their responses to their teachers and the researcher, the participating students stated that they valued the investigative approach for affective and motivational reasons. The students noted that they were more personally engaged in, and thinking about, their work and recognised a gain in their understanding and learning resulting from their personal involvement and the opportunity for visualisation of concepts. The students also indicated that such an approach not only helped them understand the procedural concepts associated with investigation but also declarative biological concepts. In addition, the students appreciated the opportunity to apply biological knowledge, the personal challenge of this approach and changes to regular classroom routines that this work brought.

11.3.2 Perceived constraints regarding the introduction of investigative activities into school Biology.

The second research question focussed on the constraints associated with the introduction of investigative activities to school Science and Biology. From the data gathered throughout the research project it can be seen that the perceived positive outcomes listed above did not necessarily or effortlessly accrue. The teachers became dilemmas managers (Lampert, 1985) as they coped with the many different issues that arose when a different approach to practical work was introduced into their programmes. Whilst the teachers perceived that there were many benefits accruing from the introduction of openness into the Year 12 Biology practical programme, these benefits claims frequently had to be qualified. If the positive outcomes were to be achieved then teaching approaches may have needed to change (see Sections 8.4 and 10.4). The teachers needed to actively and openly teach their students how to carry out investigations, through strategies such as analysis of structured experimental methods, having trial runs, providing planning sheets, providing 'questions to think about', offering alternatives to think about, by being constructively critical, by initiating considerable discussion and by allowing repeated attempts.

The teachers wished their students to have positive experiences when carrying out practical investigations. For this to happen the teachers found that they often needed to act as role models in order to demonstrate possible approaches to investigations. Additionally, they gave students increasing freedom of choice through a staged introduction of openness and cued students to help them make appropriate connections between past and current situations (See Section 8.4). The teachers directly taught their students to appraise and critique their work and continually encouraged them to do so. The teachers gave their students time to think about the decisions that they were making and time to test their ideas (see Section 9.4). The students were encouraged to be accurate and precise with respect to detail both in discussion and when gathering data (see Section 8.4), and were helped to write reports which appropriately targeted a nominated audience. Students were provided with detailed feedback after an investigation had been completed. Students were questioned rigorously in the Biology classroom and encouraged to debate and value an apparent multiplicity of outcomes arising from open investigations (see Section 6.4).

The teachers helped their students to redefine their ideas about what it means to learn be a learner of Biology in order to help the students adjust to the changing requirements which carrying out open investigative work demanded of them (see Section 10.4). The teachers also acknowledged that the students were often thinking along lines which were very different from those of the teacher, that some students had difficulty working within a less structured environment and that some students did not necessarily possess sound co-operative learning skills (see Section 8.6).

These teachers who had introduced a greater degree of openness into their practical programme in Biology, were also aware of assessment focused considerations and time and/or equipment resource related concerns. They acted to address or minimise these.

Assessment focussed issues had a strong influence upon the introduction of openness into practical work in the case study school (see Section 8.6). Such assessment considerations related to all of the Year 12 Biology teachers as they were required to work within a common assessment programme. The experiences of the City High teachers were that it was advantageous for them as teachers working within a common assessment programme to debate their philosophy of the role of assessment in relation to open practical work and to reach a shared understanding of the assessment practices they were to employ. The debate covered aspects of assessment such as what would be assessed, how it would be assessed, how frequently the assessment would take place, and whether whole investigations or aspects of investigations be assessed. If the latter, how many times would each aspect be assessed? How would the students be grouped during the assessment? Would there be individual or group assessment? How would the assessment be organised during the investigation and over the year? Would there be opportunities for repeat assessments? It would have been of value for all of the Year 12 Biology teachers working within a common assessment programme at City High, to have both agreed on the nature of the assessment programme for the year at the beginning of the year, and for all of the teachers to have contributed to the development of this programme.

Resource linked concerns related to time limitations, equipment restrictions and the ready access to contextually-based practical investigative exercises (see Section 8.7). The teachers concerns regarding time limitations included the impact of introducing open investigations on the overall scheme of work for Year 12 Biology. Several issues were addressed by the teachers in order to reach shared school-based understandings and / or decisions about this impact. These included the breadth and depth of coverage of the curriculum, whether students should be allowed sufficient time for conclusion of an investigation even if other work is unable to be covered as a result, and a possible change to prevailing teaching strategies or homework requirements to allow for the introduction of a different approach to practical work (see Sections 8.7 and 9.5).

With regard to restricted equipment availability, the teachers in the research project reached shared understandings and made shared decisions regarding the value (requirement and degree) of having possibly useful equipment visible to students during the design stage of an investigation (see Section 8.7). They considered what was an acceptable balance of cueing of technical aspects of procedures to enhance an investigation, against the loss of creativity which might ensue. They also needed to find ways of overcoming the difficulty of suddenly requiring equipment which had not been pre-ordered through the school science technician.

A lack of readily accessible contextually-based practical investigative exercises was perceived by the teachers to restrict the introduction of open investigative practical work as both teacher creativity and the time to develop these resources were identified as limited (see Section 8.7). The teachers acknowledged a need for either contextually-based practical investigative exercises which were other produced (commercially or otherwise) and readily available, or professional development time during which groups of teachers could produce such exercises.

11.3.3 Supporting teachers and students during the introduction of openness to investigative practical work in Biology

The first and second research questions focussed on the support that teachers and students perceived they needed in order to introduce openness to investigative practical work so that student learning would be enhanced. Concomitant with any change in expected procedures were changes to previously understood classroom relationships and task related activities. The teachers and students engaged in this research project experienced changes in their respective roles, and in their beliefs and expectations about the activities of a Biology classroom (see Section 10.4). The teachers and the students were all learners in this new situation.

Figure 11.1 is a diagrammatic representation of possible inter-relationships between teachers and students engaging with an investigative task and the learning outcomes which result from this engagement. Teacher and student relationships occur within the framework of the classroom activities, in this case the investigative task. As a result of the interaction of the teacher and the students with each other and the task, knowledge is generated relating to the task. Although this diagram represents the interactions within one biology classroom, within a school the teacher and students may also interact with other teachers and other students within the specific context of the biology investigative task. Students may also interact with other persons outside of the school community as they engage in an investigative task. Figure 11.1 is therefore a very simplified representation of a complex interaction system.

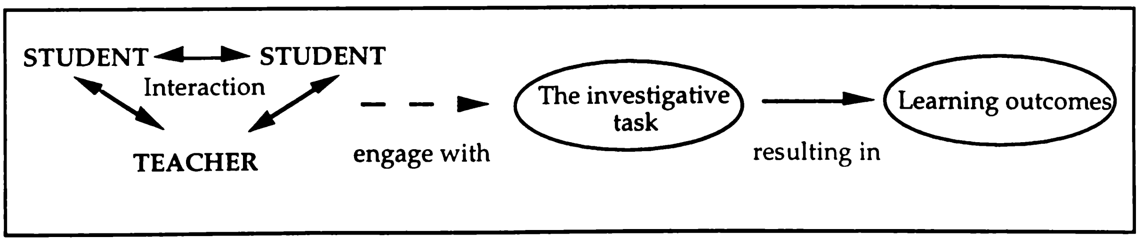

Figure 11.1: Interpersonal and task interactions leading to learning outcomes in a classroom

The impact of the challenges and changes to the interactions represented by Figure 11.1 on the students and teachers as they engaged in investigative practical work will be discussed.

Teacher-student interactions

Teacher style is often represented by stereotypes (White, 1988). Teachers have been classified as consistently and predominantly informers, problem-solvers or inquirers. Although teachers may change their approach during a year, depending on the subject being taught or make-up of the students in the class, a teacher's style is considered to vary only slowly with time (Galton and Eggleston, 1979). However, ideally, teaching style should match with lesson content and task if an optimal learning situation is to develop. Introducing students to investigative practical work required the teachers to adopt a more facilitative, enabling style rather than to be the informer that many of the students appeared to expect and wish for. The teachers therefore found it necessary to modify their usual teaching styles (see Section 10.4). Such a shift can be destabilising and alter a student's confidence if it occurs suddenly with no warning. The students needed to be prepared for the new approaches required by this curriculum change in order for the outcomes from the new learning strategy to be maximised. Whilst some of the students in this study were not able to adjust to the 'new' and 'unexpected' approach, others were personally empowered by this approach, such that they took responsibility for re-designing an investigation when, at one stage, they were given a carefully planned recipe to follow.

Student - student interactions

When students were placed in a situation which required them to work co-operatively within small groups, they had to redefine/renegotiate their working relationships with their peers. Although small group activities appear to be a significant part of most science classrooms, these groups may not be truly co-operative (Graves and Graves, 1990; Segal and Haigh, 1991). The nature of the research investigative tasks often required a division of labour if the task was to be completed within the given time and this did not always occur without cueing from the teacher (see Sections 8.4 and 10.4). Data from earlier phases of this research (Haigh, 1993) supported the assertion that students were not always demonstrating the intra-group assistance required if all members of their group were to understand the task or to have equal opportunities to contribute to planning discussions and achieve desirable learning outcomes. The students therefore, needed opportunities to become aware of, and practice, successful co-operative learning strategies.

Student - task engagement

Unless the students were prepared before-hand, a sudden shift from carefully structured experimental work to the relative freedom of partially open investigations caused confusion. More was required of students as they tackled a task incorporating a degree of openness than would have been the case if they had been carrying out practical work following set instructions. Carrying out investigations required the students to link contextual cues and declarative concepts with procedural concepts (see Sections 6.3 and 8.4). They needed to understand why they were doing the investigation, to recognise what previous content knowledge could be relevant and what technical procedures would be applicable and then they had to put this information together to conduct the investigation. Making such linkages required time for personal reflection, group discussion and research. Strategies for encouraging such link-making needed to be emphasised and valued if students were not to proceed immediately into activity without prior thought and planning. Thinking about these aspects of the investigation did not stop once the students started to conduct the practical aspects of the investigation. Doing science is an holistic activity and it is to be expected that, as the student proceeds what is being done will alter the state of affairs in some way. Thus, refinement of initial understanding was occurring at the same time as the students were proceeding with the practical work. The teachers' acknowledgement and valuing of this and the provision of opportunities for the students to reflect and re-direct their efforts were important aspects of this approach to practical work (see Sections 6.4, 8.4 and 10.4).

As was discussed in Sections 7.2 and 7.3 the students suggested that their confidence with investigating would be enhanced if they were given the opportunity to reflect on the process of scientific inquiry and their own practice in this area. They also indicated that the teachers could help by making linkages between prior knowledge and present situations more explicit and by facilitating 'refresher' courses on all aspects of designing, carrying out and reporting on the findings of practical investigations.

As indicated in Section 6.2. the students also required direction when generating hypotheses. The results of this case study indicated that students did not often, of themselves, write more than simple descriptive and predictive hypotheses (Wenham, 1993). If the students were to progress beyond writing descriptive statements as hypotheses then the teachers needed to ask their students to rewrite descriptive hypotheses as predictions and to encourage the students to tentatively indicate a possible cause of the relationship that they had identified. Couching the investigation question with a clearly proposed causal relationship whenever possible has been shown to help in this regard.

The students also indicated that they required help to design an experiment within their investigation which would produce significant data, and help to understand why such evidence was required (see Section 6.3). Findings from the research project indicate that the students' plans were enhanced if individual planning was followed by opportunities for group planning and discussion. The students' investigations benefited from teachers who reiterated the characteristics of a fair test and asked directed questions of the students regarding the development of a fair test for the specific investigation. The students required cueing regarding significant variables and how to conduct carefully controlled experiments. They needed to be encouraged to take precise quantitative measurements. It was useful for teachers to demonstrate required specific techniques and to indicate expected format(s) for the collection of data. The students needed also to be encouraged to trial techniques, change their plans, and repeat experiments.

Some students requested an indication of when working co-operatively could facilitate the investigation. The students also indicated that they appreciated teachers who managed and organised the classroom equipment and student dynamics in ways that facilitated their working and that they wanted teachers who allowed them to learn through their own mistakes.

The teachers who led class discussions relating to particular aspects of the context of the investigation which may have a bearing on the procedures being carried out in the investigation, improved the students' investigative skills. As did the teachers who helped students with an interpretation of the findings, and who challenged the students to consider the reliability and validity of their findings. In addition the students asked that their teachers provide opportunities for whole class discussions regarding possible applications of the findings of an investigation.

Approaches to carrying out investigations are very context dependent and different students tackled the tasks in different ways. However, the students were helped by the teachers who gave them opportunities to analyse others' approaches, and by teachers who staged the introduction of openness (see Section 8.4).

The City High teachers developed strategies to help students engage more profitably with the investigative task. These included questioning strategies to help students to recognise linked declarative and procedural concepts; to form hypotheses from which they could develop specific questions; to identify variables and the consequent identification of the dependent and independent variables, to increase the validity and reliability of their gathered data; to take appropriate measurements; and report in an appropriate genre. These questioning strategies were developed in detail as guidelines for the teachers during the third phase of the research project.

Teacher - task engagement.

The teachers in this study reported that time became a limiting factor in the success, or otherwise of the introduction of partially open investigations into their biology programme (see Sections 8.7 and 10.5). There were considerable time demands for prior-class organisation, completion and evaluation of the investigation. Such dilemmas invited the teachers to reflect on such aspects of their teaching as their overall aims of their teaching programme, specific aims of particular lessons, and their own understanding of and expertise in the investigative process. Practical difficulties eased as the teachers' involvement with investigative approaches increased but demands for technical assistance were always likely to be made, with requests for unanticipated equipment constantly possible.

The case study teacher who introduced a greater emphasis on investigative work in 1994 found that such an approach was not always compatible with the biology department's schemes of work. For example, difficulties with incorporating this approach into only one of several Year 12 biology classes generated difficulties with assessment procedures for the other teachers in this department (see Section 8.6). Time for the Biology teachers in a school to develop shared understandings of philosophy and intent of Biology programmes would appear to be useful. Some of the teachers reported that engagement in these tasks highlighted ongoing departmental debates in science education such as those regarding "process versus content", the nature of science, general aims of science education and learning outcomes associated with practical work (see Section 8.8).

Learning outcomes

A very noticeable consequence of student engagement in investigative tasks was a resultant multiplicity of learning outcomes (see Sections 6.4 and 8.3). When students were asked to identify what they had learnt as a result of carrying out an investigation their lists covered a range of understanding of context, content and procedure. They also regularly listed affective outcomes such as learning to work within a group or that listening to other people is a good idea. Some of the outcomes the students listed might not at first glance be considered to be positive such as "how to break scientific equipment!" but one would hope that this experience may reduce the frequency of further breakages.

During investigations the students assumed responsibility for their own learning with their teacher acting as a catalyst, mediator and facilitator. The students have claimed that involvement in investigations 'personalises' their learning (Haigh, 1993; see also Section 7.3). The teachers contributed to this process of meaning-making through having greater access to the social domain of 'science' and therefore being more aware of scientific understanding. The teachers were able to help the students to move closer towards scientific understanding through having an awareness of the students' present knowledge and by extending a challenge to change. There was also the challenge of helping students to identify what may be common in a variety of diverse investigative tasks.

11.3.4 Enhancing students' learning during open investigative practical work

The first research question asked how the students' abilities at carrying out open investigative practical work could be enhanced. Broad based answers to this question have already been given. The focus here is on a possible pedagogical framework to enhance the students' learning during investigative practical work.

Knowledge generation is the product of joint construction of understanding by the student and more expert members of the culture (Wood, 1988). In the case study's Biology classrooms the social relationships that impacted on the students' learning in relation to investigative practical work were between the students and their teacher, and between student and student as the students gained in confidence with respect to the task. The cultural processes within these classrooms related to both general classroom expectations and those more directly linked to the learning of biology. The co-constructivist processes which enabled the generation of socially constructed knowledge when the students and their teacher were working together on a practical investigative task are shown in Figure 11.2.

Figure 11.2, which is an elaboration of Figure 11.1, acknowledges the social, cultural and scientific factors which influence the student - teacher and student - student interactions and construction of knowledge. The students' developing understanding of biology was thus a 'product of dynamic, mutual and interdependent constructions of an active learner and social and cultural processes' (McNaughton, 1995, p 199). The teachers and their students were drawing on their prior knowledge of declarative and procedural scientific concepts. Their use of this knowledge was influenced by the prevailing and negotiated cultural norms and social behaviours of the classroom (Rogoff, 1990).

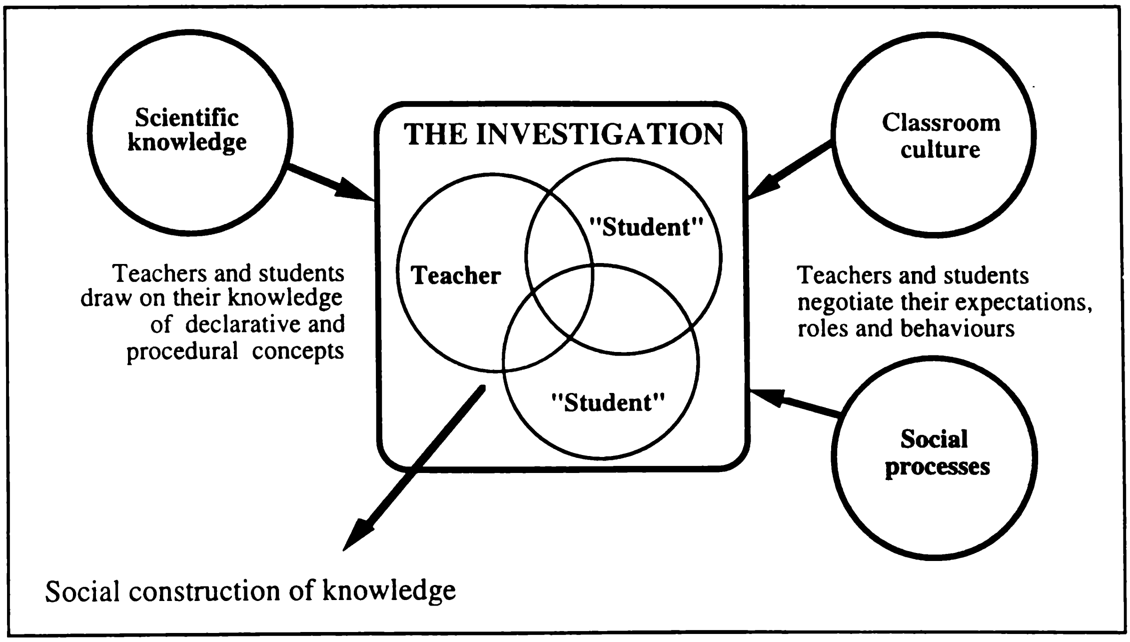

Figure 11.2: Co-constructivist processes at work in a Biology classroom

The teachers in the case study school became more aware of the need to deliberately address their students' prior knowledge. For the students to function optimally as they investigated they needed to be challenged and helped to learn the declarative and procedural concepts inherent in a Year 12 Biology programme. Classroom data support the researcher's contention that the depth of the students' learning was dependent upon the particular task on which the students were engaged and on the manner of the presentation of this task (see Section 6.3). As is recognised by those who work within a co-constructivist learning environment (Rogoff, 1990) the 'expert', usually the teacher but sometimes it was requested of the researcher, impacted on the process of the students' construction of meaning. The teachers helped their students through reassurance and encouragement, by offering constructive criticism, by cuing connections for the students, by cuing students with respect to required degrees of precision of measurement and required reporting format. The teachers also found that they needed to help their students to identify the commonalities of investigative procedures which would assist them to tackle the different investigative tasks (see Sections 6.3, 8.4, and 10.4).

The teachers worked towards a small number of previously defined learning outcomes through having an awareness of the student's present understanding and by presenting an opportunity for learning. However a multiplicity of learning outcomes made them increasingly aware that students were learning more than they had anticipated (see Section 6.4). The students' demonstrated inability to work in a co-operative learning manner without direct teaching in this regard has indicated that unless students are directed to work in this way, learning outcomes which are unexpected, and sometimes undesirable, may result (see Section 8.6). Changes in the classroom culture which may need to be made to maximise the learning opportunities for students as they carry out investigative practical work are addressed in Section 11.8.

11.3.5 Supporting teachers as they introduce openness into Year 12 Biology practical work

The second research question asked how teachers can be supported as they introduce openness into Year 12 Biology practical work. Broad based answers to this question have already been given. The focus here is on identifying practical ways of helping the teachers. Time for preparation of tasks, equipment and materials, time for completion of the activities, time for assessment and report back have all been identified as significant for the successful introduction of partially open investigations into biology programme (see Sections 8.7 and 10.5).

Increasing the availability of other prepared resources, which include detailed teacher guide material based on carefully trialed investigations may be useful, though such materials may restrict creativity and not allow for learning which arises from specific contextual happenings. A department who plans to introduce a greater number of investigative tasks into their Year 12 Biology programme may need to consider the impact of this on the overall structure of the years' teaching and assessment programmes. Time for the Biology teachers in a school to develop shared understandings of philosophy and intent of Biology programmes would appear to be useful. Suggestions for teacher development with respect to this curriculum change are given in Section 11.8.

Demands for an increase in technical assistance are a common feature of school Science department management and the findings from this study demonstrate the importance of the availability of proficient ancillary support.

11.4 Curriculum expectations and demonstrated classroom practice

The findings of this research project have challenged the rhetoric which suggests that open investigative practical work can be introduced into Year 12 Biology classrooms with ease. They also point to a mismatch between curriculum expectations and many Year 12 students' actual ability with respect to investigative practical work and this is now discussed.

The New Zealand Curriculum Framework (Ministry of Education, 1993a) describes the progression of student achievement in eight levels from junior primary to senior secondary. The students who were participating in this research project were in Year 12 where the majority of the students are generally expected to be working at and achieving curriculum levels 6 and 7.

However, it is important to recognise that students as individuals will be learning at different rates and that it is 'not expected that all students of the same age will be achieving at the same level at the same time' (Ministry of Education, 1993b, p 15).

The *Biology in the New Zealand Curriculum* document (Ministry of Education, 1994) restates achievement objectives from *the Science in the New Zealand Curriculum* document (Ministry of Education, 1993b) for the strand entitled "Developing Scientific Investigative Skills and Attitudes in Biology" with just 'minor revisions to make them more specific to biology' (Ministry of Education, 1994, p 37). The achievement objectives for this curriculum strand are grouped into two-level bands. The achievement objectives for levels 7 and 8 repeat those for levels 5 and 6 but are extended to indicate additional requirements and/or rigour.

Whilst there is a general expectation by national and school level curriculum developers, and assessors, that students will have achieved national curriculum level 6 achievement objectives by the end of Year 11 many of the student participants in the research project were not confident of their ability to work at this level with respect to investigative skills. Their demonstrated abilities were also not consistently at level 6 either at the start of their Year 12 studies or at the end of the year (see Section 6.3). For example, the students demonstrated that they had difficulty with aspects related to obtaining reliable and valid results. Most students did not plan to repeat the experiments, often did not use an appropriate sample size and had difficulty deciding how to use a control. They needed teacher direction in order to move to precise quantitative measurement, to question and analyse the validity of their findings and to produce well reasoned and concise reports. The changes in the students' declared confidence and demonstrated ability indicated that for most students, and for most aspects of investigating, the students gained in confidence and ability after experience with investigating, with a greater number of the students achieving learning outcomes associated with level 6 achievement objectives by the end of their Year 12 Biology year. Whilst a number of students were moving to achieving the level 7/8 achievement objectives expected of the majority of students by the end of Year 13, many were not able to work at that level. It would appear that the students in the research project needed more direct teaching in this regard in Years 11 and 12 if they were to be able to achieve the level 8 scientific investigative skill objectives listed in the curriculum documents by the end of their Year 13 schooling (see Section 7.2).

Another challenge from this study's findings to the national biology curriculum document relates to the iterative nature of investigation. Although the Biology curriculum refers the reader to the Science curriculum for detail of the achievement objectives below level 5 it does not include the note found in the science curriculum (Ministry of Education, 1993b) which alerts the reader to the iterative nature of investigation, viz:

> The processes of investigation are not necessarily sequential. ... Students should be reflecting on their decisions, actions and findings and modifying their plans and actions as they are proceeding.
> Ministry of Education, 1993b, p 47

The iterative nature of investigation was supported by the research because, as the activities associated with investigation in a Biology classroom were closely observed and analysed, the complex, iterative and holistic nature of an investigation became increasingly obvious. Tobin (1984) has indicated that process skills are not as likely to be separated out from science content when problems are encountered in real life situations, compared with the separation of content and process which occurs when problems are encountered in school situations. The nature of the investigative tasks in the intervention was such that although they were encountered in school situations they were perceived by the students to be 'real life' (see Section 7.3). It is thus possible that this separation of concept and process was less likely to occur as the students tackled the investigations. Investigative work may therefore be a means of unifying or delivering a more holistic approach to science education. It allowed for the transforming of scientific knowledge for action in practical situations.

Figure 11.3 summarises the actions of students who were investigating and links these with the processes of investigating as outlined in the Science and

Biology curriculums (Ministry of Education, 1993b and 1994). The diagram shows that, contrary to the apparent simplicity of the process as stated in the Science and Biology curriculum documents, when students were investigating they were utilising procedural and declarative concepts in a complex and integrated manner within a particular context.

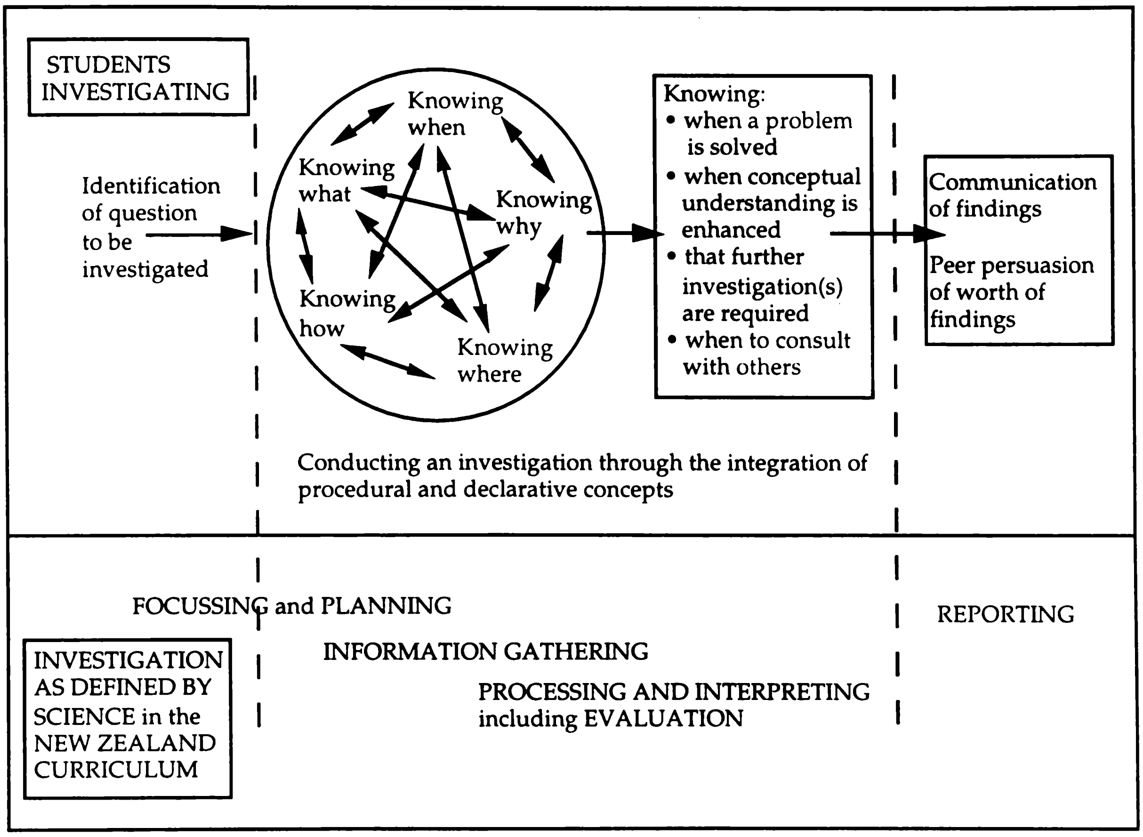

Figure 11.3: Investigating - curriculum requirements and demonstrated classroom practice

As shown in Sections 6.2, 6.3 and 7.2 the students had to draw upon their understanding of the particular context - they had to know why they were conducting the investigation and to integrate this knowledge with their understandings of what, and how, and where, and when they were to carry out the investigation. They had to draw upon their prior knowledge related background information - the knowing what aspect. They had, also, to retrieve and action their prior knowledge relating to how to carry out an investigation and which specialised techniques to use - the knowing how aspects of an investigation. In addition, they had to access their knowledge of where to go to get information, their knowledge of the most appropriate place to carry out their investigation and when to do this. The accessing and application of this knowledge did not occur necessarily in a linear fashion. As one aspect of knowing was accessed, this information triggered the realisation that other aspects must also be considered. At times, several aspects had to be considered together.

The students' utilisation of both procedural and declarative conceptual knowledge as they investigate is supported by writers such as Gott and Mashiter (1994) and Hodson (1993a). Ohlsson (1992) similarly challenged the drawing of a sharp distinction between declarative "knowing that' and procedural 'knowing how' knowledge and supported Bereiter's (1992) contention that such a distinction results in impoverished learning, where understanding becomes identified only with descriptive knowledge and problem-solving is reduced to mechanical procedures. It is during investigation that the declarative and procedural concepts become closely linked and both were required to be accessed by students who were investigating.

Once the students had gathered their data and processed it, through the integration of procedural and declarative knowledge, they were required to make decisions regarding the closure of the investigation (see Section 6.4). They needed to be able to recognise when they had solved their problem and to be able to acknowledge what they had learnt from investigating it. Whilst some students realised that they were able to draw conclusions from their gathered data, some made a decision that further investigations were required and others realised that they needed to consult further before they could come to any conclusions regarding the gathered data. Once they had made these decisions and acted upon them, the students were able to communicate their findings and persuade their peers regarding the worth of their findings. The processes of investigation, and the introduction of degrees of openness inherent in investigative practical work to school students, has thus been shown to be very complex.

11.5 A model for investigating in school Biology

The following model, Figure 11.4, has been developed to help science educators, teachers and students clarify and make sense of the complexity of investigative practical work in Biology classrooms.

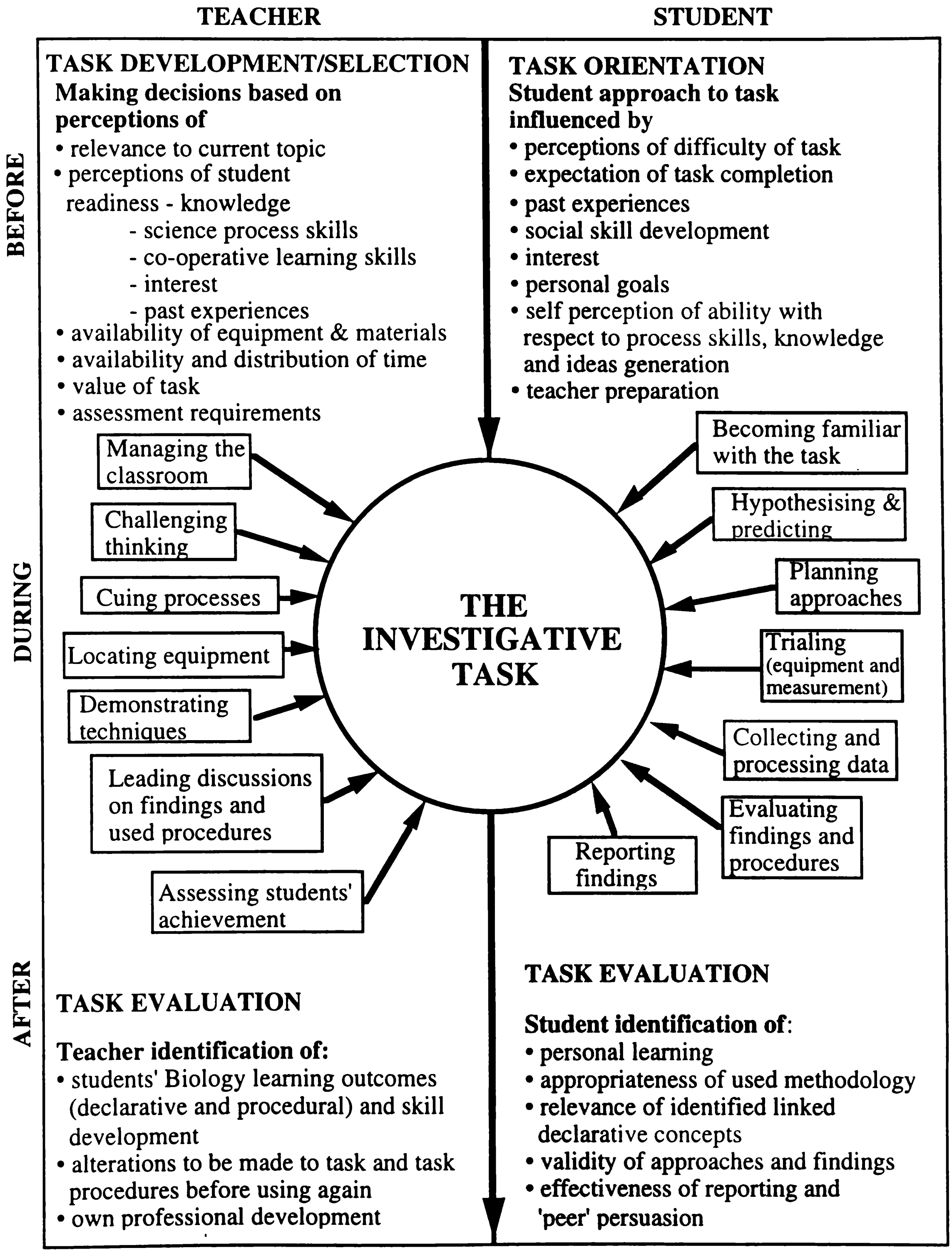

Figure 11.4: Teacher and student acts associated with investigative practical work in Year 12 Biology classrooms

A similar framework for describing open work in the school Science classroom was developed by the OPENS project (Simon *et al*, 1992). The model suggested here develops and elaborates the framework defined by the OPENS team to cover the process of investigation from the students' and teachers' first encounter with the investigation to the post investigation evaluation process.

In this model, the data which supported the holistic and integrative nature of investigating as shown in Figure 11.3, are re-considered so that the complexity of the investigative act is unravelled to elucidate its component parts. For both the teachers and students in the research, investigation related acts could be arbitrarily divided into activities which occurred, and decisions which were taken, before, during and following the actual investigation. Whilst the activities may appear to be linear and separate in this model, they were likely to be iterative and linked in reality and required an integration of procedural and declarative concepts. The activities and decisions of the students and teacher were also closely linked. Additionally the decisions made following one investigation had cognitive and affective influence on the development and direction of the next investigation. The investigation linked activities of the teachers and the students will be considered in turn.

The teachers

Before the task, the research teachers made decisions regarding the development or selection of the task. These decisions were influenced by the task's relevance to the topic being studied, and the teachers' understanding of the students' knowledge base, science process and co-operative learning skill levels, interests and past experiences. The teachers also made judgements regarding the value of the task, the availability of equipment, materials and time, and assessments associated with the task.

During the investigation the teachers managed the classroom, challenged the students' thinking, cued investigative procedures, located equipment, demonstrated techniques, led discussions on findings and used procedures, and assessed the students' achievement. All these activities occurred within an investigative session.

After the task was completed the teachers evaluated the task against criteria such as expected student learning outcomes. Decisions regarding possible alterations to the task before it was used again were also made at this time. As a result of discussion with other teachers and personal reflection the teachers also became aware of their personal professional development arising out of involvement in this task.

The students

In this research project the first encounter for the students was with tasks which had been generated for them by their teacher or the researcher. The students' approach to the investigative task were influenced by their perceptions of the difficulty of the task, their expectation of task completion, their past experiences, their social skill development, their interest, personal goals and their self perception of their ability to carry out an investigation. The manner by which their teachers prepared them for the task also influenced their orientation to the task.

During an investigation the students began by becoming familiar with the task. Once they understood the nature of the task the students hypothesised and predicted, planned and trialed their approaches, made measurement and equipment decisions, collected and processed data, and evaluated and reported their findings. To do this they were integrating their procedural and declarative knowledge.

After the investigation was completed the students could identify, or be helped to identify, their own personal learning, the appropriateness and validity of their approach and findings, the relevance of their chosen linked understandings and their effectiveness at reporting their findings.

In summary, if these classroom-based investigations in Biology were to be rich and directed learning experiences then all aspects of the process of investigating which are identified above had to be acknowledged and made clear to all of the participants in the investigating process. This required the teachers and the students to work together to understand the activity in which they were jointly engaged. The teachers worked with their students to encourage the students to become more metacognitively aware of what they were learning, the ways they were learning, and of the role that their personal engagement played in this learning. The teachers were scaffolding the students' learning. The students learnt to recognise that they could have personal direction of the investigative processes they were engaging in. They became aware that their learning was enriched when they were challenged to make decisions for themselves about their investigative activities. The students' learning was also enriched when they clarified their made decisions through discussion with their teachers and their fellow students.

After the investigative task was brought to completion the teacher and student learning generated by the task could be brought to bear upon a subsequent task. The process is thus iterative on a macro as well as a micro scale.

11.6 Links between this research and other research findings

In Chapter 3 aspects of research in science education connected to investigative practical work were briefly surveyed. Research foci which were identified were the general effect of an investigative approach on student learning and the role of the teacher in the investigative classroom; investigation's link with group work; the degree of openness of investigations; specific aspects of the investigative process; investigation's links with essential skill development such as numeracy; the differences between expert and novice investigators and assessment of students who are investigating. Two of these research foci were not addressed in any significant manner during the research project. Those not addressed were investigation's links with essential skill development such as numeracy, and the differences between expert and novice investigators. The contribution of the findings of this research project with respect to the other main fields of investigation-focussed science education research will be discussed below.

11.6.1 The general effect of an investigative approach on student learning and the role of the teacher in the investigative classroom

In contrast to the work of researchers such as Yager *et al* (1969) there was, in this interpretivist research, no direct, carefully controlled, attempt to measure differences in students' learning of biological concepts between students who were engaged in an investigative approach and those who were following a non-investigative approach. Instead, there was a monitoring of the students' and teachers' perceptions of the students' learning. The participating teachers and their students believed that there were many positive learning outcomes accruing from the investigative practical work. They claimed that the required personal engagement of the students was motivating, and that it increased their personal commitment and confidence. This increase in student engagement at science tasks was perceived to have positive effects on student learning. The students became more metacognitively aware, and more determined about their learning. Students and teachers thus represented the students as having a better understanding of biological concepts and the nature of scientific activity as a result of their involvement in investigative practical work - a judgement which supports the findings of researchers such as Shymansky (1984) and Tinnesand and Chan (1987).

However, the findings of this research project also indicate that the positive learning outcomes were not easily achieved, and resulted only after changes to the format of the tasks, and shifts in the teaching approaches taken by the participating teachers, had occurred. In line with the findings of Millar *et al* (1994) it is apparent that a student who was investigating was required to access the complexity of his/her prior knowledge of biological concepts - both declarative and procedural. If this prior knowledge was patchy or faulty then the students' investigations could only be flawed. Researchers, such as Toh (1990) and Gayford (1989) have shown, also, that when students are provided with instruction regarding the fundamentals of carrying out scientific investigations they perform their investigations better than those students that have not had such instruction. The students in this research project maintained that they were best served in this regard by direct and explicit teaching rather than just by practice. They indicated that their teachers could help them with the process of investigating, if the teachers openly discussed links between past experience and present situation and facilitated refresher courses on the processes of investigating.

Researchers have also alerted science educators to the part that tacit knowledge plays when students are investigating (Toh, 1990; Woolnough and Allsop (1985). Some, such as Gott and Murphy (1987) have claimed that tacit understanding alone can prove adequate for performing investigations. Whilst there is debate about the relative value of knowledge which is explicit or remains tacit, the data from this research project would support the notion that moving to make knowledge explicit helped the students to carry out an investigation. However there were problems with what students put down in written plans. There was evidence that students did not always write down all that they knew before they began to manipulate equipment as they followed through their plan. Thus, there were assessment issues here, as well as challenges to the teachers who were trying to scaffold their students' learning without having a full picture of the students' level of understanding. More research remains to be done in this area.

There has long been a focus on what is learned during practical work, with some saying that not much is, for example Johnstone and Wham (1982), and Clackson and Wright (1992). However when the students who participated in this research project were asked to indicate what they had learned during the investigative practical work their responses indicated that there were multiple learning outcomes. Other researchers have suggested that student learning during practical work can be increased by reducing 'noise' (unnecessary information through which students are required to manoeuvre) by means such as sequencing experimental procedures into numbered steps (Byrne, 1990). However, this approach is not consistent with the openness inherent in an investigation. Moreover, the positive response of the students in this study to investigative practical work, and their perception that such an approach increases their learning of biological concepts and processes, would suggest that including contextually-based investigative practical work into a biology programme is of sufficient value to outweigh considerations of 'noise'.

It has been claimed that 'much practical work is confusing and unproductive because teachers fail to recognise the separateness of learning science and learning about science' (Hodson, 1993a, p 111). The positive cognitive benefits of investigative approaches to practical work as perceived by the teachers and students in this research project may be sufficient to challenge science educators to reconsider this view with respect to investigative practical work where it can be argued students are 'learning science' and 'learning about science' as they 'do science'. When the students and their teachers were engaged in investigative practical work an interweaving of procedural and declarative concepts appeared to be a necessary requisite for reaching a satisfactory conclusion to the investigation. The learners (students and teachers) were both accessing and developing their declarative and procedural understandings as they engaged in the processes of biological investigation.

Overall, the findings of this research project support the work of researchers such as Shymansky and Penick (1981) who claimed that the teacher does make a difference in the hands-on classroom. In addition, the findings of this research project indicated that when the students were investigating they were working within a context that often challenged their understandings of science classroom norms, including their expectations of the roles of a student and the teacher. The teachers were required to help their students understand these changes to the expected norms and behaviours.

11.6.2 Investigation's link with group work

Solomon (1994b) suggested that during group discussion students negotiate common understandings for declarative and procedural concepts. However, transcripts of groups of students developing plans for their investigations in this research project showed that whilst there was clear negotiation of meanings in some instances there was also much interruptive speech during discussions. Such behaviour may be an indication that the students already shared common understandings or it may be that the students required more direct teaching regarding co-operative group skills, and on-going encouragement of these from their teacher. The latter interpretation supports the contention that students need to be taught skills to help them communicate, and discuss, ideas and to consider alternatives in a systematic manner (Blumenfeld *et al*, 1991).

It should also be noted that whilst much practical activity may benefit from students working collaboratively, it is not always the case that the presence of a partner is helpful (Rogoff, 1990). Transcripts of student conversations, and the researcher's classroom field notes taken/written when students were working in group situations would support Rogoff's contention that in some situations the presence of a partner may serve as a distraction, requiring attention to be focussed on the division of labour and on social issues rather than providing support.

11.6.3 The degree of openness of investigations

The investigations reported on in this research project were partially open in that the students did not have choice regarding the problem that they were to investigate. However the manner by which the students could find answers to the investigative problem was open.

The students in this research project were older than those who have participated in other open investigation-linked research projects such as those reported by Jones *et al* (1992) and Gott and his co-workers in a series of papers and books presented from 1987 until 1995. Most were at least sixteen years of age at the start of the intervention, turning 17 or 18 by the end of the school year. The research project thus allowed for a consideration of the investigative approaches of older students.

11.6.4 Specific aspects of the investigative process

Much of the research associated with specific aspects of the investigative process has been carried out in carefully controlled experimental conditions. However, the contribution of this research project is that it has reported on students' hypothesising and planning competencies as they approached investigative tasks in the context of their everyday Biology classroom. As with the younger students in Gott and Duggan's study (1995), these students required significant support from their teachers if they were to design experiments which could produce significant data. Aspects of reliability and validity were poorly understood by these sixteen year old students as they were with the younger students in Gott's study (*ibid*), as were variable categorisation and variable control. The findings of this study support the notion that investigation is an holistic endeavour with students being required to juggle many aspects of investigating at any one time; a conviction expressed strongly by Duveen *et al* (1993) who warned that we narrow our understanding of investigating if we focus strongly on only one or two aspects of the process.

11.6.5 Assessment of students who are investigating.

The difficulties of assessing students who were investigating became a major concern for the teachers at the case study school. The issue was largely one of searching for a shared understanding of the means of assessing students' investigative skills in a manner which was representative of the holistic nature of investigating (Hodson, 1991, 1992a, 1993a). The research study has not generated any easy answers to the problems associated with the assessment of this holistic group activity.

11.7 Future research

Future directions for research which arise from this project encompass both student and teacher domains. Future research could focus on:

- students' held meanings for the processes of investigation;
- students' understanding of the nature of scientific enquiry resulting from engagement in investigative practical work;
- the multiplicity of cognitive, skill and affective learning outcomes which result from students' engagement in investigations;
- the effectiveness of investigations for the learning of specific declarative concepts;
- the role of specific co-operative learning strategies in the senior Biology classroom;
- the relative importance of tacit and explicit knowledge as students investigate
- beginning teachers' understandings of the place of investigation within the scientific endeavour and its role in school Science;
- the assessment of investigative practical work.

11.8 Implications of research findings

Data from case study research is not directly generalisable to populations. However, possible implications for both classroom practice and teacher development can be seen to emerge from the findings of this research project.

11.8.1 Implications for classroom practice

Generalisation of the findings from this study to all Year 12 Biology students has not been attempted. However, an analysis of the data does point to ways by which teachers may facilitate the investigative process for students.

Implications for classroom practice relating to students hypothesising, planning and gathering data and to students evaluating themselves as investigators will be discussed in turn.

Implications for classroom practice relating to students hypothesising

The findings from this phase of the research project indicate that student ability at generating hypotheses for practical investigation was enhanced when:

- the teachers helped their students to understand the differences between descriptive, predictive and explanatory hypotheses and the appropriate use of these forms of hypothesis;
- the teachers encouraged students to rewrite descriptive hypotheses as predictive or explanatory hypotheses;
- investigative questions contained clearly proposed causal relationships;
- the teachers had students analyse experimental procedures which had been structured by others.

If teachers wish their students to pose predictions capable of falsifying an explanatory hypothesis then the students will have to be taught this procedure deliberately.

Implications for classroom practice relating to students planning

The findings from the research project indicate that student planning for practical aspects of an investigation was enhanced when:

- individual planning was followed by group planning, but note that group planning will be more likely to be fruitful when students have been introduced to, and practised, co-operative group discussion;
- the students received clear indications as to how previous theoretical study and practical experience linked to the current task;
- the students were asked to identify variables which may influence the investigation and to check whether they have considered these during their planning;
- the students were asked to identify and carry out precise quantitative measurement techniques;

- the students understood the features of a 'fair test';
- the students were given the opportunity to discuss the aspects of an investigation with which they were unfamiliar, for example, terminology, techniques, report writing;
- the teachers had appropriate equipment on view, or students were directed to consider the appropriateness of the equipment they had chosen;
- the teachers demonstrated required specific techniques;
- the students had the opportunity to trial techniques, change their plans, repeat experiments;
- the teachers indicated expected format(s) for reporting of data;
- the students were encouraged to discuss their plans with their teacher.

Implications for classroom practice relating to students evaluating themselves as practical investigators

The students become more critically aware of themselves as investigators when they:

- were challenged to consider whether their work was exhibiting the characteristics of a fair test;
- were involved in class discussions relating to particular aspects of the context of the investigation which may have had a bearing on the procedures being carried out in the investigation and on interpretation of the findings;
- were challenged to consider the reliability of their findings and the validity of their conclusions.

In addition to pointers for classroom practice which arise from an analysis of data generated when students were investigating, the response of the students to investigating also generated some indicators for classroom practice. These indicators are outlined in the next section.

11.8.2 Facilitating students as investigators

The students in the four Biology classes at City High in 1993 declared an overall increased confidence with investigating after experiencing a practical programme which included a number of open investigative tasks. However there was a reported loss of confidence with regard to some aspects of investigating. An evaluation of this information enabled the identification of strategies which may have boosted the students' confidence when they were investigating. These strategies included:

- discussion on the nature of scientific inquiry;
- 'refresher' courses on all aspects of designing, carrying out and reporting on the findings of practical investigations;
- 'whole class' discussion and planning of an approach to solving a particular "problem";
- analysis of "recipe" style investigations from texts with discussion as to why the planner may have chosen to carry out the investigation in that particular manner;
- the breaking down of an investigation into its particular phases and concentrating discussion on one aspect only;
- 'whole class' listing of possible variables, with identification of the independent and dependent variables and those that need to be kept constant or acknowledged as impacting on the generated data;
- having students plan an investigation and then comparing their plans to a "given" method (text or teacher supplied);
- asking students to plan their investigations separately and then sharing their ideas in small groups so that they argued for, and agreed on, a group plan;
- having students critically analyse each others' plans;
- having students evaluate their own work on completion of the investigation;
- emphasising the benefits of, and encouraging, co-operative working practices;
- encouraging the explicit formation of linkages between prior knowledge and present situations by the teacher;
- teachers and students acknowledging the value of failure to reach expected outcomes in understanding the processes of science;
- asking many cuing questions of the students as they carried out their investigations.

Analysis of data relating to the students' response to the introduction of investigating to their Year 12 Biology programmes suggested that the students appreciated teachers who managed and organised the classroom equipment and student dynamics in ways that facilitated their working. They saw a definite role for their teacher. They wanted teachers who allowed them to learn from their own mistakes. They appreciated teachers who left them to design their own experimental procedures and who let them test their own ideas and yet, at the same time, provided cues as to procedural approaches and 'required type' of answer. The students also indicated that they valued the opportunity to have 'whole class' discussions regarding the application of the findings of an investigation. They did not want to work independently of their teacher but rather to work with their teacher to construct their knowledge.

11.8.3 Suggestions for teacher development

The findings of this research project provide clear pointers as to a possible format for teacher development programmes relating to the introduction of a higher degree of openness into senior Biology practical work. The complexity of the investigative process in a Biology classroom should be addressed as should ways of facilitating students' learning as they investigate. These two facets of a possible teacher development programme related to students investigating will be addressed in turn.

Teacher development programmes focussing on investigative approaches to learning in Biology could, firstly, include sessions which are structured to help teachers address their understanding of science education and their expectations of the role of practical work in science education. Teachers could also be assisted to identify, analyse, and acknowledge their held views about teaching and learning in, and of, Biology. They could address such issues as the construction of knowledge, degrees of transferability of knowledge from one situation to another, the situated nature of much learning and the multiplicity of learning outcomes which may arise from any investigative Biology learning context. Teachers could be encouraged to explore the nature of scientific inquiry, and experience this for themselves in a practical context, in order to develop their own professional understanding of open investigative practical work.

Following this personal experience at investigating teachers could be challenged to consider the impact of this shift in curriculum approach on their students and their learning. The teachers could examine how effective different teaching approaches/strategies are when they are working with students who are investigating. They could reflect on, for example, the effect of facilitative approaches compared with didactic approaches. They may also consider how to alter classroom dynamics to allow for increased student responsibility and engagement in their learning. They could develop and trial strategies for encouraging student thinking about investigating. The teachers could be assisted to develop and trial techniques for staging the introduction of openness and for leading pre- and post-investigation classroom discussions. The teacher development programme could also address strategies for helping students to work co-operatively and to take personal and co-operative responsibility for their learning.

Any teacher development programme relating to the introduction of open investigative practical work could also address pedagogy related concerns such as the teachers' anxieties about the less able student. The course could also address resource related concerns and encourage teachers to find ways to overcome limitations of ideas, equipment and time. Teachers could trial means of managing the laboratory to minimise these perceived constraints. The assessment of investigative practical work assumed major significance for the teachers in this research project and ways of doing this could be explored, developed and trialed.

Whilst teachers could address some of these issues for themselves provided facilitative leadership is available, the value of their sharing their ideas or experiences with other teachers should be acknowledged. The demonstrated value of long-term ongoing debate to arrive at common understandings with respect to an investigative approach to teaching Biology, indicates that it would be beneficial if this teacher development was school based with all members of the department being involved.

11.9 Concluding remarks

Overall, this study has contributed to our understanding of students' and teachers' approaches to investigative work. Investigative problem solving has been included in science curricula for many years - from the heurism of Armstrong (van Praagh, 1973) and Dewey's emphasis on problem solving (Dewey, 1995) at the turn of the century, through an emphasis on scientific inquiry (Klinckmann, 1970; Rowe, 1978; Shymansky, 1984), to an emphasis on problem solving and investigation in the latter part of the twentieth century (for example, Hadfield, 1987; Lock, 1990a, Flannery, 1991; Simon *et al*, 1992). Science education writers have also frequently pondered about why investigative problem solving is included in school science programmes, what its nature is, and what we should be presenting to school students in this regard (for example, Nott, 1988).

Aspects of investigative problem solving have also received considerable attention from researchers in science education. However, after carrying out a major review of research related to problem solving in science education Garrett (1986) stated that:

> A major contribution of science education to the understanding of problem solving must be the study of subjects in natural laboratory settings, confronting problems requiring both thinking and visible, observable acts of manipulating equipment and designing of hypothesis testing experiments.
> *ibid*, p 90 - 91

This research project, which focussed on the introduction of an investigative approach to practical work in a Year 12 Biology programme, was such a classroom based study. It was therefore necessary for both gatherers, and interpreters, of the data to recognise the complexity, and influence, of the intervention context. The complex and busy nature of the intervention context presented methodological challenges to the researcher (Lacey, 1976 and Brown, 1992) and these have been discussed in Chapter 5. However, an advantage arising from situating the research in the social context of the classroom was that it allowed for student learning arising from the intervention tasks to be viewed from a co-constructivist perspective, and for the role of social interaction in the facilitation of cognitive development to be recognised (McNaughton, 1995). In addition to helping their students understand biological concepts, the teachers in this research project were supporting and stretching their students' 'understanding of, and skill in using, the tools of the culture' (Rogoff, 1990 p vii).

The questions which guided the direction of the research project centred on the enhancement of the students' learning as they engaged in investigative practical work. The project also sought to identify benefits which might accrue from introducing investigative activities, constraints which might restrict this introduction, and ways of supporting the teachers as they introduced investigative practical work to their students.

The findings from this study contribute to our understanding of students' learning as they are carrying out scientific investigations and of the teaching approaches which facilitate this process. In comparison to most internationally reported research, the students in this study were in their senior years of secondary school. The research findings challenge curriculum statements regarding investigative practical work in a Year 12 Biology programme in that it was found to be complex and demanding for both teachers and students. However, the students valued the opportunity to have more control over the direction of their practical work. They found investigative work motivating and claimed that it increased their learning. Some students accepted the opportunity for personal involvement, self-direction and responsibility very quickly whilst others needed ongoing support and encouragement. Overall, the students required deliberate and focussed teaching if they were to progress their scientific inquiry skills.

The teachers who participated in the research project perceived cognitive and affective benefits accruing from an investigative approach to practical work in a Biology programme. However, they also reported considerable difficulties with the introduction and assessment of the approach. There were pedagogical and resource dilemmas and challenges to address. It is suggested that teacher development programmes provide opportunities for teachers to develop their own understandings and skills in relation to investigative science. Teacher development programmes could also include an emphasis on pedagogical practices which may enhance their students' learning in this regard.

Appendix A: Contents of the teachers' guide book developed during the study

Title:
Open Investigative Practical work in Level 7 Biology

Contents:

1. Letter to the teachers involved in the trial

2. Checklist for information to be returned to the researcher

3. Teacher questionnaire

4. Why encourage students to be involved in open investigative work in Biology

5. "Open" Investigations

6. Introducing students to investigative practical work

7. Questions you can ask students when they are carrying out open investigations

8. Investigation survey forms (beginning and end of year forms for students to complete and teachers' summary forms)

9. Teacher's investigation comment sheet

10. Student planning sheet

11. Outline for students' report

12. Student lesson evaluation sheet

13. Links between the trial investigations, the present Form 6 Biology syllabus and *Biology in the New Zealand Curriculum*

14. The investigations - task sheets and teachers guides to
    - "Green Streams"
    - "Factor X"
    - "Potatoes for Dinner"
    - "Sweet Export"
    - "Plant Cells at Work"
    - "Plants for Dry Conditions"

Appendix B: Additional investigative tasks

Potatoes for dinner!

One of Nicky's jobs is to prepare the vegetables for dinner. He decided to peel the potatoes in the morning because he had rugby practice after school. So he peeled the potatoes, cut them up into small pieces and left them to soak in water. His mother said that he shouldn't do that because the potatoes would swell up. Nicky has been studying osmosis at school and he thought that wouldn't happen because "potato juice is pure water."

Should Nicky have put some salt in the water? Would it have been better if Nicky had not cut the potato into small pieces?

Plan and carry out investigations to test
(1) if the amount of salt put into the pot makes a difference (is potato juice pure water?) and

(2) if the size of the potato pieces makes a difference (would larger pieces of potato have changed relative mass less than small pieces?)

Was Nicky's mother correct in saying that the potatoes would swell up?

What could Nicky say to his mother when he was explaining what was happening to the potatoes during the day? What would be the best way to keep the potatoes from changing size? What would be a more scientific way of saying that "potato juice is pure water"?

Hint: Remember to carry out a "fair test". What conditions will you have to keep the same and what could you change?

Plants for Dry Conditions

You are working in the research section of a plant supply company. An industrial firm wants your company to supply a large number of shrubby plants for planting on a steep bank. They do not have the money to set up extensive irrigation systems to supply the plants with water during the 5 - 6 weeks of near drought they will experience most summers.

A number of suitable plants have been identified and it is your job to provide the company with evidence to help them decide which plant is most likely to be suitable. You are provided with leafy shoots from a variety of plants and some apparatus which could be useful.

After you have carried out your investigation write a report for your employer explaining what you did and the reasons for your decision. What other tests could you have carried out if you had more time and the necessary equipment?

HINT: The industrial firm will be wanting a plant which loses water from its leaves at a slow rate. You will probably need to record this in terms of volume lost from a standard unit surface area of leaf over a set period of time. Remember to carry out a "fair test".

Adapted from Gayford, C.: 1989 *Journal of Biological Education,* 23 3

Plant cells at work

Because single celled plants are very small it is difficult to watch one at work. Sometimes it is easier for us to "capture" a large number in one place and then watch what they do in differing conditions. We can trap these plants inside jelly like beads of sodium alginate and then use these beads to investigate the effects of varying environmental factors on the rate of photosynthesis.

How to trap the single-celled plants.
1. Collect a thick "paste" of the plant cells either by filtering some water which is coloured green by the plants or by scraping some of the green slime from the side from a fish tank.
2. Add about 1 mL of this to 10 mL of 3% $^{W/V}$ sodium alginate solution. Mix well with a glass rod.
3. Draw some of this mixture into a 5 mL syringe (no needle). Hold the syringe vertically about 10cm above a beaker of 3% $^{W/V}$ calcium chloride solution. Gently push down to release a steady stream of drops. Green coloured beads should form in the calcium chloride. Continue until you have about 50 beads
4. Remove the beads and put into a petri dish.

Beads of sodium alginate/single-celled plants will rise in water if they are releasing a gas. What gas do you think they could be producing? What cell process is involved? Plan an investigation which you could carry out, using the beads you have made, to test one of the factors affecting the rate of production of this gas. What hypothesis are you testing? Write down the method you will follow, what measurements you expect to take, and how you will present the data. Do the investigation. Analyse the results. Have you proved your hypothesis? How could you convince others that you have proved your hypothesis? Write a brief report for your teacher about what you have found out.

Hint: Remember to carry out a 'fair test'. Equipment which you might find useful: Thermometer, stopwatch, measuring cylinder, potassium bicarbonate powder, light source. Ask your teacher for any other equipment you might need.

Appendix C: Research audit trail

Key: DMT = Departmental meeting transcript; IT = Interview transcript; CT = Classroom transcript; GPT = Group discussion transcript

1992:

April

- Published findings of Problem solving survey in Term 2 Auckland Science Teachers Association newsletter.
- Requested registration of interest in ongoing research

October:

- Finalised school arrangements

November:

- First departmental meeting at City High (DMT 27/11/92) Discussed research questions, negotiated procedures, established ethical guidelines, established classroom intervention.

December:

- Administered first questionnaire to teachers' regarding their attitudes to problem-solving (advantages and difficulties/constraints) - based on results from 1991 survey of Auckland teachers - and gathered biographical details of four teachers
- Interviewed Roy Skinner regarding problem solving teaching in Auckland (IT 12/2/92)

1993:

February:

- 22 - 26 Feb: Initial discussions with teachers and arrangements made for classroom visits

March:

- Researcher in classrooms - once per week per teacher. Introduction of researcher to students
  (CT 10/3/93 (T2); 12/3/93 (T1, T3 and T4); 19/3/93 (T1 and T3)
- First formal interviews with the four teachers 12/3/93 (ITs T2, 3 and 4), 17/3/94 (IT T1)
- Trial of student confidence survey at second school 25/3/93

April:

- Researcher in classrooms (one period per week per teacher) - tapes of T2 28/4/93, T3 30/4/93
- Administration of pre-intervention confidence survey and "Green streams" planning - individual and in groups - week of April 5 - 9 (transcripts of students working in groups - 5/4, 7/4 and 30/4)
- T3 starting "Factor X" on April 30
- Scoring scheme checked for ease and consistency of marking with another Biology based teacher-researcher 17/4/93
- Departmental meeting 28/4/93 (DMT)

May:

- Researcher in classrooms (one period per teacher for last week of May) T1 and T4 students carrying out "Factor X"

June:
- Researcher in classrooms (one period per week per teacher) - T2 carrying out "Factor X" (CT 2/6/93 and 16/6/93)
- Researcher working with students feeding back findings (transcripts with T1 and T2 students and researcher 16/6/93 and 23/6/93 respectively)

July:
- Researcher in classrooms (one period per teacher for first, third and fourth weeks)
- Teacher interviews - all four on 2 July (ITs)
- "Water efficient plants" material sent to school 27/7/93 + info re unavailability of researcher in school during Teaching Experience period

August:
- Telephone conversation with T4 re teachers' guide for "Water efficient plants" 4/8/93
- Teachers' guide for "Water efficient plants" sent to school 9/8/93
- Researcher in school week of 16 - 20 August. Students carrying out "Water efficient plants" investigation

September:
- Phone link with teachers re end of year survey 13/9/93
- Departmental meeting 27/9/93
- Preparation for school exams

October:
- School exams
- Departmental meeting 8/10/93 (DMT)
- T2 class finishes "Water efficient plants" investigation 27/10/93

November:
- Administered post intervention survey and green streams planning exercise 5/11/93

December:
- Wrote to teachers with results of end of year survey and asked them to (i) make comment on two questions relating to the results and (ii) changes to their teaching approaches that had resulted from their involvement in the research

1994

February:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1 - frequently whilst planning for and evaluating practicals done during double period on Friday)
- Pre-intervention survey plus researcher discussion with class re hypothesis formation (CT 21/2/94)
- Students planning "Green streams" task (GPTs 28/2/94)

March:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1) (CT 24/3/94)
- Form 7 Interviews (ITs 7/3/94 and 21/3/94)
- Students carrying out "Sweet Export" (GPT 24/3/94)

April:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1) (CTs 11/4/94, 21/4/94)
- Students carrying out "Factor X" (GPT 7/4/94)
- Students carrying out teacher designed enzyme investigation (CT 21/4/94)

May:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1 - week one and four [student holidays weeks 2 and 3])
- Students preparing for "Potatoes for Dinner" (GPT 2/5/94)

June:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1) (CT 20/6/94)
- Students preparing for, carrying out and evaluating "Immobilised chlorella" investigation (GPT 14/6/94)
- Students discussing variables (CT 20/6/94)

July:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1 - weeks 3 and 4 [Mid term week 1 and exams in second week]) CT 21/7/94 and 28/7/94
- Form 4 Science class investigating (CT 28/7/94)
- Interview T3 (IT 28/7/94)
- Interview F 6 students (ITs 18/7/94 and 21/7/94)

August:
- Researcher in classroom (Mondays Pd 5 and Thursdays P1 - weeks one to three [holidays at end of August])
- Interviews with Form 6 students (IT 1/8/94, 8/8/94 and 15/8/94)
- Interview with T4 (IT 11/8/94)
- With Form 7 students as they begin their individual animal studies - at beach 21/8/94
- Presentation at SCICON '94 - expression of interest from teachers who wished to participate in 1995 phase of research

September:
- Researcher in classroom Monday 12 September [exam preparation and exams for much of September]
- Interview with two past science educators (Ray Munro and Colin Percy) (IT 6/9/94)

October:
- Researcher in classroom 6/10/94 and 10/9/94
- Students preparing for carrying out "Plants for Dry conditions" on 7/10/94 (GPT 6/10/94)
- Post intervention "Green streams" and questionnaire administered 17/10/94

November:
- Preparation of 1995 material

December:
- Further preparation of 1995 material ("Open Investigative practical work in Level 7 Biology" - student and teachers' guide material and associated research support matters)
- Interview with teachers (ITs T3 I/12/94, T1 and T2 8/12/94)
- Three remaining City High teachers complete post- intervention problem solving advantages and difficulties/constraints questionnaire
- Preparation of letters to send to 1995 schools - Board of Trustees, Principals and Heads of Departments

1995

- "Open Investigation" pack sent to 22 schools
- Letters requesting access sent to 1995 schools - Board of Trustees, Principals and Heads of Departments
- Contact with participating teachers maintained by letter and phone throughout the year
- Investigating packs received by end of year from all but one teacher.
- Teacher and students from one of 1995 participating schools interviewed by researcher on 14/6/95
- T3 from City High interviewed 12/12/95

1996

- Ongoing 1993 and 19944 data analysis and interpretation returned to 1993 and 1994 teachers for comment
- Teacher who did not return investigating pack in 1995 interviewed by researcher on 24/5/96
- 1995 data analysis and interpretation returned to 1995 teachers for comment before SCICON presentation in September
- 1995 findings presented to teachers at SCICON (Conference of New Zealand Science Teachers) for debate and discussion

1997 - 1998

- Write up of thesis
- Data interpretation discussed with the teachers from City High.
- "Kaye" asked to review and affirm her case study chapter in October 1997.
- "Kaye" affirmed case study and did not request any changes (November 15).

Appendix D: Summary of transcribed tapes

Teacher interviews and departmental meetings

First interview with teacher researchers - 93 school	27/11/92
Interviews with T2, T3 and T4 (x3)	12/3/93
Interview with T1	17/3/93
Departmental meeting	28/4/93
Individual interviews with 4 teachers - 93 school	2/7/93
Biology department meeting	8/10/93
Interview with T3	28/7/94
Interview with T4	11/8/94
Interview with T3	1/12/94
Interview with T2 and T1	8/12/94

Interview with other science educators

Roy Skinner	12/92
Rae Munro and Colin Percy	6/9/94

Classroom transcripts

T2 class	10/3/93
T3 with class	12/3/93
T4 with class	12/3/93
T1 lesson	12/3/93
T3 class	19/3/93
T1 class	19/3/93
With T4 and T1 class discussing planning after factor x	16/6/93
MH and T2 class discussing planning after factor x	23/6/93
MH with some of T3 class discussing hypotheses etc	21/2/94
T3 going over investigation assessment task	24/3/94
MH and T3's class factor X	11/4/94
T3 class going over factors affecting enzymes	21/4/94
T3 discussing variables related to colour of leaves	20/6/94
start of T3 class	21/7/94
T3 and Year 10 class investigating	28/7/94
T3 discussing a breathing experiment	28/7/94

Student interviews

94 Y13 students	7/3/94
94 Y13 students	21/3/94
Y12 interviews	18/7/94
Y12 interviews	21/7/94
Y12 interviews (x2)	1/8/94
Y12 interviews (x2)	8/8/94
Y12 interviews	15/8/94

Group investigation planning sessions

T3 students green stream planning	5/4/93
T2 students green streams	5/4/93
T1 students green streams	7/4/93
T4 students green streams	7/4/93
T3 students factor x	30/4/93
T2 students factor x group 1	2/6/93
T2 students factor x group 2	16/6/93
T3 students group1 green streams	28/2/94
T3 students group2 green streams	28/2/94
T3 students group sweet export	24/3/94
T3 students group factor x	7/4/94
T3 students group 1 potatoes for dinner	2/5/94
T3 students group immobilised chlorella (photosynthesis)	14/6/94
T3 students group plants for dry conditions	6/10/94

Appendix E (i): Investigation confidence survey form

Male/Female (Circle one) *Year studying Form 6 Biology 1/2 (Circle one)*

In Biology you are often asked to plan and do investigations and report on what you find out. Some of the things you have to do are listed below.
Put a √ in the space which best shows how you feel for each of the statements.

	Very confident	Reasonably confident	Not very confident	Not confident at all
• I can make hypotheses (predictions).				
• I can do an investigation where there is more than one changing factor.				
• I can make decisions about how many animals or plants to use when I am doing an investigation.				
• I can make decisions about how many times to repeat an experiment.				
• I can select appropriate equipment to carry out an experiment.				
• I can take measurements using appropriate measuring devices.				
• I can identify the sources of error in my experimental method.				
• I can present data in an appropriate form.				
• I can analyse data.				
• I can make conclusions.				
• I can justify my conclusions.				
• I can use appropriate language and layout when presenting what I have found out.				
• I can re-design experiments when my first results are unconvincing.				
• I can say when it is appropriate to apply what I have found out to other situations.				

Appendix E (ii): Change in overall confidence score for 1993 students

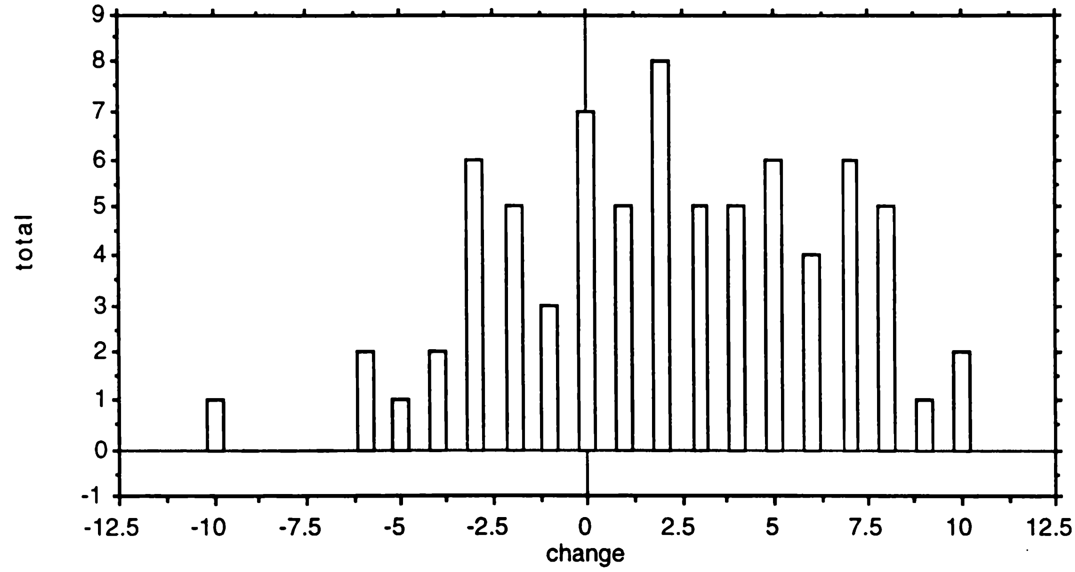

Figure ••: Frequency distribution for change in felt confidence for all 1993 students (n=74)

Appendix F: Auckland Science teachers response to including problem solving in school Science programmes

Findings of a survey of Auckland secondary science teachers in 1991. The teachers were responding to a questionnaire regarding the use of problem solving in secondary science classrooms. 256 teachers from 45 schools responded to this questionnaire. This represents 67.35% of the teachers within the 45 schools from whom returns were received and 40.96% of teachers overall in the greater Auckland district.

Advantages of problem solving as a teaching-learning strategy
(Blank responses = 15)

	%
• Encourages pupils to think (logically, creatively, independently)	42
• Students find it enjoyable, fun, interesting (stimulates enthusiasm)	18
• Its relevance to everyday situations	16
• Helps students to apply known information to unknown situation	12.5
• Encourages cooperative behaviour	9
• Helps students to learning skills (scientific and generic)	8
• Encourages creativity and initiative	7.5
• Encourages pupil independence	7.5
• Motivating	7
• Confidence building	6
• Increases pupil commitment, involvement, persistence	4.5
• Demonstrates possibility of multiple solutions	4
• Enhances understanding and memory (increasing learning)	4
• Emphasises scientific processes	4
• Student centred	3

Other advantages listed by less than three percent of teachers are not included in this summary.

Disadvantages of problem solving as a teaching learning strategy (Blank responses = 20)

	%
• Time consuming	41
• Students lacking the required background knowledge	17
• Resource demand and acquisition	16
• Syllabus constraints	14
• Demand on the teacher (assistance and preparation)	12.5
• Discipline or management problems (including safety)	9
• Development of acquisition of suitable problems	8.5
• Frustrated pupils	7
• Lack of motivation of pupils	7
• Doesn't help students to prepare for exams	4.5
• Difficulty of management of resources and teacher time with large classes	4
• Unwanted outcomes (learning and affective)	4
• Students preferring strict guidelines	4
• Requirement that pupils think	3

Other perceived difficulties listed by less than 3% of teachers are not included in this summary. 17 teachers (6% of respondents) indicated that they perceived no disadvantages with using problem solving as a teaching-learning strategy.

Appendix G: Questionnaire given to City High teachers to ascertain their views of a problem solving approach to teaching Biology

1. The following are statements made by the teachers about the **advantages** of using a problem-solving approach to teaching and learning in science. Please indicate on the scale how you feel about these statements.

	Strongly agree			Strongly disagree
A1 It is relevant to everyday situations				
A2 It helps students to apply known information to new situations				
A3 It encourages students to think				
A4 It demonstrates the possibility of multiple solutions				
A5 It enhances understanding and memory (increasing learning)				
A6 It is enjoyable, fun, and interesting for students				
A7 It increases student commitment, involvement, persistence				
A8 It encourages pupil independence				
A9 It motivates the students				
A10 It is confidence building				
A11 It encourages cooperative behaviour				
A12 It helps students to learn skills (scientific and generic)				
A13 It encourages creativity and initiative				
A14 It emphasises scientific processes				
A15 It is student centred				

In your opinion are there any other advantages?

2. The following are statements made by the teachers about the **difficulties** or **constraints** in using a problem-solving approach to teaching and learning in science. Please indicate on the scale how you feel about these statements.

	Strongly agree			Strongly disagree
D1 It is time consuming				
D2 It creates management difficulties (resources and teacher time)				
D3 There are syllabus constraints				
D4 It is difficult to find enough resources				
D5 It is hard to develop or find suitable problems				
D6 There are lots of demands on the teacher for assistance				
D7 There are discipline or management problems (including safety)				
D8 Students prefer strict guidelines				
D9 Students lack motivation				
D10 Students are reluctant to take risks				
D11 It doesn't help students to prepare for exams				
D12 Students lack the required background knowledge				
D13 It requires students to think				
D14 There are sometimes unwanted outcomes				
D15 Some students have language difficulties				
D16 Parents don't accept this way of teaching				
D17 It is difficult to assess				

In your opinion are there any other disadvantages?

Appendix H: 1995 Teacher questionnaire

Thank you very much for participating in the trial of this Level 7 investigative practical material. As part of the trial you are asked to complete the following questionnaire. Although you are asked for your name and that of your school this will only be used to enable the researcher to keep continuity of information. Your school's participation will be acknowledged but there will be no identification, either directly or indirectly, of individual teachers or schools in the body of any research report.

Teacher's name: School name:

Did any other teachers in your school participate in this trial?
(If so, they are also invited to complete a questionnaire.)

A. General statistics

Number of female students who participated in the trial

Number of male students who participated in the trial

Number of students who speak English as a first language

Number of students who do not speak English as a first language

....

B. The role of a Biology teacher

What does it mean for you to be a teacher of Biology?

Has being involved with this programme changed your view of yourself as a teacher of Biology?

C. Learning in Biology

What do you think learning in Biology involves?

What indicators tell you when your students are learning in Biology?

What happens to students' learning in Biology when they are introduced to open investigative work?

What is the range of cognitive outcomes from this type of practical work?

D. Students' views about learning Biology at school

What expectations did your students have at the beginning of the year about learning in Biology classrooms.

Have your students had to change their views about the "rules of the game" of the Biology classroom during this year? (If so, please explain what the change was, why they recognised the need for change, and what *they* did to make this change.)

What help did *you* need to provide to bring about any change in what the students were doing, or expected to be doing?

E. Reflection on the investigative approach to practical work in Biology.

Would you carry out a similar programme with your students in future years?
(Please explain your answer.)

What are you most enthusiastic about regarding this approach to practical work?

What reservations have you about this approach to practical work?

F. Further investigations

During the year you may have developed other situational open investigations.

How many would you have developed yourself? Please ring your choice.

1-2 3-4 5-6 7-8 9-10 >10

What stimulated you to develop these investigations?

G. Any other comments

Have you any other comments to make to me regarding the trial of this investigative practical work?

Thank you for your participation in this trial. It is greatly appreciated.

Mavis Haigh

Appendix I: Focus questions asked of City High teachers and students

1993
Initial individual teacher interview sheet

A. Name:

Years of teaching:

Name of teacher training institution which you attended:

Names (and numbers of years) of schools at which you have taught:

Which science classes are you expecting to teach in 1993?

How many years have you taught Form 6 Biology?

B. What schemes of work do you use for Form 6 Biology?

C. What text(s) do you issue to the students?

D. Give the names of some resource material which you consult often when you are planning for Form Biology:

E. Are some topics in Form 6 Biology more difficult to introduce problem-solving (open-ended activities) into than others? If yes, what are they?

F. What features (if any) of a topic in Form 6 Biology make it more difficult to introduce problem-solving OR open-ended activities?

G. How often do you incorporate problem-solving OR open-ended activities in your teaching of
(a) Form 3 - 4 Science

(b) Form 5 Science

(c) Form 6 Biology?

H. What **three** factors do you consider to be most important when you select problem-solving OR open-ended work in biology?

I. What aspects of problem-solving OR open-ended work might make you less likely to use it as a teaching-learning strategy?

Focus questions for individual interviews with all four of City High teachers 12/3/93 or 17/3/93

What is your opinion of the Form 6 Biology syllabus?

What changes might you like to make to the syllabus?

What do you consider to be the role of practical work in Form 6 Biology?

Focus questions for individual interviews with all four of City High teachers 2/7/93.

1. These are questions relating to students' learning when they are engaged in open practical work

• how does students' existing knowledge and experiences affect their learning when they are engaged in open work?

• what were your expected outcomes from this open work?

• how does this teaching/learning approach affect learning?

• what impact does placing practical work in contextual situations have on students' approach to the open work?

2. These are questions relating to the management of open-ended work

What impact might .... have on open work?
• availability of resources
• organisation of students into groups
• the way the material is presented
• the number and type of cues given by the teacher
• student reporting of the work they have done?
• feedback to students
• assessment

3. where to next?

Questions for written response from teachers - end of year 1993

- What do you see as possible reasons for the students' scores regarding the demonstration of their ability at planning an investigation being significantly lower at the end of the year from the beginning of the year?

- How do you think being involved in this research has affected your teaching?

1994

Focus questions for interviews with 1993 year 12 students in April of 1994

- What is it that we as teachers can do to help you do investigations better, more easily?
- If a teacher is going to help you do an investigation, can you think of the best way a teacher could be helpful to you?
- What sort of information would be helpful to help you do the design the investigation?

Focus questions for interview with T3 28/7/94

1. These are questions regarding the practical session (glucose/starch) on 21/7/94

- What were your expected outcomes?
- What do you think were the outcomes? Were they the same as you had expected?
- Did anything happen during the period which you were not expecting?

2. A question regarding the nature of science

- I have been asking the students what they think science is and how they think studying science is different from studying other subjects at school. Could you discuss these two things with me

3. A question regarding a change in teaching approach over these two years.

- How do you think your teaching approach has changed for you as you have been involved in this project?

Focus questions asked of small groups of 1994 Year 12 students in July and August 1994

- How do you think studying in Science and Biology is different from studying the other subjects that you are doing?
- How can your teachers help you with your investigations?
- With respect to investigating what do you feel differently about doing now than at the beginning of the year?

Focus questions for interview with T4 11/8/94

- What have you done in the area of investigative work this year?
- What are your responses in terms of being another teacher, seeing what was going on in [T3]'s class and how that might impact on you and your class?

Focus questions for interview with T3 1/12/94

- How would you describe yourself as a teacher?
- What do you think that it means to do science in school? Does doing open investigative work in science cause you to rethink this?
- Do you think that you have changed as a teacher of biology over the last few years? Can you describe this change? What helped you to make this change?
- What is going on in your classroom which makes you feel that you are the teacher you would like to be?
- What is it that the students are doing which make you feel better as a teacher?
- Earlier this year you said to me "Last year I did this because you wanted us to - this year I did it because I wanted to." What do you put this change down to? Did the student response influence this? (enjoyment, increased thinking, better at scientific procedures like making hypotheses, identifying variables)
- What are your "Yes,[I like this kind of work] but....."? Have any of the "buts" disappeared this year?
- Did you ever think that by doing this kind of work you were going against the grain of the other biology teachers, science dept, school?
- What do you think is happening to the students learning in biology when they are introduced to open investigative work? Does it make them more like scientists? Are they learning science more? Are they becoming more aware of the nature of science? Do we really want them to be more like scientists?
- What help do you think the students need to help them make the change from recipe following to open investigative work?

Focus questions for interview with T1 and T2 8/12/98

- I'm interested in finding out about what, if anything, you carried on independently doing from last year.
- Did doing investigative work in biology cause you to rethink your role as a teacher of science? If so, how?
- What are some of your "Yes, buts ..."?

Appendix J: Percentage of types of hypothesis generation in 1994 and 1995

Investigation (Title, date and number of student completing worksheet)	**No hypothesis stated**	**Hypothesis as an explanation**	**Hypothesis as prediction**	**Hypothesis as description**
Sweet Export 23/3/94 n=29	3	3	84	10
Factor X (i) 8/4/94 n=31	0	0	39	61
(ii) n=31	74	0	26	0
Potatoes for dinner (i) 5/5/94 n=28	29	0	42	29
(ii) n=28	18	21	29	32
Factors affecting photosynthesis 17/6/94 n=26	0	0	65	35
Plants for dry conditions 7/10/94 n=23	0	26	74	0
Total percentage frequency of different types of hypothesis	**19**	**7**	**50**	**24**

Table Appendix ••.1: Percentage frequency of different types of hypotheses stated by students for five investigations carried out during 1994. (reported to the closest whole number.)

Investigation (Title, date and number of student completing worksheet)	**No hypothesis stated**	**Hypothesis as an explanation**	**Hypothesis as prediction**	**Hypothesis as description**
Green Streams 29/5/95 n=39	0	61	39	0
Sweet Export 16/6/95 n=39	0	23	77	0
Factor X (i) 27/6/95 n=33	15	12	73	0
(ii) n=33	85	15	0	0
Potatoes for dinner (i) 19/7/95 n=34	18	0	82	0
(ii) n=34	53	0	47	0
Factors affecting photosynthesis 8/11/95 n=17	53	47	0	0
Plants for dry conditions 6/11/95 n=22	55	9	36	0
Total percentage frequency of different types of hypothesis	**31**	**19**	**50**	**0**

Table Appendix ••.2: Percentage frequency of different types of hypotheses stated by students for six investigations carried out during 1995 by students at one participating school. (reported to the closest whole number.)

Appendix K: The scoring schedule for "Factor X"

Note that a score of 4 = strongly indicated
3 = moderately indicated
2 = weakly indicated
1 = no indication

	4	3	2	1
Range of factors to be considered and controlled e.g. • *size of material pieces* • *weight of material pieces* • *amount of hydrogen peroxide* • *temperature* • *consistency in grinding* • *heating time* • *time of bubbling*	Three or more	Two or Mentions the need to keep factors the same but no detail	One or "the same"	No mention of range of factors involved
Sample size - both in number and volume *(note that there is need to consider this otherwise the bubbles can overflow the collecting container with resulting loss of precision)*	Detailed consideration of how much material to use and consistency from Part A to Part B	Generalised and poorly detailed consideration, little detail of consistency from Part A to Part B	Little consideration, no attempt to indicate need for consistency from Part A to Part B	No consideration or consistency
Adequate repetition	Detailed statement regarding need to repeat (number of times indicated and how it will be handled), or indication of checking using another method	Statement regarding need to repeat with either number of times and how it will be done, or checked using another method	Some general statement about repeating but no detail given	No indication that experiment will need to be repeated
Appropriate equipment (e.g. the choice of equipment which will enable accurate volume measurements and time intervals)	Equipment carefully detailed and likely to provide precise measurements e.g. Narrow measuring cylinders; collection of gas by displacement of water; stopwatches	Equipment carefully detailed but unlikely to give precise measurements	Equipment will provide only qualitative or semi-quantitative observations e.g. Petrie dishes, test-tubes	Equipment not detailed - just implied
Appropriate measurement	Need to consider timing and amount of gas given off - indications given as to how these will be carefully observed and measured	Considers timing and gas given off but not detail as to how these will be measured	Indicates either time or amount of gas	No indication given
Sources of error e.g. • *size constraints* • *cleanliness of equipment* • *accuracy of measurements* • *small number of variety of vegetables types*	More than two	Two	One	None

Appendix L: Comparison of "Factor X" planning scores and Sixth Form Certificate scores

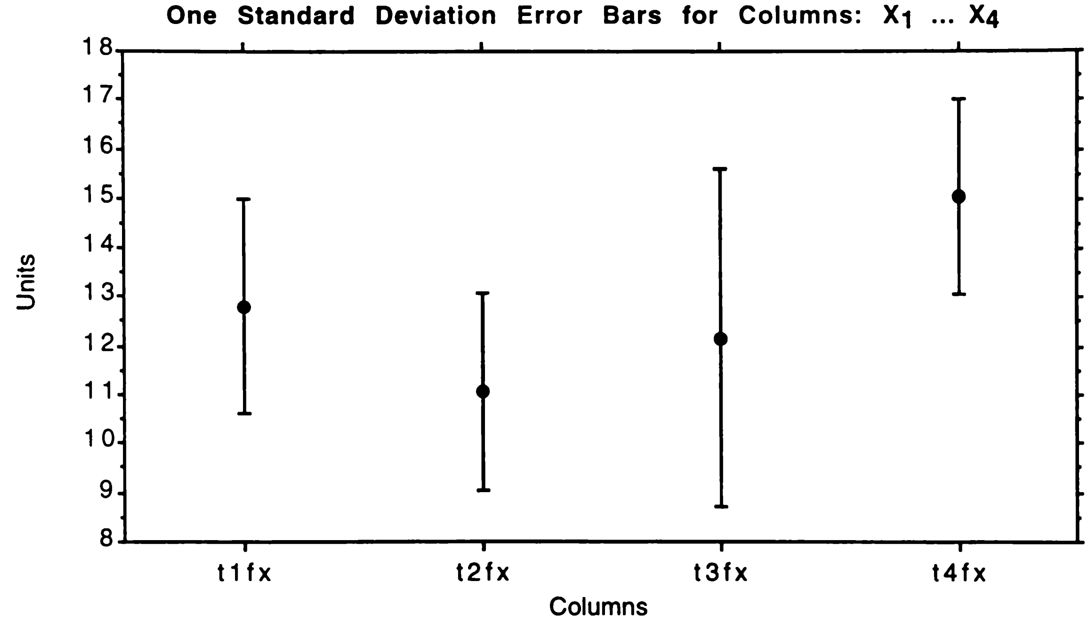

Figure Appendix L:1: Comparison of Planning Scores for 'Factor X' for four classes in 1993 (total n=77).

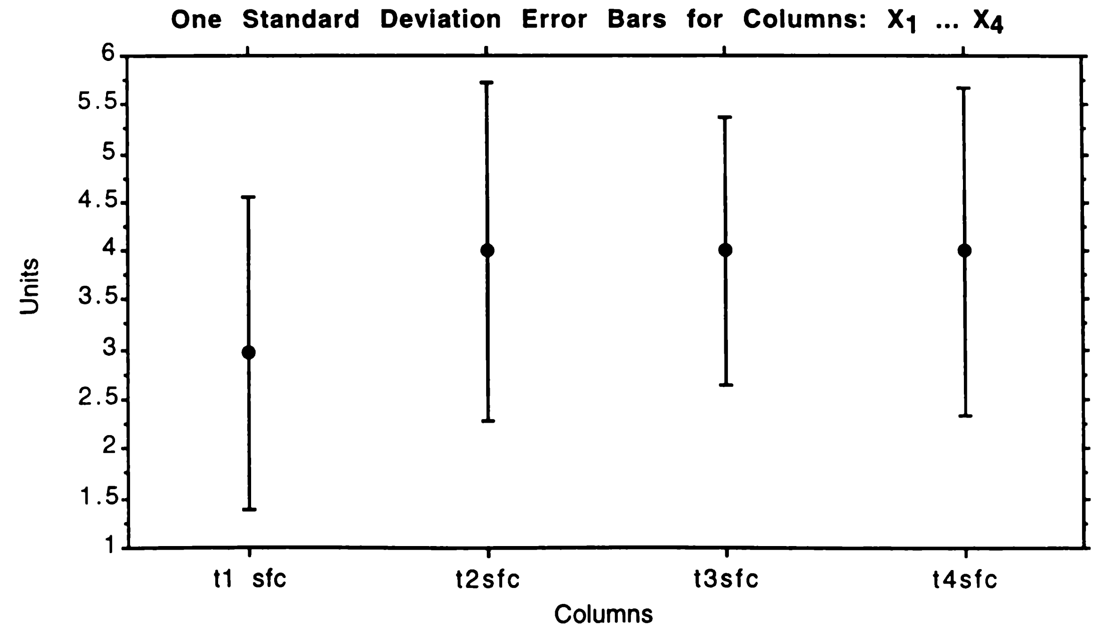

Figure Appendix L.2: Comparison of Sixth Form Certificate Grades for the four classes of 1993 students (total n=77).

	T1	T2	T3	T4
T1		√ 0	0	√ x 0
T2				√ x
T3				√ x
T4				

Key:
√ = significant difference at 95% on Fisher PLSD for Factor X
x = significant difference at 05% on Scheffe F-test for Factor X
0 = significant difference at 95% on Fisher PLSD for Sixth Form Certificate grade

Figure Appendix L.3: One factor ANOVA for 1993 Factor X scores and Sixth Form Certificate Grades

Appendix M: Student end of year survey forms 1993 and 1994

1993

Form 6 Biology Questionnaire End of year 1993

Student's code | | | | | | | | | |

1. How do you think doing practical work helps your learning in biology?

2. What do you think doing a "Fair test" means?

3. How does carrying out an investigation like "Factor X" affect your learning of the ways in which enzymes work?

4. Would you have liked to have done more investigations similar to "Factor X" and "Water Efficient Plants" in biology this year? Please explain your answer.

1994

Form 6 Biology Questionnaire End of term 2, 1994

Student's code | 9 | 4 | | |

1. Did doing investigative practical work this year in biology help you learn the concepts (the ideas) of biology? How?

2. What skills and attitudes do you think you need to carry out investigative practical work in biology?

Did doing investigative practical work in biology this year help you learn or further develop these skills and attitudes? How?

3. What did you find easy about doing investigations this year?

4. What did you find difficult about doing investigations this year?

5. What extra help would you have liked to have been given when you were doing investigations?

Appendix N: Questions students can be asked when they are carrying out open investigations

When students are carrying out investigations they do not require to be "told the answer" but need their thinking stimulated in such a way that they can begin to find answers for themselves. We have found that our questions tended to be those that

- referred students to past experiences
- helped students to switch into the relevant knowledge base
- helped students to decide the approach they will take
- helped students to make decisions about the recording of the data
- helped students to identify the significance of their observations/gathered data
- helped students make decisions regarding the reporting of their findings:
- helped the students become more precise in their thinking:
- encouraged the students to reflect on the overall process

Some possible questions are listed below. This list is not intended to be inclusive and some questions can belong to more than one grouping.

Questions which refer students to past experiences

How in the past were you presented with ...[*glucose, ...*]? What did you do with it?

Do you remember when ...[*we tested for ..., used similar apparatus, constructed a model for our hypothesis*]?

What did that [*reference to a particular happening*] mean when we have seen that before..?

What sort of things come to mind when we think about this [*situation*]?

Questions which help students to switch into the relevant knowledge base

How does this relate to ...?

Has anyone ever stated any laws or theories which relate to this situation?

How would you describe ...?

What might be the first thing we need to think about ?

What do you think that might be involved here?

What do you think might happen to [ ] if...?

Is it reasonable to assume [ ]..?

What might [ ] depend on?

Where could you go to find out more information?

Questions which help students to decide the approach they will take

What information have you been given?

What have you decided needs to be done?

Are you investigating the conditions you have named in the hypothesis?

Is this a fair test ?

What are you testing?

How big a sample do you need?

How many times will you need to repeat the experiment?

How long are you planning to take measurements for?

Are you taking enough measurements?

Do you need to be careful to standardise some aspects of the investigation?

What are the variables you have identified - which are you going to make the independent variable - how are you going to "manage" this?

How are you going to measure the dependent variable?

What are the factors influencing this situation - how many can you name?

Are there some factors you are going to have difficulty in keeping constant?

Which variables are you going to keep constant?

Have you named/identified the control?

Why have you chosen to do [ ] in [*this particular way*]?

How can you make sure that [*you are not contaminating, using unclean equipment,...*]?

Questions which help students to make decisions about the recording of the data

What information do you need to record?

Would a table help?

Could you draw a picture here ?

How could you represent this graphically ?

Could you gather this data through the use of ... [*information technology*]?

Questions which help students to identify the significance of their observations/gathered data?

What measurements might you need to take to confirm your observations?

What evidence has helped you to change your mind?

What reasons can you give for any unexpected results?

Can you see any patterns in this data?

Questions to help students make decisions regarding the reporting of their findings:

Who are you writing this report for? [*teacher, journal, school magazine, out of school adult, younger student?*]

How much information do you need to include to tell the whole story?

Do you need to include some pictorial/graphical material?

Would someone reading this know exactly what you have ...[*done, based your conclusions on* ...]?

Questions to help the students become more precise in their thinking:

If I picked this method up would I know exactly what to do?

Have you written your method out in enough detail so that anyone else could follow it?

How much of [.......] are you going to use?

How long are you going to take measurements for?

What equipment are you going to use?

In what order are you going to do things?

What might be the reasons why ....?

What do you think the purpose of [*this*] might be ....?

Can you imagine what might happen if ...?

How can you be sure?

Have you thought about what might happen if ....?

Questions which encourage the students to reflect on the overall process
What have you learnt today?
Did you enjoy having to decide the method for yourself?
What are you thinking about this kind of work?
What do you expect to happen in your biology classroom?
What are you liking about this kind of work?
What are the sticking points? What do you find difficult?
Could you learn in this way for everything?
Does it matter if your hypothesis turns out to be "right" or "wrong"?
Did you understand what you were doing?
Do you understand why you did [ ] in this particular way?

Appendix O: City High teachers' views of problem solving

The senior Biology teachers at City High (the 1993 - 1994 research school) were surveyed to find out their opinions about the application of problem-solving (investigative) strategies in secondary science classrooms. The questionnaire was developed from the responses given by teachers to a 1991 survey of Auckland teachers who were asked to indicate the advantages and difficulties or constraints associated with a problem-solving approach to science education.

The responses from the four City High teachers were analysed for degrees of concurrence regarding these statements. There was strong concurrence for all of the perceived advantages statements, with all of the teachers either agreeing or strongly agreeing with the statements. All the teachers strongly agreed, both at the beginning of 1993 and end of 1994, with three of the statements (It helps students to apply known information to new situations; It encourages students to think; It demonstrates the possibilities of multiple solutions). In addition the three teachers who completed the two years in the same school over the research period concurred on 'strong agreement' with five more statements at the end of 1994 (It encourages pupil independence; It encourages co-operative behaviour; It helps students to learn skills - scientific and generic; It encourages creativity and initiative; It emphasises scientific processes).

There was, however less consensus amongst these teachers regarding the statements made by the Auckland teachers regarding the difficulties or constraints of using a problem-solving investigative approach. They all agreed or strongly agreed with five statements at the start of 1993 (It is time consuming; It creates management difficulties - resources and teacher time; There are a lot of demands on the teacher for assistance, Students prefer strict guidelines, It requires students to think). At the end of 1994 they concurred with only two of these statements (It is time consuming; It requires students to think) and concurred at the level of agreement on one additional statement (some students have language difficulties). They all disagreed or strongly agreed with three statements at the beginning of 1993 (There are discipline or management problems - including safety; It doesn't help students to prepare for exams; Parents do not accept this way of teaching). By the end of 1994 they still disagreed or strongly disagreed with these statements and in addition they had shifted to disagreement or strong disagreement for the statements 'There are lots of demands on the teacher for assistance', 'Students lack motivation' and 'Students lack the required background knowledge'. The statements for which the responses were most widely spread by the end of 1994 were 'It creates management difficulties - resources and teacher time' (SA to D), 'There are syllabus constraints' (SA to D), 'It is hard to develop or find suitable problems' (SA to SD), 'Students prefer strict guidelines' (SA to D), 'There are some unwanted outcomes' (A to SD) and 'It is difficult to assess' (SA to SD).

In a small number of instances the teachers annotated their responses. T1 added the phrase *'for most'* to the three advantages responses she dropped from strongly agree to agree. These were the statements 'It enhances understanding and memory - increasing learning'; It increases student commitment, involvement, persistence' and 'It encourages cooperative behaviour'. She also qualified her responses to the difficulty or constraint statements - strongly agreeing to 'It creates management difficulties - resources and teacher time' during *the initial setting up stage,* to 'There are syllabus constraints' by indicating that this would only be so if this were the *only method* to be used, and that 'There are lots of demands on the teacher for assistance' *until the pupils get used to it.* She disagreed with the statement that 'Student lack motivation' but added that the *odd one may* when working in this way. Both at the beginning and the end of the research period T1 indicated that students preferred strict guidelines but on the closure questionnaire qualified this response with *'some do'.* T2 also commented that this approach may be time consuming and demanding of the teacher *at the start.* T2 indicated that she agreed with the statement it is 'confidence building' and on questioning by the researcher as to why she had changed this from strongly agree to agree she indicated that "after kids get the wrong idea they come out even more confused". T3 added a comment at the base of advantages list which indicated that she had observed a change in the teacher's role when working in this way - "the teacher has less of an instructional role; more of an encouraging/stimulating role". T3 and T4 both commented that though 'There are sometimes unwanted outcomes' these are useful and that "unwanted outcomes are an item for discussion and not a disadvantage" (T3, 1994 questionnaire sheet).

The four teachers in the 1993-1994 research school had a high degree of consensus regarding the advantages of approaching practical Biology from a problem-solving investigative mode. There were less commonalities regarding the perceived disadvantages of this approach which may have reflected the teachers different preferred ways of teaching, the differences they exhibited with regard to expectations of students and perhaps their responsibilities with regard to the development of the curriculum for Form 6 Biology. T3 was more positive (with only 4 Strongly Agree or Agree to the difficulties and constraints list compared to 8 for T1 and 7 for T2) and this may be a reflection of the additional intensive time spent with the researcher during 1994.

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