

**A study of the implementation of scientific investigations at Grade 9
with particular reference to the relationship between learner
autonomy and teacher support**

by

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ABSTRACT

The purpose of the study was to investigate the implementation of scientific investigations at Grade 9. The study focussed in particular on the autonomy learners have in doing scientific investigations, and the strategies that teachers employ in supporting learners when they are doing investigations. The study adopted a mixed methodology research design which involved the collection of both quantitative and qualitative data. The quantitative data was collected by means of questionnaires which were administered to teachers and learners. Qualitative data was collected by means of classroom observations, teacher interviews and learner interviews. The general trends that were quantitatively established were validated and explicated by the qualitative analysis.

A finding of the study was that at schools where scientific investigations are taking place, the learners have varying degrees of autonomy across the different stages of the investigation. In general, autonomy increases from little autonomy at the start when formulating the investigation question to significant autonomy in drawing conclusions. The study also revealed that both teachers and learners believe that when learners do their own investigations, it facilitates conceptual understating, leads to the development of scientific skills, and helps to motivate learners. In addressing the question of teacher support, the study found that teachers support learners by asking questions at all stages of the investigations, offering suggestions when necessary, giving learners a prompt sheet, and instructing learners in the use of practical techniques. Finally, the study identified class size, the availability of resources, the availability of time, and teacher competence as significant factors which affect the degree of learner autonomy in the implementation of scientific investigations in the classroom.

These findings have implications for the implementation of scientific investigations at schools. Firstly, the findings it is believed will inform the practice of teachers who would want to introduce learner-centred investigations in their teaching. Secondly, the study has identified factors which will need to be considered by curriculum planners if the scenario of learners doing their own investigations is to become a reality in South Africa.

PREFACE

The work described in this thesis was carried out in the School of Science, Mathematics and Technology Education, University of KwaZulu-Natal, from January 2001 to December 2006 under the supervision of Prof Paul Hobden.

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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DECLARATION

I, Umesh Dewnarain Ramnarain declare that:

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ABBREVIATIONS

OBE	Outcomes-based education
RNCS	Revised National Curriculum Statement
AAAS	American Association for the Advancement of Science
NRC	National Research Council
FET	Further Education and Training
GET	General Education and Training
APU	Assessment of Performance Unit
TIMSS	Third International Mathematics and Science Study
AKSIS	ASE-King's science investigations in schools

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CHAPTER ONE

INTRODUCTION

The purpose of this study is to investigate the implementation of scientific investigations at the Grade 9 level. The particular focus is the degree of autonomy learners receive in doing scientific investigations and how teachers support learners when they are doing scientific investigations. This chapter presents a brief overview of the study. Firstly, the background situates the study in the context of changes which have taken and are taking place in science education, in South Africa and internationally. Secondly, the rationale for the study explains the significance of the study. Thirdly, the research aim explains the purpose of the study. Fourthly, the research approach describes briefly how the research questions were addressed.

1.1 BACKGROUND TO THE STUDY

The new social and economic demand for higher-order intellectual skills which has accompanied the global information technology revolution has impacted on school curriculum reform. National growth and competitiveness is dependent on continuous technological improvement and innovation, driven by a workforce that needs to be adaptable in its thinking and operate with greater autonomy. Whereas skills in set routines were valued as attributes in the past, today each worker is expected to think critically, solve abstract problems and generate new ideas for improvement (United States Department of Commerce, 1999). This means that people should acquire the capacity to constantly re-define the necessary skills for a given task (Castells, 2000). These new demands from the workplace and the technological advancements of the world in which we live have served to stimulate much change in national curricula throughout the world.

In South Africa, outcomes-based education (OBE) which forms the foundation of the new curriculum, advocates a learner-centred and activity-based approach to education (Department of Education, 2003a). This curriculum aims to develop the full potential of each learner as a citizen of a democratic South Africa. A basic tenet of this curriculum is

that teachers should create opportunities for learners to demonstrate that they are able to work independently (Department of Education, 2002a).

Practical work in the school science curriculum in particular is an area which has received much attention in the curriculum reform initiatives which have taken place worldwide. One of the major changes advocated in this curriculum reform is a new conception of the role and form that practical work should assume. In South Africa, this curriculum reform is expressed through the Revised National Curriculum Statement (RNCS) for Natural Science (Department of Education, 2002b) which asserts that investigations should feature prominently in science teaching and learning. The place of scientific investigations is addressed through Learning Outcome One of this curriculum statement, which states that “The learner will be able to act confidently on curiosity about natural phenomena, and to investigate relationships and solve problems in scientific, technological and environmental contexts” (p. 6).

These developments in South Africa mirror the worldwide reform trends in science education. In the United Kingdom, Attainment Target 1 for Science in the National Curriculum has apportioned much priority to scientific investigations (Department for Education and Employment, 1999). In the United States, the American Association for the Advancement of Science (AAAS) and the National Research Council (NRC) endorse science curricula that actively engage learners using an inquiry-based approach. The National Science Education Standards developed by the NRC (1996), mandate:

Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (p. 105)

The AAAS (1993) in its Project 2061 recommends that before graduating from high school, students working individually or in teams should design and carry out at least one major investigation. In doing so they should “frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism” (AAAS, 1993, p. 9).

Some of these ideas which underpin current science education reform and in particular learner practical work have their origins in the nineteenth century. For example, the

heuristic method of teaching which was popularised by H.E. Armstrong supports learner autonomy and involvement by teaching “the pupils how to learn, how to raise interesting questions, how to investigate, and how to find answers on their own” (DeBoer, 1991, p. 56). In support of this, John Dewey made a case for the importance of inquiry-based teaching by stating that it facilitated self-directed learning in children and also cultivated their natural curiosity (Dow, 1999).

In the curriculum documents mentioned, reference is made to the terms ‘investigation’ and ‘inquiry’. These terms although related, differ with regard to their range of focus. For the purposes of this study, the relationship between investigations, inquiry and practical work may be represented as follows in Figure 1.1. An investigation is defined as an activity in which learners use thinking skills and processes such as “formulating questions and hypotheses, predicting, interpreting data, synthesizing information, and making conclusions” (Chin & Kayalvizhi, 2002, p. 269).

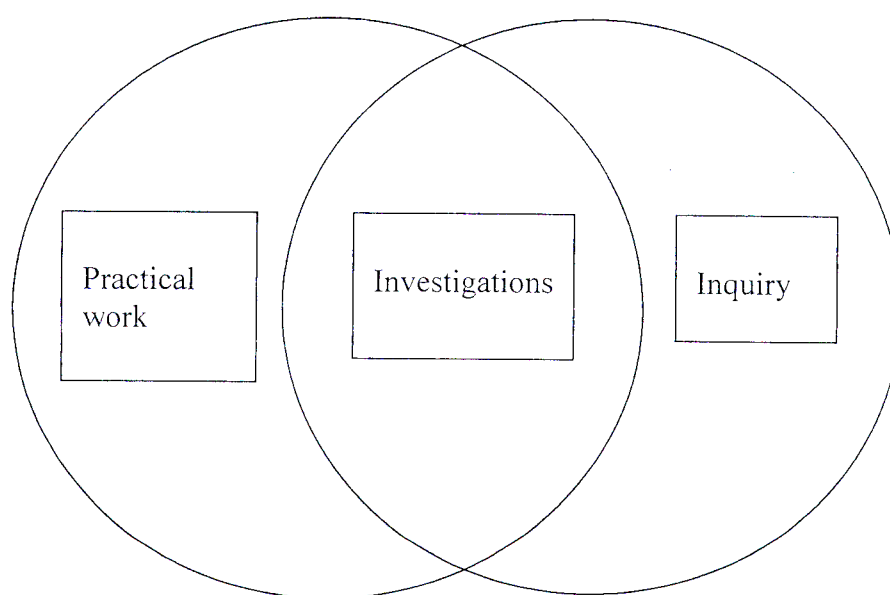


Figure 1.1 Relationship between practical work, investigations and inquiry

An investigation takes place in stages. It consists of some kind of plan, an implementing or ‘doing’ stage which should include recording in some form and a final stage where the learner examines the data and draws some kind of conclusion from them (Gott & Duggan, 1995). Investigative work also involves the use of process skills like planning, observing and gathering information, comprehension, synthesizing, generalizing, hypothesizing and communicating results and conclusions (Department of Education, 2003a). An inquiry on

the other hand, is perceived to be a more encompassing concept and includes a range of activities with a focus on describing objects and events, asking questions, constructing explanations, testing those explanations against current knowledge, and communicating their ideas to others (NRC, 1996). From Figure 1.1 it is seen that all investigations involve inquiry, however not all inquiry involves practical work. For example, apart from involving some practical work, an inquiry may take the form of a critical analysis of secondary sources such as media, books, and journals (NRC, 1996). According to Dow (1999), “scientific inquiry has its roots in the inherent curiosity of the human mind” (p. 8). This curiosity drives human beings in “exploring the natural or material world” (National Science Foundation, 1999, p. 2).

The new approach to practical work advocated in science education curricula worldwide is in stark contrast to the traditional laboratory setting where learners slavishly follow teacher directions and procedures without much thought (Hodson, 1993). The traditional science curriculum, which placed much emphasis on the transmission of scientific knowledge, was teacher-centred, and portrayed the learner in a passive role. In such a teacher-centred science classroom, communication flows from the teacher to the learner and teacher talk dominates the lesson. According to Taylor and Vinjevold (1999), this teacher-centredness and learner passivity is predominant in most South African schools. In a typical classroom, learners might sit in straight rows of desks facing the front of the class and have few opportunities to interact or work in cooperative learning groups. Experimental tasks in this mode often embodied a cookbook approach, where learners followed recipes for the execution of procedures handed down by teachers, and gathered and recorded data without a clear sense of purpose (Roth, 1994). Many of the activities carried out by learners merely confirm or illustrate what has been taught in class. Although these prescriptive exercises permit learners to learn how to follow recipes rather than develop the skill or understand the knowledge, the most crucial drawback of such exercises and other ‘cookbook’ laboratory experiments is that learners do not know why they take certain steps over others. When they do get answers which disagree with those of their peers or the theory provided by the textbook, most learners quickly learn to fudge their data so that, to receive good marks, they can show the expected results (Amerine & Bilmes, 1990). Such excessive teacher control of practical work has been a common practice in science education in South Africa. A study carried out by Hobden (1984) on chemistry practical work showed that learners were normally given written and verbal instructions to follow

when doing practical work. Practical work was perceived by learners as merely supporting theory. This was a mismatch with the teachers' stated aim of promoting logical reasoning methods. Later studies (Hobden, 2005; Taylor & Vinjevold, 1999) showed that little had changed with most practical work still being of the cookbook type.

It is envisaged that the introduction of investigative work in school science in South Africa will transform the teacher-learner relationship, in particular the control and ownership of the learning situation. The introduction of practical science investigations should redefine the traditional science teacher-learner relationship. The new curriculum for Natural Science in South Africa advocates learner autonomy as it specifies that through investigations, teachers should "create opportunities for learners to demonstrate that they are able to work independently" and encourage learners on their own to "explore objects, situations and events in their immediate environment, to collect data and record information and draw conclusions accurately" (Department of Education, 2002a, p. 34). In this new environment, teachers should surrender much of their control and act more as facilitators. According to Billings (2001), if a "sage-on-the-stage" is the metaphor for the traditional passive learning environment, then "learner-on-stage, and support staff as stage hands, with the teacher directing it all" (p. 2) is the metaphor for learner-centred learning. We should expect to find greater prominence now being given to the notion of learner autonomy and self-directed learning, and less control being exercised by the teacher in the learning situation.

1.2 RATIONALE FOR THE STUDY

In recent years, there has been increasing research interest in learner-centred, open-ended learning environments in which learners individually or in small groups determine the foci of their science-related inquiries (Gangoli, 1995). These studies have focused by and large on learner cognition and have provided scant conceptualisation of how the critical balance between learner autonomy and teacher support is established. In an overview of recent research in South Africa, Malcolm and Alant (2004) report that the dominant research has been on teaching and learning, especially cognition. Curriculum documents such as the RNCS (Department of Education, 2002b) for Natural Science refer to the facilitative role of the teacher in a learner-centred environment. However, there are few guidelines as to exactly what this entails. Teachers who choose to transform their practice, therefore have a

limited research database that they can access to inform their practice. The current knowledge about how to promote a learner-centred environment of scientific investigations is limited (Fradd & Lee, 1999), primarily because researchers have found that science inquiry is resistant to analysis, and the development and application of science inquiry is a complex problem (Germann, Aram, & Burke, 1996). Thus few programmes have been able to encourage inquiry teaching with student-designed experiments (Pizzini, Shepardson & Abell, 1991).

Much of the research that has explored classroom-based investigations draws from privileged classroom settings. Despite research reporting learning benefits in a range of classroom settings (White & Frederiksen, 1998) the field remains somewhat uninformed about the challenges of implementing investigations across a range of classroom contexts which differ in terms of resources, constraints placed on the teacher, the backgrounds of the teachers and learners, and class sizes. In the South African context, limited research has been conducted on the implementation of scientific investigations. In the period 1991-2000, Laugksch (2003) reports that only 1,1% of science education publications have been related to inquiry. Two studies which have been conducted have highlighted the lack of learner autonomy in science practical work. Firstly, a classroom environment study on the impact of Curriculum 2005 on the learning environment of science classrooms in the Limpopo Province has revealed that there is a difference between the learners' actual and preferred perception in their autonomy in doing scientific investigations (Seopa, Laugksch, Aldridge & Fraser, 2003). The learners would prefer more autonomy in doing scientific investigations than they receive. Secondly, Rogan and Aldous (2005) observed in a study conducted for schools in Mpumalanga, that science practical work was dominated by teacher demonstrations. When learners did have the opportunity to do practical work they followed cookbook instructions given by the teacher. Despite the imperative to increase the amount of practical work, and in particular the implementation of science investigations in the classroom, the researcher, being a Natural Science educator has learned that there is a very limited database of research which can inform the practice of educators who are willing to implement scientific investigations in the classroom.

The present study delved deeper into the implementation of scientific investigations and explored how much autonomy learners have in doing scientific investigations and where the learners do have this autonomy, how the teacher supports them. The study also

attempted to identify the factors which affect the relationship between learner autonomy and teacher control in the implementations of scientific investigations. The study focused on scientific investigations at Grade 9. The Grade 9 year was significant, as it was the final grade in the General Education and Training (GET) phase for which a new curriculum was described in the RNCS. It was only in 2006 that a new curriculum was introduced in Grade 10.

1.3 AIM OF RESEARCH STUDY

The study in describing the implementation of science investigations in Grade 9, had two primary functions. Firstly, the study described the degree of autonomy that learners experience in doing scientific investigations, and secondly explained how teachers support learners when doing scientific investigations. Other purposes of the study which are related to these two aspects included identifying the perceived benefits of learners doing their own investigations, and identifying the factors which affect the degree of learner autonomy. Given these purposes, this led to the formulation of the following guiding research questions:

1. What are the degrees of learner autonomy in the implementation of scientific investigations ?
2. What are the perceived benefits of learners doing their own scientific investigations ?
3. How do teachers support learners doing scientific investigations ?
4. What factors affect the degree of learner autonomy ?

It was envisaged that the study, in exploring the implementation of scientific investigations in South African schools with particular reference to the re-defined relationship between the learner and the teacher, would yield substantive findings to enable teachers of Natural Science to reflect on and maybe inform their current practices. It was also expected that the findings of the study would yield important baseline data for the Further Education and Training (FET) curriculum in Physical Science. Outcomes-based education, which underpins the National Curriculum Statement for the FET phase (2003), also encourages a learner-centred and activity-based approach to education. Learning Outcome One for Physical Science emphasizes the important role that scientific inquiry and problem-solving

skills is to play in the new curriculum. According to this learning outcome, “The learners’ understanding of the world will be informed by the use of scientific inquiry skills like planning, observing and gathering information, comprehension, synthesizing, generalizing, hypothesizing, and communicating the results and conclusions” (Department of Education, 2003a, p. 13). It would therefore appear that learner autonomy in an investigative learning environment will also be a critical issue in the FET Physical Science curriculum.

1.4 RESEARCH APPROACH

The aim of the research determines the methodology and design of the research (Cohen, Manion & Morisson, 2000). This study, in addressing the research questions employs a pragmatic, mixed methodology design (Johnson & Onwuegbuzie, 2004) which uses a combination of quantitative and qualitative methods and procedures. This resulted in both quantitative and qualitative data being collected. In recent years, significant progress has been made towards the desirable goal of combining quantitative and qualitative methods within the same study, such as research on classroom learning environments (Fraser & Tobin, 1991).

In this study, a descriptive research approach has been used. This research approach as stated by Best (as cited in Cohen et al., 2000) is concerned with practices that exist; beliefs; points of view, or attitudes that are held; or trends that are developing. All these aspects mentioned are consistent with the dual focus of the study, i.e. the degree of learner autonomy, and the support strategies used by teachers. The descriptive data were both quantitative and qualitative.

Initially, there was a large-scale survey involving the collection of mostly quantitative data through a structured questionnaire distributed to a purposefully selected sample of Grade 9 Natural Science teachers in public and independent secondary schools throughout KwaZulu-Natal. Analysis of the data collected through the teacher questionnaires allowed tentative findings to be made. This enabled the researcher to sharpen his focus for the subsequent phase involving the collection of qualitative data.

Qualitative data were collected from classroom observation of investigations taking place at five schools drawn from the sample which had been surveyed in the quantitative phase

of the research study. These schools were chosen using a combination of purposeful sampling which entails “selecting information-rich cases for study in-depth” (Patton, 1990, p. 169) and convenience sampling which involves “choosing the nearest individuals to serve as respondents” (Russell, 1998, p. 25). The findings of the questionnaire survey enabled the researcher to identify those schools where teachers were engaging learners in scientific investigations. The researcher acted as a complete observer by being detached as possible from what happened in the classroom (Schumacher & McMillan, 1993). The observations focused on the degree of autonomy learners had during the investigative process, and described the strategies used by teachers in supporting learners who were doing scientific investigations. A questionnaire was administered to learners in this sample to ascertain how much autonomy they had in doing scientific investigations and to gauge their perceptions of doing investigations on their own. Interviews with teachers and learners further probed and validated the findings of the questionnaires and classroom observations. Fieldwork conducted at a young scientists exposition competition held at the University of KwaZulu-Natal (Durban campus) also produced qualitative data which were used to describe the nature and extent of support learners receive in doing investigation projects for science expositions.

The data collected through the classroom observations and interviews were analyzed by reading, reflecting on the data, organizing the data and searching for patterns (Schumacher & McMillan, 1993). This was done using accepted methods of analyzing qualitative data. The findings from this analysis as well as the statistical analysis of the teacher and learner questionnaires were used to generate assertions pertaining to the research questions. These assertions are “concise statements that represent patterns or regularities” within the data and are essentially the answers to the research questions (Gallagher & Tobin, 1991, p. 91).

1.4 STRUCTURE OF THESIS

The study is presented in the following chapters. Chapter Two reviews literature related to scientific investigations. A theoretical and conceptual framework for the implementation of scientific investigations in the science classroom is also constructed. This chapter provides a basis for interpreting the analysis of data in Chapter Five. Chapter Three describes the research study in addressing the research questions posed in Chapter One, in terms of the

research design, the sampling procedures, methods of data collection, and data management and analysis procedures which were employed. The case studies described in Chapter Four provide a real context for understanding the analysis of data and assertions generated in Chapter Five. Furthermore, investigation projects which were submitted for a science exposition (commonly known as expo) are described as exemplars of the kind of support that learners receive in doing such independent projects. Chapter Five involves the analysis and interpretation of the data collected through the quantitative and qualitative phases of the research study. Chapter Six the final chapter, attempts to draw conclusions from the findings of the data analysis in Chapter Five, and also to make recommendations for the implementation of scientific investigations in the classroom.

CHAPTER TWO

THEORETICAL FRAMEWORK AND A REVIEW OF RELATED LITERATURE

This chapter describes the place of practical work in science education, and how scientific investigations as a practical activity foster learning in science. The different types of investigations which learners can do, and models for the implementation of investigations in the classroom are described. Learner autonomy is explored both as a characteristic and a benefit of doing scientific investigations. If the doing of scientific investigations means learners have more autonomy in the learning situation, then the traditional teacher control will need to be replaced with teacher support. In trying to understand the nature of this teacher support, a theoretical framework for analyzing teacher support is constructed. Also, the role of the teacher in supporting the learner according to this framework is described. Finally, a classification scheme which can be used to classify investigations in terms of the degree of learner autonomy and the extent of teacher control is described.

2.1 PRACTICAL WORK IN SCIENCE EDUCATION

In almost all countries, science education involves learners and teachers doing practical work. This practical work varies in form and intention. Millar, Le Marechal and Tiberghien (1999) believe that if researchers are to explore the effectiveness of practical work in achieving educational goals, then there needs to be clarity about the different types of practical work and their different purposes. It may be useful in this review to begin by making clearer exactly what is included within the category of 'practical work'. Millar et al. define practical work as: "All those kinds of learning activities in science which involve students at some point in handling or observing real objects or materials they are studying (or direct representations of these, in a simulation or video-recording)" (p. 36). According to this definition, practical work is more than laboratory work. It refers to all practical activities involved in the development of scientific literacy (Bradley, 2005).

Millar et al. (1999) propose that practical tasks may be classified according to the intended learning outcomes. These intended learning outcomes are presented in Table 2.1.

According to Millar et al. many practical tasks are likely to result in more than one of these learning outcomes. It is therefore suggested that "in classifying a task by its learning objective(s), it is more useful if the focus is on the most important outcomes rather than identifying all possible outcomes which the task might be said to address" (p. 42).

Table 2.1 Intended learning outcomes for practical work

AREA	Outcome
Content	To help students identify objects and phenomena and become familiar with them
	To help students learn a fact (or facts)
	To help students learn a concept
	To help students learn a relationship
	To help students learn a theory/model
Process	To help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus
	To help students learn how to carry out a standard procedure
	To help students learn how to plan an investigation to address a specific question or problem
	To help students learn how to process data
	To help students learn how to use data to support a conclusion
	To help students learn how to communicate the results of their Work

There is a wide variety of practical work which may be classified according to these content and process learning objectives. Another way of classifying practical work is that used by Roth et al. (2006). What follows is a précis of this classification. According to them, practical work may be broadly classified into whole-class practical activities and independent practical activities. Whole-class practical activities involve mainly teacher demonstrations of phenomena and objects. In a whole-class activity, the learners may be presented with a situation and then asked to make a prediction derived from their existing science knowledge. A whole-class activity generally involves learners watching the teacher generating and collecting data. In such an activity, the learners do not formulate questions to investigate, formulate a plan to investigate the question, and collect their own data. The learners link the data collected by the teacher or the phenomena they have observed to the predictions they made before the activities. Teacher demonstrations range from simple displays of objects such as the model of the heart to displays of objects with related phenomena, for example showing how substances react with oxygen. A teacher demonstration may be used to help learners learn a concept or relationship. The outcomes of the teacher demonstrations are therefore mainly content-based. In independent practical activities, learners work either individually or in small groups on tasks that involve “observing, handling, or manipulating objects, materials, 3-dimensional models, or organism” (p. 47). The following types of independent practical activities have been

identified: create models; display or classify objects; use tools, procedures, and science processes; conduct an experiment, and produce or observe phenomena. They provide the characteristics of these activities and examples to illustrate the different types. Learners design and make models for the purpose of “illustrating scientific principles” (p. 103). For example, learners may be asked to use materials to illustrate one of Newton’s Laws. In displaying or classifying objects, learners identify certain features of objects. For example, learners may organize metals into categories. Learners may engage in an activity where they practice using a scientific instrument or to master a scientific procedure. For example, learners may learn how to read an ammeter. Learners may conduct an experiment in the form of a “fair test” where an independent variable is manipulated to have an effect on a dependent variable, while controlling all other relevant variables. For example, learners may investigate how water temperature affects the time taken for sugar to dissolve. Learners may also produce or observe phenomena that are not part of a controlled experiment. For example, they may use batteries, light bulbs, and connecting wires to build a circuit that will enable the bulb to glow. It would appear that these independent practical activities result in process outcomes being realised.

Various reasons have been offered for the inclusion of practical work in science education. Firstly, practical work has been offered as a means to facilitate the understanding of concepts in science. Lawson (1975) suggests that science involves highly complex and abstract subject matter and many learners would fail to comprehend such concepts without the concrete props and opportunities for manipulation afforded in the laboratory. According to Roth et al. (2006) this view is supported by researchers such as Hodson and Watson who assert that practical work helps learners to build and understand science concepts by making ideas more concrete and less abstract. Practical work also helps to challenge learner’s experience-based but scientifically naïve conceptions and thereby inducing conceptual change (Lawson, Abrahams & Renner, 1989). Practical work has therefore been found to offer unique opportunities for the identification, diagnosis and remediation of students’ misconceptions (Driver & Bell, 1986). Secondly, the development of experimental skills and techniques is often seen as a goal of practical work. According to Woolnough and Allsop (1985) the aim of developing such skills is fundamental in science education as “one cannot be a craftsman unless one can manipulate one’s tools” (p. 41). Woolnough and Allsop identify observation, measurement, estimation and manipulation as key skills which can be developed by learners doing practical work.

Millar (1991) unpicks the idea of 'practical skills' (p. 51). He divides the skills which he feels can be taught and improved into practical techniques: e.g. measuring temperature to within certain limits, separating by filtration or other 'standard' procedures, and inquiry tactics: e.g. repeating measurements, tabulating data and drawing graphs in order to look for patterns, identifying variables to alter, control, etc. According to Millar, by developing these skills, learners will develop their 'procedural understanding' of science (in contrast to their conceptual understanding). Thirdly, practical work also gives learners the opportunity for learners to act like a real scientist by engaging the learners in the scientific method (Bruner, 1966). The scientific method describes what the scientist does in practice. For example, it is seen as a "systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experimentation (experiential element), the formulation of a hypothesis, and the testing and confirmation (or rejection) of that hypothesis" (Fields, 1987, p. 18). Finally, practical work can also help to motivate learners in science. Learners usually enjoy activities and practical work, and when they are offered and given a chance to experience meaningful and non-trivial experiences they become motivated and interested in science (Woolnough & Allsop, 1985).

There has been much debate and controversy surrounding these aims of practical work. The TIMSS study of 1999 reveals that many of the critiques of practical work point to the mixed evidence regarding that effectiveness of practical work in achieving these aims (Roth et al., 2006). For example, reviews of literature by Hodson and White (as cited in Roth et al., 2006) revealed little evidence that practical work improved learner understanding of science concepts. In fact, a study by Leach and Scott (as cited in Roth et al., 2006) has shown that sometimes learners develop ideas unintended by the curriculum. In order to prevent this from happening, practical work is often tightly structured with the learner expected to follow 'cookbook' instructions. Gunstone (1991) also mentions the difficulty of using practical work as a way of reconstructing learners' knowledge, as the clutter and complexity of the equipment becomes distracting and becomes an end in itself. Gunstone has stressed the need to make learners to think, consciously, about what they are doing and explicitly to make links for them. Where the aim has been to teach learners how to work as scientists, the emphasis has often been on exercises to develop scientific process skills rather than on complete investigations to develop full scientific capability. Millar (1991) maintains that these science process skills need to be developed in the context of

doing science. Studies by Lynch and Ndyetabura (as cited in Roth et al., 2006) have also raised doubt about the effectiveness of practical work in motivating learners. From the above it is seen due to the wide range of outcomes for practical work, the extent to which these outcomes can be realised may vary.

2.2 THE ROLE OF SCIENTIFIC INVESTIGATIONS IN THE SCHOOL SCIENCE CURRICULUM

Recent science education reform initiatives have advocated practical work in the form of scientific investigations and inquiry as a goal of science education. As previously mentioned, both the National Curriculum (1999) of the United Kingdom and the National Science Education Standards (NRC, 1996) of the United States have given much priority to science investigations. In South Africa, the place of scientific investigations is addressed through Learning Outcome One of the RNCS (Department of Education, 2002b).

2.2.1 What is an investigation ?

According to the RNCS (Department of Education, 2002b) of South Africa, competency in the learning outcome of scientific investigations can be seen as “the learner searches for information from books and resource people, generates products and questionnaires, collects data and materials from nature or industry, creates testable questions and fair tests, and explains conclusions” (p. 8).

A scientific investigation is also described as a process which takes places in stages. These stages are identified by the RNCS (Department of Education, 2003b, p. 69) according to the following assessment standards which serve as indicators that this learning outcome has been achieved:

- Planning investigations, where the learner plans a procedure to test predictions or hypotheses, with control of an interfering variable.
- Conducting investigations and collecting data, where the learner contributes to systematic data collection, with regard to accuracy, reliability and the need to control a variable.

- Evaluating data and communicating findings, where the learner seeks patterns and trends in the data collected and generalizes in terms of simple principles.

In summary, it could be said that an investigation would therefore involve the use of process skills such as formulating questions and hypotheses, predicting, planning, observing, measuring, recording, interpreting data, generalizing, and making conclusions.

2.2.2 The contribution of scientific investigations to science learning

Many reasons have been advanced for the prominent role that investigations are to play in the science curriculum. As a scientific investigation is a type of practical work, some of the aims for practical work are achievable through scientific investigations. In fact, some of these aims are more achievable through scientific investigations than any other type of practical work. For example, scientific investigations in particular parallel the way in which scientists work. Roth (1995) states that by doing investigations learners are provided with “opportunities for authentic inquiry, that is, inquiry with some degree of resemblance to what scientists actually do in their laboratory work” (p. 110). Scientific investigations are also highly motivating in science learning. Evidence of this is shown in studies where learners doing investigations had developed an improved attitude towards science. Harlen, Black and Johnson (as cited in Chin & Kayalvihzi, 2005) reporting on a study involving 11-year-olds found that they showed a high level of interest and enthusiasm when doing investigations. A similar finding was obtained by Piburn and Baker (as cited in Chin & Kayalvizhi, 2005) who found that doing investigations provided opportunities to work with other learners and this was highly motivating to learners. The development of conceptual understanding is another aim of practical work which may be realised when learners do scientific investigations. When engaging in investigations, learners describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. In this way, learners actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills (NRC, 1996). In this way concepts that result from learners doing investigations are likely to have greater significance to the learner because they have come from his own acts of searching and data processing. This is supported by a survey study

conducted by Morrow (1999) which found that 72% of all learners felt they learned scientific concepts better when they designed their own experiments.

In addition to those mentioned, other reasons have also been offered for the scientific investigations in the science curriculum. Firstly, investigative inquiries is a powerful way of learning that stems from our natural curiosity to understand our natural world around us (Llewellyn, 2002). “As children discover objects and situations that are puzzling or intriguing-things that provoke their curiosity-they begin asking questions and looking for ways to find answers, all in an effort to understand the world around them” (National Science Foundation, 1999, p. vii). This is the essence of the inquiry process. Millar (1998) believes that doing investigations at schools will help learners to better understand the natural world around them. This natural curiosity, which we all possess, can therefore be tapped and reinforced by making investigations at the heart of science education at school.

Secondly, by doing scientific investigations, learners also develop capacity in applying the science process skills which is a characteristic of the scientific activity. These process skills form the core of inquiry-based, hands-on science learning (Martin, 2000). Examples of science process skills include observing, making measurements, classifying data, making inferences and formulating questions for investigations (Department of Education, 2002b). These skills can lead children to the concepts, principles, laws and generalizations which scientists have established (Martin, Sexton, Wagner & Gerlovich, 1990). In a broader sense, these science process skills are a means by which the learner engages with the world and gains intellectual control of it (Department of Education, 2002b). In referring to tension between the products of science and the processes of science, Sund and Carin (1964) have reinforced the notion of engaging learners in the processes of science by writing that:

Schools have traditionally overemphasized the product of science, the subject matter, and underemphasized or forgotten the process of science. A look at the process by which the subject matter is obtained reveals the dynamic nature of the scientific process, for facts become valid and cumulative only after they survive unrelenting scrutiny. Thus, scientific facts although extremely necessary for any scientific investigation are only a product of the greater contribution of modern science, the process of inquiry. (p. 4)

These process skills are therefore a necessary and important means by which the learner engages with the world by doing investigations and gains intellectual control of it (Department of Education, 2002b).

Thirdly, scientific investigations may lead to the development of higher-order thinking skills. Higher-order thinking is defined as “non-algorithmic; complex; amenable to multiple solutions; involving nuanced judgement; imposing meaning; and effortful” (Resnick, 1987, p. 3). In a community of inquirers, using exploration and discourse strategies stimulates learners to think critically about the data and evidence accumulated during the inquiry. This motivates learners to analyze and synthesize the data and to make judgements and evaluations about the results and conclusions. As learners experience investigations, they use thinking skills that cause them to reflect about their work and pose logical arguments to defend their conclusions. The inquiring learner therefore “moves beyond the concrete situation to higher levels of abstraction and generalization, using his own skills and powers of perception” (Suchman, 1960, p. 33). These higher-order thinking skills are far superior in developing scientific literacy to the recall of science facts in traditional classrooms.

Fourthly, investigations contribute to children’s social development, as well as to their intellectual development. There is a social context to doing investigations as the learners discuss and share new ideas (Pappas & Tepe, 2002). Children discuss plans and work collaboratively in carrying out inquiry activities. They also prepare themselves and present their work in a public forum to their classmates, who serve as critical friends (National Science Foundation, 1999). According to Llewellyn (2002), “groupwork during inquiry can allow the members to learn from each other, share and challenge their ideas, and distribute the work in an equitable fashion” (p. 57). Learners learn to construct knowledge together and build positive peer relationships. Groupwork also allows learners to build self-confidence while working collaboratively in a group to complete a common goal.

Curriculum reform initiatives in science education reflect a paradigm shift from a teacher-dominated to a learner-centred approach. Science is depicted as a human activity and there is a strong emphasis on engaging the learners in the processes of sciences. There is strong evidence from literature that when learners do scientific investigations it develops science process skills, it is highly motivational to the study of science, it leads to the development of higher order thinking skills, it facilitates conceptual understanding, and it contributes to the learner’s social development.

2.3 TYPES OF SCIENTIFIC INVESTIGATIONS

Investigations may be classified into different types depending on what is trying to be achieved through the investigation. The classification schemes which have been devised by researchers broadly classify investigations into four types. These are constructions, comparisons, explanations and explorations. These investigation types are closely related to the kinds of investigations identified by the researchers of the AKSIS (Association for Science Education-King's College London Science Investigations in Schools) project who conducted research on the implementation of scientific investigations at schools in England and Wales (Goldsworthy, Watson & Wood-Robinson, 1998). As part of the AKSIS project, a questionnaire survey was conducted with over a 1000 teachers. These teachers were asked to describe an investigation that they were currently using. Their descriptions of the investigation were then used to categorise the investigation into one of six categories. These are classifying and identifying, fair testing, pattern seeking, investigating models, exploring, and making things or developing systems. This classification system like the one which is described below is based on the structure of the investigation rather than whether it is a part or whole investigation, or whether it is open or closed.

In doing a construction, learners design and build an artefact. This type of investigation corresponds with the category 'making things or developing things' used in the AKSIS project. According to the categories of Goldsworthy et al. (1998), a construction can only be regarded as an investigation if it has a high scientific content. An example of such a construction would be a model of a house with lights. Learners would need to have knowledge of electrical circuits to build this model. A comparison type of investigation is where learners manipulate variables to find something out e.g. which washing powder works best. In terms of the AKSIS classification scheme, a comparison type of investigation would closely resemble 'fair testing'. Goldsworthy et al. state fair testing investigations "are concerned with observing and exploring relations between variables or factors" (p. 16). In an explanation type investigation, learners try to find something out e.g. what factors influence the drying of clothes. This type of investigation again may be considered fair testing. In investigations which relate to an exploration, learners explore a phenomenon in order to understand it e.g. the bending of light through different media. In exploring, learners make a series of observations of objects or events over time.

The four investigation types also closely resemble the investigation problems identified in the RNCS (Department of Education, 2002b). According to the classification used in the RNCS, constructions may be seen as “problems of making”, comparisons as “problems of comparing”, explanations as “problems observing, surveying and measuring”, and explorations as “problems of determining the effect of certain factors” (p. 27).

According to Watson, Goldsworthy, Wood-Robinson (1998) as different kinds of investigations place different emphases on different skills and process, learners need to be exposed to all investigation types so that they can develop these skills and process. This view is supported in the RNCS (Department of Education, 2002b) which emphasizes that “learners need to be given every opportunity to put their minds to different kinds of problems” (p. 27). However, research conducted in the AKSIS project (Watson, Goldsworthy, Wood-Robinson, 1999) has revealed that a very narrow range of investigations is being used in schools in England and Wales. It was reported that at Key Stage 3, about 90% of all investigations done were ‘fair testing’ ones. Watson et al. also observe that most of the literature on scientific investigations is dominated by investigations falling into the category of fair tests. It was therefore interesting to learn whether a similar trend existed in South Africa. This is one of the issues which was addressed in the study.

2.4 MODELS OF SCIENTIFIC INVESTIGATIONS

A number of different instructional models have been developed that can help teachers organize and sequence investigative learning experiences for their learners. By means of a model, the features of a scientific investigation may be combined in a series of coherent learning experiences that help learners build new understandings and develop their investigative skills over time (NRC, 2000). They also provide opportunities for learners to extend, apply, and evaluate what they have learned (Bybee, 1997).

2.4.1 The RNCS model

Implicit in the RNCS (Department of Education, 2002b) for Natural Science is a model which sequences the investigation process into stages. The following stages have been identified, planning investigations; conducting investigations and collecting data; and

evaluating data and communicating findings. This model implies a linear approach to investigation, where there is a starting-point at which the investigation question is formulated and an end-point at which the findings of the investigation are communicated. This model if applied rigidly, suggests limited learning experiences as there is no opportunity for the learners to apply and extend what they have learned. For this reason other types involving cyclic types are recommended.

2.4.2 Wellington's model

Wellington states that “in an ideal world, however, a model of investigational work should follow a cyclic approach” (2000, p. 162). The following model by Wellington (2000, p. 162) explains this cyclic approach.

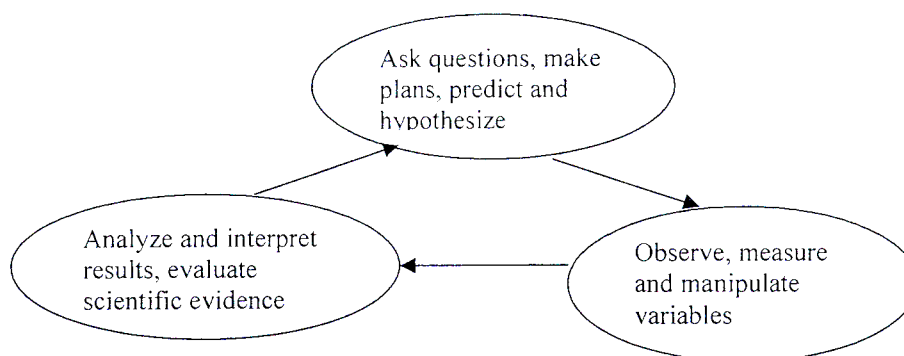


Figure 2.1 A cyclic view of investigational work

Note: From “Teaching and learning secondary science” (p. 162), by Wellington, 2000, London: Routledge

From this model it is seen that the process of interpreting and evaluating results is not necessarily an end-point. Instead, it leads back to the first activity of asking new questions, making revised plans and revisiting predictions.

2.4.3 Llewellyn's model

A similar model referred to as an inquiry cycle is described by Llewellyn (2002, p. 15). The model comprising of six cyclic phases is shown in Figure 2.2. This model is similar to Wellington's model, however it is more descriptive and detailed in identifying six phases in the inquiry cycle. In this cycle, the phases of the inquiry are sequentially arranged from the acquisition phase through to the exhibition phase. Following the inquiry cycle, learners

often enter and re-enter the phases at different aspects of their inquiry process. Thus, the inquiry cycle serves as a model to guide learners through their inquiries and investigations (Llewellyn, 2002).

This description of an investigation in terms of the inquiry cycle is compatible with the definition of a “full inquiry” as presented by the NRC (1996) of the United States in the National Science Education Standards. This document defines “full inquiry” as a process in which students (a) pose a productive question; (b) design an investigation directed towards answering that question; (c) carry-out the investigation, gathering the applicable data in the process; (d) interpret and document their findings; and (e) publish or present their findings in an open forum.

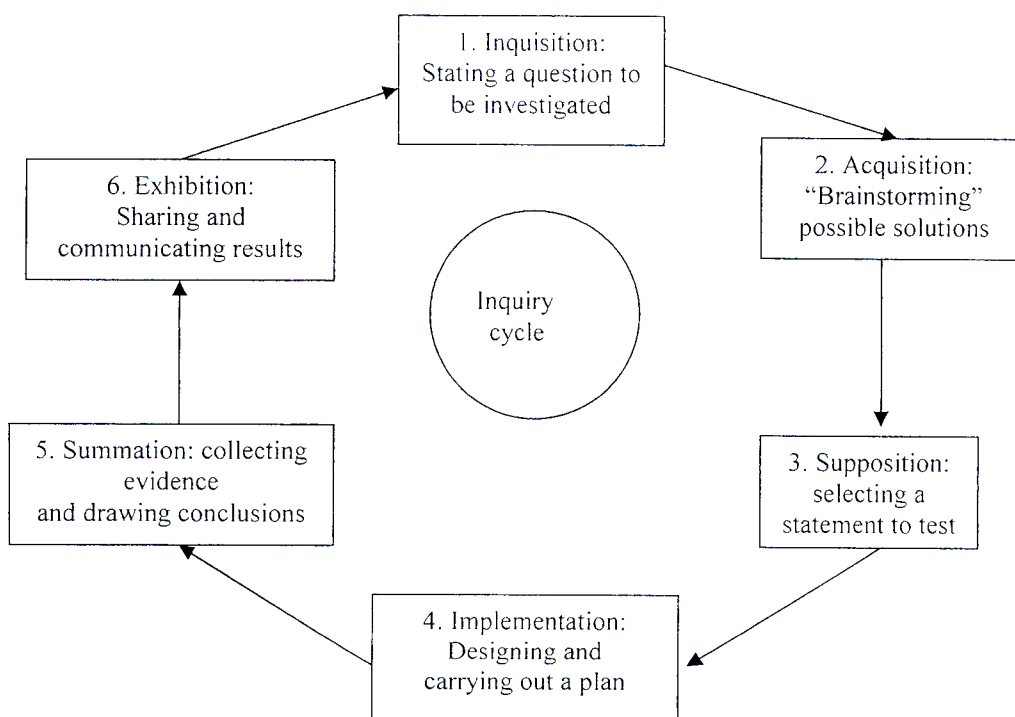


Figure 2.2 The inquiry cycle

Note: From “Inquire within” (p. 15) by D. Llewellyn, 2002, Thousand Oaks, CA: Corwin Press.

2.4.4 The APU model

In addition to the inquiry cycle described above, a further iterative model (Figure 2.3) is used by the Assessment of Performance Unit (APU) (as cited in Watson, 1994, p. 28).

According to this model, the starting point in the investigation process is to find out from the learners what the problem is, what they think the problem is about, and so is concerned with the learner's perception of the problem and its reformulation into a form which can be investigated. The iterative part is concerned with changing one's mind in the light of fresh evidence and going back to an earlier stage to reformulate the problem or change the plan.

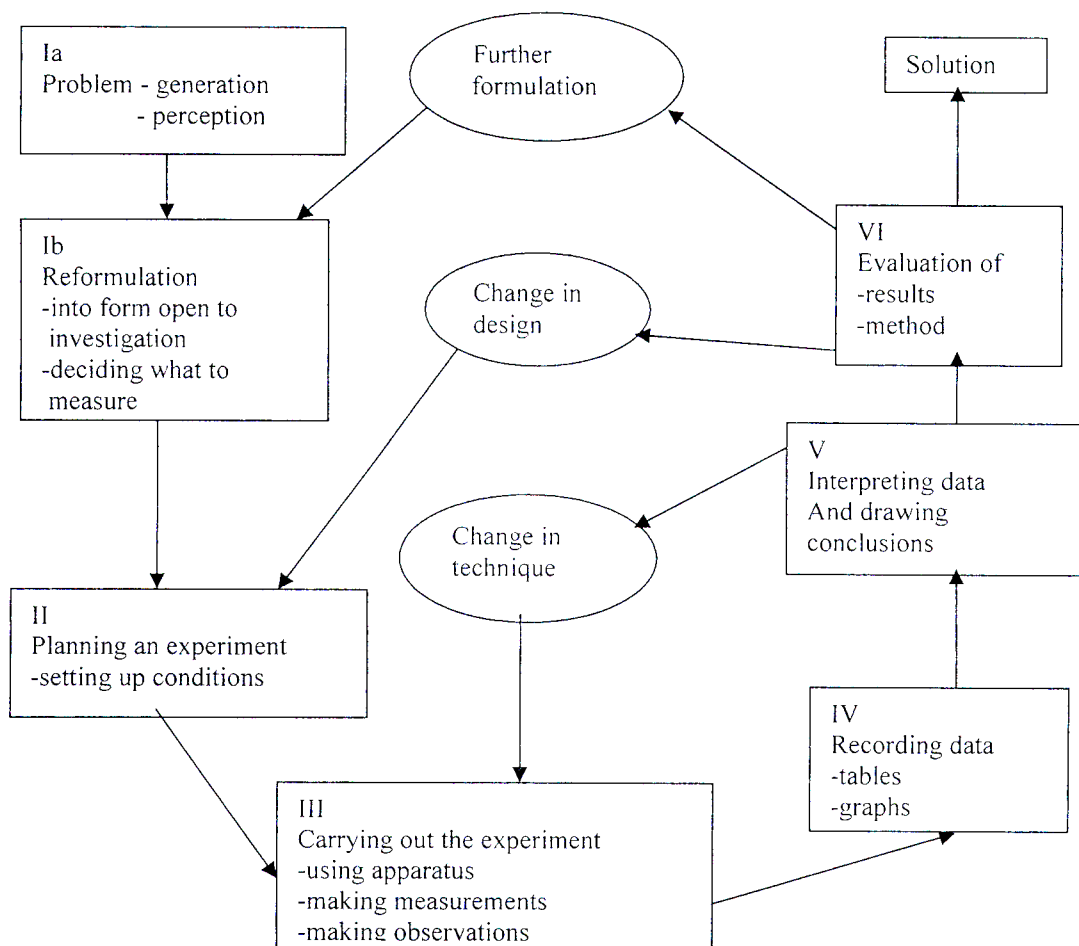


Figure 2.3 The APU model of an investigation

Note: From “Students’ engagement in practical problem solving” (p. 28), *International Journal of Science Education*, 16(1), 27-43 by J.R. Watson, 1994.

2.4.5 Commentary

The criticism leveled at instructional models for investigations is similar as that which applies to models in general. That is, they simplify the world. Teachers and others can be misled into thinking of them as “lockstep, prescriptive devices – rather than as general guides for designing instruction that help learning to unfold through inquiry, which must always be adapted to the needs of particular learners, the specific learning goals, and the

context of learning” (NRC, 2000, p. 35). In developing a suitable model for investigation “the aim must therefore be to develop a general model of ‘investigational work’ which learners can use and apply in a number of different situations” (Wellington, 2000, p. 162). The need is for a flexible model that provides guidance for learners and teachers who are comfortable with more autonomy and open-endedness, as well as for learners and teachers who have little previous inquiry experience and need more guidance (Songer, Lee & McDonald, 2003). One of the foci of the current study was to develop such a model which could assist teachers in the implementation of scientific investigations as described in the RNCS (Department of Education, 2002b) in South Africa.

2.5 LEARNER AUTONOMY IN SCIENTIFIC INVESTIGATIONS

Historically, there has been strong support for a learner-centred school curriculum. Jean Jacques Rousseau (as cited in Lawrence, 1970) believed in a student-centred curriculum, which ultimately results in deepened student understanding. John Dewey also called for more active student involvement in learning. He supported problem or thematic based learning where the content was selected by adults alone (Travers & Rebore, 1987). Later, Bruner (1966) supported Dewey’s ideas and further said that subject matter could be changed to fit the child’s individual needs by making the activities open-ended. Bruner believed that learners should be scientists in their own inquiry. The importance of learner autonomy in science learning was recognised years ago by Sund and Trowbridge (1973) who stated that “the greater student involvement, the greater the learning” (p. 65). They believed that the mere assimilation of knowledge is a very limited view of learning. In their view learning involves those total aspects that contribute to the individual becoming a fully functional person. Today, the idea of learner-centredness is reflected in outcomes-based education which forms the foundation of the curriculum in South Africa. According to the RNCS (Department of Education, 2002b), “the outcomes encourage a learner-centred and activity-based approach to education” (p. 1).

In a review of literature on the relationship between learner autonomy and scientific investigations, learner autonomy has been described as both a rationale for and a characteristic of learners doing scientific investigations. Suchman (1960) explains how through inquiry the learner gains autonomy:

Learning through inquiry transcends learning which is directed wholly by the teacher or textbook; the autonomous inquirer assimilates his experience more independently. He is free to pursue knowledge and understanding in accordance with his cognitive need and his individual level and rate of assimilation. (p. 74)

In doing an investigation, learners learn not only concepts and principles, but self-direction and responsibility. In teacher-centred instruction, on the other hand, “much of the opportunities for developing these talents are denied to the student by the instructor. The instructor provides the self-direction and retains the responsibility, etc.” (Sund & Trowbridge, 1973, p. 65). However, as Faraj (1986) suggests, when doing investigations “the learner is seen as a ‘programmer’ of his own learning, and he is the centre of the learning experience” (p. 40). In such a learning situation, the learner should be free to initiate the investigation by posing a question, then can generate his own theories, test them through experiments and through gathering suitable data, and finally formulate a conclusion (Faraj, 1986). In doing investigations, learners play an active rather than a passive role. This active learner involvement in a task is highlighted by Bibens (1980) who states that:

Inquiry requires that students participate actively, and interact directly, with the content. The learner is not allowed to sit passively while the instructor reviews the main thrust of the learning experience for him. In essence, inquiry strongly suggests that the learner is his own teacher. (p. 90)

Investigative inquiries therefore provide opportunities for a shift from a teacher-centred to a learner-centred curriculum where learners have much autonomy and control over their learning.

The principles of constructivism lay the foundation for understanding the need for learner autonomy in scientific investigations. In the constructivist view of learning, the learners are actively involved in their learning as they set their own goals and control their own decisions (Driver & Bell, 1985). The knowledge which the learner gains is constructed within his cognitive structure, and depends on his experiences in the learning environment (Grabinger & Dunlap, 1995). According to Fosnot (1996), in this setting “the traditional hierarchy of the teacher as the autocratic knower and learner as the unknowing, controlled subject studying to learn what the teacher knows begins to dissipate as teachers assume more of a facilitator’s role and learners take on more ownership of the ideas” (p. iv). The principles of constructivism therefore reinforce the desirability of learner autonomy which is a characteristic of learners doing scientific investigations.

Also, in contrast to traditional classrooms, teachers who hold a constructivist view of learning know that learners bring with them to the classroom a diverse set of alternative conceptions that they have developed to explain the world around them (Driver, 1983). These teachers realize that prior conceptions brought to class are often based on misinformation or naïve understandings of complex subjects. These preconceptions are generally ideas that are reasonable and appropriate in a limited context, but learners inappropriately apply them to situations where they do not work (Anderson & Smith, 1987). Learners often hold tenaciously to these ideas, and their preconceptions can be resistant to change, particularly using conventional teaching strategies (Wandersee, Mintzes & Novak, 1994). In traditional classrooms, such misconceptions often go undetected. Uncovering these misconceptions or naïve conceptions forms the foundation of a constructivist lesson. In order for learners to give up their previous alternative conceptions about a particular topic, they have to experience something that challenges their misconception and allows them the opportunity to form new beliefs. According to Piaget (as cited in Llewellyn, 2002), for conceptual change to occur, the child must be faced with new conceptions that are inconsistent with presently held beliefs. Piaget called this cognitive conflict. Hewson and Lemberger (2000) explain that learners change their ideas when they find these ideas to be unsatisfactory, that is when their present ideas do not sufficiently describe or explain an event or observation. The learner must be convinced that the scientific explanation is better than theirs. Learners only change their ideas when they discover alternatives that seem plausible and appear to be more useful.

The investigative approach which stresses learner autonomy is a viable teaching strategy to test the degree of fit between one's preconceptions and the scientific explanation of things. During the investigation, the learner makes a prediction based on his or her present understanding, and then gathers evidence to test this understanding. At times, the learner goes on to record observations and measurements that point out a discrepancy or difference between the predicted and the observable results. This can cause disequilibrium, forcing the individual make accommodations with his or her present cognitive structures to allow the new knowledge to replace the previous (Llewellyn, 2002).

The new emphasis in science education reform in South Africa and other countries is on learner autonomy and scientific investigations. It has been shown in the argument so far

that these concepts are inextricably related. The full benefit of scientific investigations can only be realised if learners are actively doing these investigations themselves.

2.6 A THEORETICAL FRAMEWORK FOR TEACHER SUPPORT OF LEARNERS DOING SCIENTIFIC INVESTIGATIONS

Along with learner autonomy, a responsive environment in the form of teacher support is considered a crucial condition for scientific investigations to take place. In supporting the learners doing investigations, the teacher is the key to the investigation process. Welch, Klopper, Aikenhead and Robinson (1981) state:

The teacher is the critical factor in achieving a desired state consistent with inquiry teaching. Effective teachers would value inquiry, would encourage an inquiry orientation in others, and would possess skills in enabling others to understand inquiry as a way of knowing. (p. 34)

In such an environment, “the teacher provides guidance in dealing with the problem raised and is seen as a facilitator” (Faraj, 1986, p. 39). Vygotsky’s notion of learning in the zone of proximal development (ZPD) and the related apprenticeship model provide a theoretical grounding for the supportive role that the teacher is to play when learners do scientific investigations.

2.6.1 Vygotsky’s theory of learning

Piaget’s developmental theory and von Glaserfeld’s radical constructivism focus to a large extent on the individual, isolated minds that construct knowledge from experiences in the world (Roth, 1995). However, a theory of knowing and learning with a focus on the individual may be inappropriate in accounting for learning situations where social interactions take place. Vygotsky’s theory (as cited in Roth, 1995) on the other hand, “directs our attention not to the individual that tries to build an understanding independent of others, but instead, to individuals as they become functioning members of communities before they become Selves” (p. 16). Accordingly, the roots of our intellectual functioning are first to be found in our surroundings and through interactions with others before they appear internally (Bruner, 1986). From this perspective, Vygotsky (1981) formulated a general law of development:

Any function in the child’s cultural development appears on the stage twice, or on two planes. First it appears on the social plane and then on the psychological plane. First it

appears between people as an interpsychological category, and then within the child as an intrapsychological category. This is equally true with regard to voluntary attention, logical memory, the formation of concepts, and the development of volition. (p. 163)

The translation of development from a cultural to an internal plane happens in the *zone of proximal development*. According to Vygotsky (as cited in Roth, 1995), the zone of proximal development (ZPD) is the difference between a child's independent problem solving ability and the level of problem solving possible under the guidance of an adult or from a more capable peer. While the theory mentions problem solving in the ZPD, the same applies to scientific investigations. The child's actions interact with those of the adult in the ZPD. It is in joint activities between adult and children that the latter appropriate into their own repertoires, knowledge and skills that were initially external to them. Critical to the development of skills is the engagement in joint activity. "Novices develop cognitive skills, that is they become fully-fledged members, by participating in joint activities with more knowledgeable others" (Roth, 1995, p. 17). The key element in this notion is that students can participate in tasks they are to learn without yet mastering the whole task on their own. Once appropriated, children can use knowledge and these skills to control their own actions. Cole (1985) extends the notion of ZPD in such a way that it becomes "the structure of joint activity in any context where there are participants who exercise differential responsibilities by virtue of differential expertise" (p. 155). Thus the zone of proximal development is a dynamic region of sensitivity to learning the skills of culture, in which children develop through participation in problem solving with more experienced members of the culture (Vygotsky, 1978). In this way, the learners "advance their capabilities for independently managing problem solving" (Rogoff, 1990, p. 146).

Vygotsky's model for the mechanism through which social interaction facilitates cognitive development resembles apprenticeship, in which a novice works closely with an expert in joint problem solving in the zone of proximal development. The novice is thereby able to participate in the skills beyond those that he or she is independently capable of handling (Rogoff, 1990).

2.6.2 Rogoff's apprenticeship model

The apprenticeship model described by Rogoff (1990) considers children as apprentices who develop skills and understandings from participating with peers and more skilled

members of their society within the context of sociocultural activity. These learners who are novices in an activity are supported, challenged, and guided by more skilled members of the community (Rogoff, 1990). Rogoff points out this guidance may be tacit or explicit, and involves building bridges from children's present understanding and skills to reach new understanding and skills. Children therefore assume increasingly skilled roles in the activities of their communities.

Rogoff uses the example of shared problem solving to explain this guided participation. A similar explanation could be given for scientific investigations. Skilled partners guide novices with difficult problems by structuring sub-goals of problem solving to focus the novice on a manageable aspect of the problem. The structuring of the problem should be tailored to the child's level of skill. Such structuring does not focus on breaking a task into minutely ordered steps to be mastered in a lockstep fashion. Rather, effective structuring maintains children's involvement with the purpose of the activity, integrating varying aspects of the task in a manageable chunk. In this way children get to see how the steps fit together and to participate in aspects of the activity.

Rogoff explains that children take on increasing responsibility for managing situations as they become familiar with a particular task. This transfer of such responsibility depends upon the child's present level of competence in particular tasks. "With evidence of increasing skill and understanding, expert partners can revise their level of support to be at the edge of the novice's skill, where it is needed for both mutual understanding and the novice's progress" (Rogoff, 1990, p. 100).

2.6.3 Commentary

Vygotsky's theory of learning and the related apprenticeship model as presented by Rogoff suggest that learner autonomy and teacher support are not mutually exclusive concepts. Teacher support exists to guide learners through the stages of the investigation while they are doing the investigations on their own. Both the theory and the model therefore have implications for practical work in science education, and in particular the teaching of scientific investigations. Firstly, learners when doing investigations on their own should receive feedback and guidance as they attempt these tasks for themselves. Wellington (2000) in explaining this states that "as performance improves with feedback becoming

increasingly positive, guidance should be reduced until acceptable performance occurs unaided” (p. 222). In terms of Wood’s (1989) theory of ‘contingent control’ (as cited in Wellington, 2000) there exists levels of directiveness which can be followed when offering guidance. An example of relatively low-level guidance would be indicating that a problem has occurred, while an example of relatively high-level guidance would be explaining the precise nature of the problem and suggesting an alternative approach. Wood proposed that guidance should progress upwards one level at a time until success is achieved, and then downwards one level at a time so that unaided success is approximated gradually.

Secondly, the apprenticeship model has the value of including more people than a single expert and a single novice. The apprenticeship system often involves a group of novices (peers) who serve as resources for one another in exploring the new domain and aiding and challenging one another. The implication for scientific investigations in the classroom is that learners should be encouraged to work collaboratively with each other in groups. Through groupwork the learners share, exchange and challenge each other’s ideas. Lave (1988) suggests that “apprentices learn to think, argue, act, and interact in increasingly knowledgeable ways with people who do something well, by doing it with them as legitimate, peripheral participants” (p. 2). In this apprenticeship system, the expert too is still developing breadth and depth of skill and understanding in the process of carrying out the activity and guiding others in it. This is especially pertinent in the South African context where the teacher may lack experience and expertise in doing science investigations.

Thirdly, learners should also be encouraged to engage as far as possible in whole activities rather than partial ones. According to Roth (1995), “students should engage in entire research projects so that they would learn what is meant to conduct research from the beginning to the end of a project” (p. 18). That is, learners should be given the opportunity to do complete investigations where they are engaged in all stages of the investigation process, i.e. from formulating the investigation question to reporting their findings.

2.7 THE ROLE OF THE TEACHER IN SUPPORTING LEARNERS DOING SCIENTIFIC INVESTIGATIONS

Using this theoretical framework for teacher-learner interaction, the role of the teacher in supporting learners doing scientific investigations is now considered. In order for investigations to be an effective learning experience, there is strong support in the literature for the development of learner autonomy. Such a learning environment re-defines the traditional teacher-learner relationship where the teachers traditionally are considered the experts who pass knowledge to passive learners. Based on this new focus, the teacher must now consciously develop a classroom environment that is supportive and conducive to learners doing their own investigations. There needs to be a harmonious working relationship between the teacher and the learner, that is characterised by mutual respect. In this relationship, the teacher is no longer a threatening force to the learner, but a resource that learners can access for clarification and guidance (Flynn, 1999).

In classrooms where investigations do take place, the teacher's role should be less involved with direct teaching and more involved with scaffolding. Scaffolding refers to the support which the teacher provides to students to allow them to complete task. According to Roth (1995) this support comes in the form of "suggestions, help, procedural facilitation or physical supports" (p. 242). Gabel (2001) describes scaffolding as "a bridge used to build upon what students already know to arrive at something that they do not know" (p. 61). In scaffolding, a teacher helps learners to focus on some aspect of the task that they did not attend to, or helps learners to integrate skills through interactive and situated feedback. The teacher may also take over those parts of the overall task which learners cannot yet manage on their own. But scaffolding also requires learners, as soon as possible, to take responsibility for the task and make important decisions on their own. The process of phasing out support is called fading and "involves the gradual removal of support until students can manage problems on their own" (Roth, 1995, p. 242). In the process of an investigation, the teacher should guide and gradually transfers responsibility for aspects of the investigation to the learner. Ultimately, with sufficient experience and expertise the learners take responsibility for all stages of the investigation. As learners master their investigation skills, they take action to initiate their own investigations, and collecting and interpreting evidence on their own (Ash, 1999). In supporting the learners through scaffolding, the teacher should adopt strategies such as asking questions, facilitates learner

collaboration, facilitates learner reflection, provides explicit instruction on skills, and helps motivate learners. These five strategies will now be described.

2.7.1 Asking questions

A survey of the literature on the facilitative role of the teacher in a classroom where investigations are taking place provides further elaboration of what the teacher can do in such an environment. In facilitating the learners' progress in an open investigation, the teacher can use strategies to help focus their attention on the stages of the investigation and thereby structure their work. In providing this structure the teacher helps the learners "without telling them what to do" (Monk & Dillon, 1995, p. 82).

Teacher questioning can play a pivotal role in helping learners obtain a sense of structure and direction in the investigation. According to Mines (1995), "the art of skilful questioning appears to be crucial to achieve the balance between giving students suitable guidance and leaving sufficient scope for them to think independently" (p. 14). Questioning if used effectively can provide a bridge towards greater learner autonomy. This questioning allows the teacher to create specific "scaffolding" for the learner whereby the unknown or unfamiliar is controlled by the teacher until such time as the learner can assume this control (Bradbury, 2000, p. 57).

Llewellyn (2002) describes four types of questions which are commonly asked by teachers in supporting learners who are doing investigations. These are clarifying, focusing, probing and prompting questions. Clarifying questions require learners to make their thoughts and understanding more explicit. Teachers often ask clarifying questions by asking "What do you mean by that ? or Can you be more specific about that ?" Focusing questions are asked when learners provide vague or generalized responses. Focusing questions require learners to provide more specific responses. Teachers often pose focusing questions by asking "Can you give me an example of that ?" Probing questions require learners to explain, justify or expand upon their original response to a question. They are aimed at expanding a learner's original response to a question. Teachers often pose probing questions by asking, for example, "What are you thinking about when you say that ? or What do you think you should do next ?" Prompting questions require learners to provide answers that are guided by questions that are asked by the teacher. These prompting questions often contain hints

or clues to guide the learner to answer correctly. Sometimes, the teacher will use a prompting question as a follow-up question when a learner cannot answer an original query correctly. Some examples of prompting questions are “Don’t you think you should try it again ? or Have you thought about increasing the angle of the ramp ?” (Llewellyn, 2002, p. 134).

In planning the investigation, such questions can appear in the form of a thinking schedule or prompt sheet. These prompt questions focus the learners on the stages of the investigation. The learner responses to the prompt sheet can also inform the teacher about the progress the learners are making in the investigation (Monk & Dillon, 1995). Harlen (2001) illustrates how a prompt sheet can be used by the teacher in facilitating the learners’ thought process in the planning stage of investigation. The investigation she uses to illustrate this is a fair test to decide the effect of the strength of a dye on colour. A prompt sheet by Harlen which engages the learner in the steps of the planning process is shown in Table 2.2.

Table 2.2 Prompt sheet for the planning stage of an investigation (Harlen, 2001)

Investigable question	What happens to the colour if we change the strength of the dye ?
What should be changed in the investigation ? (the independent variable)	The amount of dye dissolved.
What should be kept the same ? (the controlled variable)	The amount of water, the temperature, the type of material, the time of soaking, and any others that might be thought likely to make a difference.
What kind of effect should be observed ? (the dependent variable)	The colour.
How will the result be used to answer the question ?	If there is a difference, it will be possible to say what change resulted in a deeper or paler colour. If not, the answer will be that changing the strength made no difference in the investigation.

Note: From “Primary science taking the plunge” by W. Harlen, (p. 71), 2001, Portsmouth, NH: Heinemann.

As the teacher circulates around the class during the investigation, the responses to the prompt sheet below provides a focus for discussion between the teacher and the learners. It enables the teacher at a glance to know what the learners are setting out to do, to ensure that the method is safe and to ensure that the apparatus is available. Summerfield (1995) observes that these supports seemed to offer learners a simple cognitive scaffolding to reach the various parts of the investigation.

For learners who are not acquainted with or have limited experience of a 'fair test', the teacher may have to play an overt role in ensuring that they have a good grasp of the notion of a variable. The teacher may give them prompt sheets in the form of proformas of incomplete two-column tables which would ask them to record the nature and/or value of the independent variable and the value of the dependent variable. Setting up an experiment requires explicit definition of the variable or variables which form the focus of the investigation and of other variables which need to be controlled (Brook, Driver & Johnston, 1989). Such a table gives structure to planning an investigation by indicating which variable is to be changed, which is to be measured, and how many measurements are to be made (Phipps, 1996).

Questioning, apart from providing structure and direction in the investigation, may also be used by the teacher to help learners who encounter difficulties while conducting the investigation. In facilitating the learners' progress, the teacher should seldom tell but often question. According to Sund and Trowbridge (1973), "The teacher must switch from the classical concepts of telling to listening and questioning and being open to the students' thought." (p. 111). After perceiving the learner's difficulty, the teacher has to formulate a question which will be a challenge yet give guidance to the learner. The teacher does this by focusing on some aspect of the task that the learners did not attend to, or helps them to integrate skills through interactive and situated feedback (Roth, 1995).

In asking questions, the teacher should provide adequate time for reflection and analysis. Rowe's (1974) research in this area has identified two kinds of wait time: (a) wait time 1 is the time after the teacher asks a question and before anyone speaks again; (b) wait time 2 is the time after a pupil speaks before anyone else speaks. Rowe found that teachers typically wait less than one second for learners to answer a question. This doesn't give learners time to form an answer unless it is only something from memory, that is, something that

requires no thinking. Some teachers also answer their own questions before learners have time to respond to them (Howe, 2002). For teachers to support and guide learners doing investigations, they should attempt to increase their wait-time tolerance so that learners have more time to think about their responses.

2.7.2 Facilitating collaboration

Learning takes place more effectively in an investigative environment if the teacher facilitates collaboration amongst learners (Hodson, 1998). When learners are faced with challenging tasks learners can feel insecure because they are threatened by the risk of failure. Hodson points out that cooperative learning contributes to self-esteem by providing an emotionally secure social environment. In this environment learners feel more comfortable to ask questions, try new things, and support each other. According to Hodson, working together can also help learners to “identify and correct misconceptions, inappropriate inquiry strategies and poor learning methods” (p. 99). The teacher must ensure that each learner is playing an active role in the activities of the group. The structure of groupwork lends itself to the need for all learners to take responsibility for their roles in the investigation. Individuals should not be allowed to let others do all the work as learners work together as a community of learners. The teacher should ensure that learners reflect and build on each other’s ideas, and have the freedom to challenge arguments underlying different points of view (Layman, Ochoa, Heikkinen & Orrill, 1996). The teacher should also facilitate discussion between groups. After the investigations are completed, “the teacher moderates the discussion as groups of students share and critique each other’s findings” (Layman, et al., p. 39).

2.7.3 Facilitating reflection

After the learners have conducted the investigation the teacher may direct them to reflect upon what they have done. Harlen (2001) suggests that the teacher may ask questions such as “How did you decide what masses to add to the truck ?; What results did you get with each one ?; How did you use the results to decide whether the mass added to the truck made any difference ?; Do you think that you’d find the same results if you added a really big mass to the truck ?” (p. 81). Often these kinds of questions help the learners to realize the alternative course of action they could have taken and the improvements that they

could have made. The discussion would thereby lead the learners to identify the weaknesses in what they did. These questions should be open, with no critical implications. When the teacher gives an opinion, it should be “part of the general pooling of ideas, not a judgement on the success of the work” (p. 81). The principal aim should be to develop in learners the habit of self-reflection and self-criticism.

In this post-lab, the teacher is advised to facilitate discussion so that the results of the investigation are meaningful to them. The value of investigations for helping learners’ understanding may be lost if they stop at the point of arriving at results. According to Howe (2002), “An important part – maybe the most important of an inquiry lesson is discussion of what the data mean. An inquiry is not complete without this phase where “hands-on” becomes “minds-on” (p. 128). The discussion should involve returning to the initial question or the original purpose of the investigation and considering the results in relation to it, as well as reviewing the way the investigation was carried out. Harlen (2001) suggests that the teacher should pose questions such as, “Has the question been answered or the problem solved? What has been learned that helps develop an understanding of the subject of the investigation?” (p. 77). The teacher thereby helps them make a connection between the result of the investigation and the concept, principle or law being addressed by the investigation. The teacher can achieve this by encouraging learners to form tentative explanation for their observations.

2.7.4 Teaching skills

If learners are lacking in investigation skills they may not be in a position to do an investigation on their own. Roth (1995) suggests that in such a case, the teacher “designs the tasks in such a way that students can practice their knowledge and skills in settings which are challenging but at a complexity appropriate to the students’ current abilities” (p. 243). These investigative skills and techniques can be taught almost as rules of thumb by means of a prescriptive activity (Newton, 2002). Wellington (2000) suggests that “the pupils can be taught how to read a range of measuring instruments, how to set up data-logging equipment, how to record results manually, and how to set up certain common types of apparatus, such as for distillation” (p. 162). Apart from recording numerical (quantitative) data, learners also need teacher support in recording descriptive (qualitative) data (Phipps, 1996). Such a skill is necessary especially in chemistry investigations where

learners may be required to describe their observations of any changes which take place during a chemical reaction. Empirical evidence in support of the need for the teacher to provide explicit instruction in skills, is presented from a study by Toh, Boo and Yeo (1997) with thirteen-year-old learners who were explicitly taught the strategies in connection with planning, measurement, procedural and communication stages of open-ended laboratory tasks. The study concluded that learners who did receive explicit instruction in these skills found to be better prepared to deal with such tasks than those who had no instruction in such skills. Depending on the learners' level of expertise, the teacher may need to model the skills he would like the learners to learn. In such a case the teacher should demonstrate to learners how to use new tools or materials, or help learners design and carry out skills of recording, documenting, and drawing conclusions (Ash & Kluger-Bell, 1999).

2.7.5 Motivating learners

Finally, in providing support for learners doing scientific investigations, the role of the teacher as a motivator should not be underestimated. It is important for a teacher to show his or her students that there is some importance to learning the material and that it can be engaging. A study by Brophy, Rashid, Rohrkemper and Goldberger (1983) shows a higher quality of student task engagement can be expected when students are working on tasks that they enjoy or believe to be interesting or worthwhile than when they are working on tasks that they dislike or believe to be boring or pointless.

2.8 CLOSURE/OPENNESS OF A SCIENTIFIC INVESTIGATION

The interaction between the degree of learner autonomy and the extent of teacher control in a scientific investigation may be understood in terms of the openness or closure of the investigation. Researchers use different terminology to describe the openness or closure of an investigation. However, there is some consensus that in open investigations, learners have more autonomy in decision-making during the stages of the investigation, but in closed investigations, teachers have more control over this decision-making. Therefore, in terms of the degree of learner autonomy and the extent of teacher control, scientific investigations may lie along a spectrum from open to closed depending upon who makes the decisions in the investigation process (Abraham, 1982; Hackling & Fairbrother, 1996).

Various frameworks have been used to describe the degree of openness or closure of a scientific investigation. However, there is a lack of consistency regarding the terminology used, the number of levels that are described and whether discrete levels exist (Gabel, 2001). In mapping the field of these frameworks, broadly two types of these frameworks may be distinguished. A framework may be in the form of a continuum from open to closed, depending upon who makes the decision-making in the investigation, or the framework may classify investigations into categories.

2.8.1 Continuum frameworks for the openness and closure of investigations

The NRC (2000) describes such a framework (Table 2.3) by outlining how variations in the five essential features of classroom inquiry with regard to learner self-direction and amount of direction from the teacher can be used to describe the inquiry in terms of openness or closure. The framework describes variations in the amount of structure, guidance, and coaching the teacher provides for learners engaged in inquiry, in terms of the five essential features. The framework also shows along a continuum, the degree of learner direction and the degree of teacher direction in scientific inquiry. The most open form of inquiry-based teaching and learning occurs when the learner's experiences are described by the left-hand column in Table 2.3. However, according to the NRC (2000) "students rarely have abilities to begin here. They first have to learn to ask and evaluate questions that can be investigated, what the difference is between evidence and opinion, how to develop a defensible explanation, and so on" (p. 29). In such a case, a more structured type of teaching is needed to develop learners' abilities to inquire.

The degree to which teachers structure what learners do is sometimes referred to as "guided" versus "open" inquiry. This table illustrates that inquiry-based learning which includes investigations cannot simply be characterized as one or the other. Instead the more responsibility learners have for posing and responding to questions, designing investigations, and extracting and communicating their learning, the more "open" the inquiry (that is closer to the left column in the table) and the more responsibility the teacher takes, the more guided the inquiry (that is, the closer to the right column in the table).

Table 2.3 Essential features of classroom inquiry with regard to learner self-direction and the amount of teacher direction (NRC, 2000)

Essential features		Variations		
1. Learner engages in scientifically oriented questions.	Learner poses a question.	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other sources	Learner engages in question provided by teacher, materials, or other sources
2. Learner gives priority to evidence in responding to questions.	Learner determines what constitutes evidence and collects it.	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanations after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies Explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication
More-----Amount of Learner Self-Direction-----Less		Less-----Amount of Direction from Teacher-----More		

Note: From “Inquiry and the national science standards” (p. 29) by National Research Council, 2000, Washington: National Academy Press.

The framework presented by Wellington (2000) also describes the extent of learner autonomy and teacher control in terms of a continuum. The framework in Figure 2.4 shows three axes which are related.

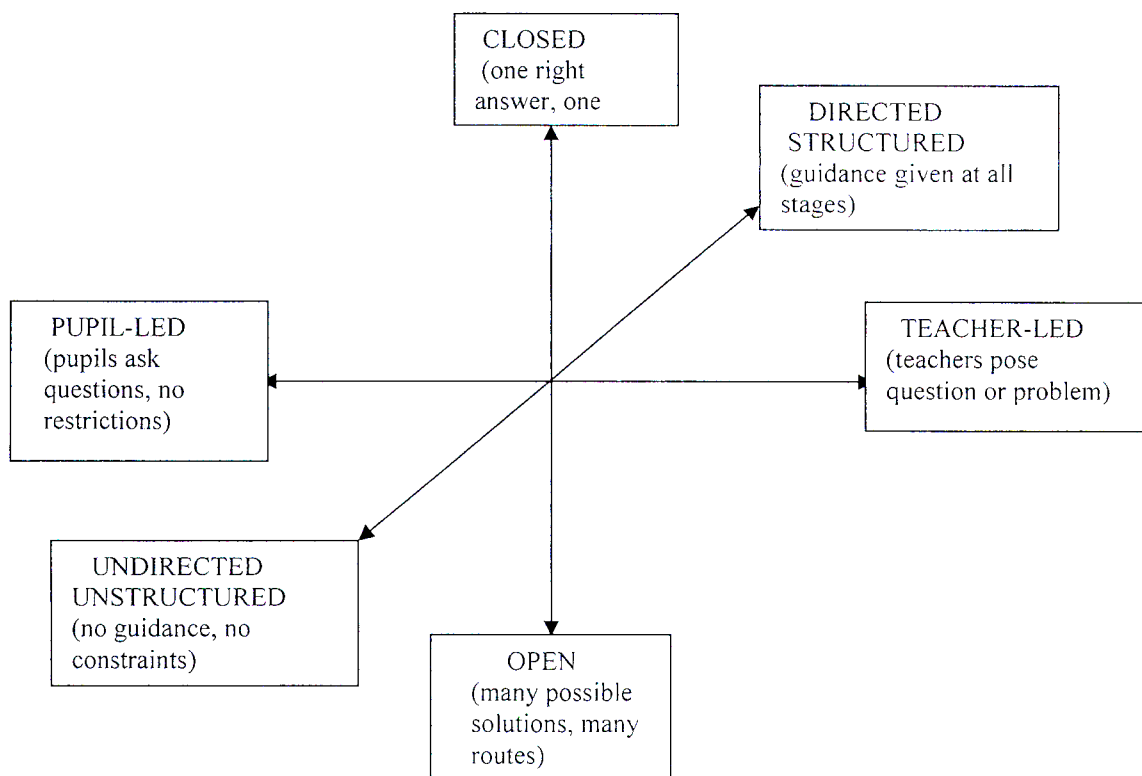


Figure 2.4 Dimensions of investigational work (Wellington, 2000)

Note: From “Teaching and learning secondary science” (p. 29) by J. Wellington, 2000, London: Routledge.

The first axis, “teacher-led to pupil-led,” indicates a continuum from one extreme at which learners pose the questions to investigate, to the other, in which all the questions are set, posed and restricted by the teacher. Wellington (2000) states that in practice, an investigative learning experience may lie at different points along this axis. He believes this will need to be the case if teachers are to meet the requirements of their curriculum. The second axis, “open to closed,” shows a second continuum from extreme in which an investigation or a problem-solving activity will have only one ‘correct’ answer and only one route for reaching it, to the other in which many possible solutions are equally acceptable, with many routes to them. In between these extremes lie many permutations and possibilities. The third axis (obviously not independent of the others but still worth separating), is from “undirected and unstructured to directed and structured”. At one extreme, learners will be given guidance, constraint and structure all along the way, i.e. in planning, designing, carrying out and evaluating. At the other, no guidance, structure and restriction will be placed on them. As this is a continuum, in practice an investigation maybe located at any point between these extremes. The main purpose of this framework, according to Wellington is to help teachers in planning for and reflecting on the type of

investigational work they do in schools. It should also help to increase the variety of investigations which are carried out.

2.8.2 Category frameworks for the openness and closure of investigations

Herron (1971) uses a different form in describing the openness or closure of an investigation. He illustrates how the degree of openness at each stage of the inquiry can be used to categorize scientific investigations into four levels as shown in Table 2.4.

Table 2.4 Levels of inquiry in the science laboratory (Herron, 1971)

Levels of inquiry	Problems	Procedures	Conclusions
Level 0	Given	Given	Given
Level 1	Given	Given	Open
Level 2	Given	Open	Open
Level 3	Open	Open	Open

Note: From “The nature of scientific inquiry” (p. 172), *School Review*, 79, 171-212 by M.D. Herron, 1971.

In a level 0 inquiry, the problem, procedure and conclusions are all given, and the only task remaining for the learner is to collect data. In a level 1 inquiry, the problem and procedure are given and the learner has to collect data and draw the conclusions. For a level 2 inquiry, only the problem is given and the learner has to design the procedure, collect the data and draw conclusions. Finally, at level 3, the highest level of inquiry, the learners have to do everything by themselves, beginning with problem formulation and ending with drawing conclusions. Tafoya, Sunal & Knecht (1980) employ a similar classification framework to Herron. However, instead of labeling the levels of inquiry as 0, 1, 2 and 3, here the inquiries are described as 1) confirmation, 2) structured-inquiry, 3) guided-inquiry, and 4) open-inquiry. These levels delineate structure and organization among different types of inquiries. At the confirmation level, learners follow a known, given procedure to verify concepts or principles. Structured-inquiry activities present learners with a problem in which they do not know the results, but they are given a procedure to follow in order to complete the activity. Guided-inquiry activities provide learners only with a problem to investigate. The learners determine the procedure to be used and the methods of data collection and analysis. Open-inquiry activities allow learners to formulate

hypotheses or problems, and the procedure for collecting data for interpretation, and conclusion drawing.

The “Invitation to Inquiry Grid” (Table 2.5) presented by Llewellyn (2002) is another classification framework that can be used to categorize investigations in terms of who has control over the stages of the investigation. Rather than referring to levels, he names and labels the activity.

Table 2.5 Invitation to inquiry grid (Llewellyn, 2002)

	Demonstration	Activity	Teacher-initiated inquiry	Student-initiated inquiry
Posing the question	Teacher	Teacher	Teacher	Student
Planning the procedure	Teacher	Teacher	Student	Student
Formulating the results	Teacher	Student	Student	Student

Note: From “Inquire within” (p. 64) by D. Llewellyn, 2002, Thousand Oaks, CA: Corwin Press.

According to this classification, in a demonstration, the teacher poses a question to his or her learners, describes how the procedure of the experiment will take place, and carries out the procedure. The teacher provides the results of the experiment and then formulates the conclusions. In an activity, the teacher poses the question to the learners and provides a procedure for answering the question. The learners follow the procedure and then formulate their own results. In a teacher-initiated inquiry, the teacher poses the question to the learners and invites the learners to plan the procedure and formulate the results. In a student-initiated inquiry, the learners pose the question, plan a procedure for answering the question, carry out the procedure, and formulate the results.

The frameworks for the openness and closure of investigations which have been described provide a mechanism by which investigations may be classified according to the degree of learner autonomy and the extent of teacher control. This is necessary if one is to gauge how investigations are being implemented, and secondly to monitor over the long term whether there is a progression towards more learner autonomy in investigations. For the purposes of this study it was deemed necessary to construct a framework which was more relevant and appropriate to address issues being raised in the study.

2.8.3 Suggested framework for investigations in practice

Informed by the preceding literature and guided by the outcomes and assessment standards of the new curriculum, a classification framework for investigations types was formulated in order to describe the extent of learner autonomy and teacher control for investigations which were observed in the present study.

This framework (Table 2.6) classifies investigations as either structured, guided or open. The framework focuses on learner autonomy and teacher control at the different stages of the scientific investigation. Based on the degree of learner autonomy and the extent of teacher control, it was decided that the most useful classification would be structured, guided or open.

Table 2.6 Suggested classification framework for investigations

Investigation type	Stages of investigation				
	Topic	Question	Planning	Data collected	Conclusion
Structured	T	T	T	L	L
Guided	T	T	L	L	L
Open	T	L	L	L	L

Note: T = Teacher controls and carries out
L = Learner has autonomy and responsibility to carry out

A structured investigation is described as one where the teacher identifies the topic or area of interest, formulates the question, and provides the plan. The learner collects data, and draws a conclusion from the data collected. A guided investigation offers the learner more autonomy in that the learner here also plans the investigation for which the teacher has provided the questions. Thereafter, the learner collects the data and draws a conclusion. In an open investigation, the teacher only identifies the topic. The learner has autonomy over the other stages of the investigation. As this categorization of investigations describes the amount of teacher control and learner autonomy, the traditional verification or confirmation investigations where the teacher identifies the topic, gives the question, provides the plan, draws the conclusion and only allows learners to conduct the investigation are not included.

The classification framework constructed is useful as it allows for the type of investigation to be determined based on the degree of autonomy given to learners at each of the stages. For example, where a learner has autonomy in choosing the question, planning the investigation, collecting data, and drawing a conclusion, such an investigation is classified as open. It was felt that such differentiation was necessary so that openness or closure of the investigation could be described in a clear and unambiguous manner. The framework is also relevant to curriculum reform in South Africa as the 5 stages in this framework are derived from the process skills and assessment standards associated with Learning Outcome One (Department of Education, 2002b). The process skills mentioned are “raising questions about a situation, planning science investigations, conducting investigations, and communicating science information” (p. 20). The assessment standards describe in particular the learners’ progression in performing at higher levels. Such progression is described according to the increasing autonomy the learner demonstrates. The assessment standards for Learning Outcome One mention planning investigations, conducting investigations and collecting data, and evaluating data and communicating findings. For example, a learner doing a structured investigation is required to demonstrate that he has attained the assessment standard “evaluating data and communicating findings” (p. 21), while a learner doing an open investigation must demonstrate that he has attained all three assessment standards relating to Learning Outcome One. Therefore, this framework while drawing from the literature, does fit the South African context.

2.9 CONCLUSION

In this chapter a theoretical and conceptual framework for the study was constructed. The role of practical work in science education was discussed in order to create a landscape within which the place of scientific investigations could be located. Curriculum documents in South Africa, and in other countries describe scientific investigations as a learner-centred activity. In such a learning scenario the learner has much autonomy and the teacher supports the learner. The concept of learner autonomy was explored and a theoretical framework for the supportive role of the teacher presented. Vygotsky’s model of learning and the apprenticeship model by Roggoff (1990) provided insight into the possible teacher-learner interaction which should now take place in the classroom if learning is to be successful. Using this theoretical framework, the expected facilitative role of the teacher in

supporting the learner doing scientific investigations was described. The theoretical and conceptual framework developed in this chapter were used in explaining the issues of learner autonomy and teacher support which are raised in this study. Finally, a classification framework to describe the degree of learner autonomy and the extent of teacher control in an investigation was formulated. This classification framework was produced so that it could be applied to investigations which were observed in this study.

Chapter Three describes the research study in terms of the research design, the sampling procedures, the methods of data collection and management, and analysis procedures which were employed.

CHAPTER 3

THE RESEARCH STUDY

The purpose of the study was to describe the implementation of scientific investigations in Grade 9 in terms of the degree of learner autonomy and the extent of teacher control. The study also uncovered the strategies used by teachers in supporting learners who were doing scientific investigations. The study employed a mixed methodology approach in addressing the following research questions:

- What are the degrees of learner autonomy in the implementation of scientific investigations ?
- What are the perceived benefits of learners doing their own scientific investigations ?
- How do teachers support learners doing scientific investigations ?
- What factors affect the degree of learner autonomy ?

3.1 RESEARCH DESIGN

The study adopts a mixed methods approach which uses a combination of quantitative and qualitative research approaches. Johnson and Onwuegbuzie (2004) describe mixed methods research as the third research paradigm after the quantitative and qualitative paradigms. They state that “the goal of mixed methods research is not to replace either of these approaches but rather to draw from the strengths and weaknesses of both in single research studies and across studies” (p. 14). Mixed methods research is described by Johnson and Onwuegbuzie as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language in a single study” (p. 17). As the philosophical assumptions are crucial to understanding the overall perspective from which the research is designed and carried out (Krauss, 2005), the philosophy which underpins the mixed methods research needs to be made explicit. Philosophically, mixed method research is informed by the pragmatic system of philosophy. Pragmatism is offered as a philosophy which can help to build bridges between the conflicting philosophies of positivism and interpretivism which underpin the quantitative and qualitative research methods respectively (Johnson & Onwuegbuzie, 2004). The value of pragmatism is that it concerns multiple perceptions

about a single, reality (Healy & Perry, 2000). Its epistemological contribution is to describe, explain and thereby improve and guide practice (Krauss, 2005). According to Krauss (2005), pragmatism offer a ‘middle ground’ between the conflicting philosophies of positivism and interpretivism. Methodologically this implies that mixed methods research is an inclusive, pluralistic and eclectic approach. According to Johnson and Onwuegbuzie (2004) the mode of inquiry which informs mixed methods research is both deductive (confirming what you expect apriori) and inductive (discovering of patterns). The study employs this mode of inquiry in addressing the research questions. For example, deductively, the teacher support strategies had been identified from the literature review and the survey sought to establish whether these were indeed the strategies that teachers were using in supporting learners doing investigations. Inductively, the study attempted to identify the factors which affect learner autonomy in scientific investigations.

In recent years, significant progress has been made towards combining quantitative and qualitative methods within the same study in science education research. For example, Fraser and Tobin (1991) have conducted studies on classroom learning environments. They point out that “researchers in various areas of educational research, especially the field of educational evaluation, have claimed there are merits in moving beyond the customary practice of choosing either qualitative or quantitative methods and instead combining methods within the same study” (p. 271).

3.1.1 The merits of a mixed method approach ?

The idea of combining quantitative and qualitative approaches in a single study is justified by considering the merits of triangulation. Denzin (as cited in Creswell, 1994) used the term triangulation to argue for the combination of methodologies in the study of the same phenomenon. According to Jick (as cited in Creswell, 1994), the concept of triangulation is based on the assumption that any bias inherent in particular data sources and method would be neutralized when used in conjunction with other data sources methods. In this way, greater credibility could be placed in findings as they emerge consistently from data obtained using a range of data collection methods (Fraser & Tobin, 1991). Although triangulation was an important reason to combine quantitative and qualitative methods, additional reasons have been advanced.

Tashakkori and Teddlie (2003) identify three areas in which mixed methods are superior to single approach designs. Firstly, mixed methods research is inclusive, pluralistic, and complementary. It enables researchers in a single study to address a combination of research questions. They suggest that “a major advantage of mixed methods research is that it enables the researcher to simultaneously answer confirmatory and exploratory questions, and therefore verify and generate theory in the same study” (p. 15). The mixed methods approach is most apt for the present study where both confirmatory and exploratory research questions are posed. Data collected through the questionnaires is analyzed statistically to deduce the degree of learner autonomy at schools where scientific investigations are taking place, and the perceived benefits of learners doing scientific investigations. The study is also exploratory as it seeks to explore how teachers support learners who are doing scientific investigations, and also to identify factors which affect the degree of learner autonomy. Secondly, mixed methods research provides stronger inferences as it leads to multiple inferences that confirm or complement each other. Greene and Caracelli (as cited in Tashakkori & Teddlie, 2003) state that using mixed methods can offset the disadvantages that certain of the methods have by themselves. Johnson and Turner (as cited in Tashakkori & Teddlie, 2003) refer to this as the fundamental principle of mixed methods research, “Methods should be mixed in a way that has complementary strengths and nonoverlapping weaknesses” (p. 16). In the present study both quantitative and qualitative methods of data collection were used to converge and corroborate the findings. Thirdly, mixed methods provide the opportunity for presenting a greater diversity of divergent views. In this way the qualitative and quantitative research methods used together, produce more complete knowledge necessary to inform theory and practice. This was hoped to be achieved in the present study where the qualitative data collected sought to give a more in-depth explanation of some of the findings which emerged from the quantitative research.

3.1.2 A triangulation mixed methods design

Scholars writing in the field of mixed methods research have presented typologies of mixed designs from the time the field emerged. Creswell (2002) classified mixed methods designs in three types: triangulation, explanatory, and exploratory. In the explanatory and exploratory design the quantitative and qualitative data are viewed separately, and used essentially to explain the findings which emerge from each of them. In such a mixed

methods design either the qualitative or quantitative method is dominant. The present study employs the triangulation mixed methods design, where the investigators “collect both quantitative and qualitative data, merge the data, and use the results to best understand a research problem” (Creswell, 2002, p. 564). In this design, both qualitative and quantitative methods have equal status.

3.1.3 The mixed methods approach in the study

The quantitative data collection of the study involved a large-scale survey, whereby a structured questionnaire was administered to Grade 9 Natural Science teachers in public and independent secondary schools in KwaZulu-Natal. Statistical analysis of the data collected through this questionnaires allowed tentative findings regarding the degree of learner autonomy, the teacher support strategies and the benefits of learners doing scientific investigations. This enabled the researcher to sharpen his focus and to inform the subsequent qualitative data collection of the study. Further quantitative data were also collected when a structured questionnaire was filled in by Grade 9 learners. The qualitative data collection through classroom observations and interviews sought more in-depth explanation of some of the findings which emerged from the quantitative survey. Investigations are new so we do not have descriptions of what is actually taking place. It was decided to contextualise the questionnaire and interview data by obtaining some full descriptions of what actually happens during a classroom investigation. Consequently, 5 different cases of investigations were captured. The findings of the qualitative data collection also strengthened the validity of the assertions which ultimately emerged from the study by providing a closer and more focused perspective from which the researcher could view the phenomenon of scientific investigations taking place in the classroom.

3.2 SAMPLING AND RESPONDENTS

Before any research can be conducted, it is imperative to clearly define the units of analysis. Babbie (1998) describes the units of analysis as “things we observe and describe in order to create summary descriptions of all such units and explain differences among them” (p. 82). Such information can be obtained by either studying or investigating every element of the targeted population or by selecting and investigating a number of elements

from the population (Stoker, 1998). In this study, the unit of analysis was Grade 9 Natural Science teachers in KwaZulu-Natal who were doing scientific investigations.

In 2003, a pilot teacher questionnaire was distributed by post to 220 public and independent secondary schools in and around Durban. A list of schools in KwaZulu-Natal was provided by the University of KwaZulu-Natal, and was comprised of schools that were poorly resourced, adequately resourced and well resourced. Schools that are well resourced are described as functioning schools with science laboratories that are well equipped and well stocked with chemicals. A total of 45 questionnaires were returned. The analysis of data collected through this questionnaire indicated that investigations were most likely taking place at well-established and well-resourced schools. There was also a poor return of questionnaires from schools which were poorly resourced. Questionnaires which were returned from such schools generally contained little information or were unfilled.

In 2004, a revised teacher questionnaire was posted to a purposeful sample of 150 public and independent secondary schools throughout KwaZulu-Natal where it was strongly believed investigations were more likely to be taking place. The analysis of the pilot questionnaire revealed that where schools reported doing investigations, they also indicated a reasonably high level of resources such as laboratories and equipment. Consequently, well-resourced schools were purposefully selected. Purposeful sampling, entails “selecting information-rich cases for study in-depth” (Patton, 1990, p. 169). In order to address the research questions, data had to be collected from schools where investigations were most likely taking place. This purposeful sample was guided by analysis of the pilot questionnaire returns and the researcher’s personal knowledge of resourced and under-resourced schools. Two questionnaires were mailed to each of the 150 schools which formed this sample, in case there were two Grade 9 Natural Science teachers. It is quite common that large schools would have more than one Natural Science teacher. Fifty five questionnaires were returned completed. A sample of five of these schools was selected for classroom observations of investigations. These schools were drawn by using a combination of purposeful and convenience sampling. The findings of the teachers’ questionnaire of 2004 enabled the researcher to identify those schools where teachers were engaging learners in scientific investigations. These schools chosen also had to be accessible in terms of convenience to the researcher. The schools were in close proximity to each other and to the researcher’s place of work. A learner questionnaire was

administered to a class of learners in each of these five schools. All 126 learner questionnaires administered were returned completed. Interviews were also conducted with ten learners from these schools. In addition, a sample of 33 Grade 9 learners who participated in the FFS science expo answered a questionnaire. Twenty of these learners were interviewed.

3.3 DATA COLLECTION METHODS AND PROCEDURE

As indicated above, multiple data collection methods were employed to obtain relevant data to answer the research questions. These are described in more detail below.

3.3.1 Teacher questionnaire

Quantitative data were collected from teachers by means of a structured questionnaire (Appendix A) which was distributed in 2004 to a purposeful sample of Grade 9 Natural Science teachers in public and independent secondary schools throughout KwaZulu-Natal. The questionnaire survey was used to gather data, to describe the degree of learner autonomy at schools where investigations were taking place, the benefits of learners doing investigations, the teacher support strategies used by teachers, and the factors which affect learner autonomy. The questionnaire survey was used as it has certain significant advantages (Cohen et al., 2000). These are that it is economical and efficient; provides descriptive, inferential and explanatory information; ascertains correlations; and supports or refutes hypotheses about the target population. The questionnaires were administered by post as a postal questionnaire is less costly, puts less pressure for an immediate response and gives respondents a greater feeling of anonymity (Cohen et al., 2000). The questionnaires were posted individually to each of the teachers in the sample, together with a covering letter, which set out the purpose of the survey. The letter also assured the respondents of the confidentiality of information provided. The principals of each of the schools being sampled were informed in writing of the research being undertaken, and a copy of the letter of authorisation from the KwaZulu-Natal Department of Education to conduct the research was enclosed.

In the questionnaire there was an introduction which gave the respondents some background information to underline the place of scientific investigations in the curriculum reform initiatives in Natural Science. The introduction also identified the three stages of the scientific investigation, and described the four kinds of investigations to which the body of the questionnaire referred. This was done so that all respondents had a common understanding of the terminology used. Section A in the questionnaire requested personal and school information such as numbers of years teaching experience, number of training workshops attended in Natural Science, availability of resources at school, and number of learners per Grade 9 classes. These data were used in identifying the factors affecting learner autonomy in doing scientific investigations (Research Question Four). Section B of both questionnaires related to the implementation of scientific investigations. In this section, the question of degree of learner autonomy in the scientific investigation was addressed (Research Question One). Section C of the questionnaire addressed the question of teacher support by concentrating on the strategies used by teacher in supporting learners doing scientific investigations (Research Question Three). Section D related to teacher perceptions of scientific investigations i.e. how investigations should be used in teaching and learning and their value for learning (Research Question Two). Sections B, C and D of the questionnaire contained statements, to which teachers had to respond on a 5-point Likert scale indicating the extent to which they agreed with the statement. The 5-point scale was chosen as most researchers have found that if there are 5 or more points in the scale, they can be treated as continuous variables and normal statistics can in most cases safely used (Zumbo & Zimmerman, 1993). In the questionnaires, teachers were also given the opportunity to comment on scientific investigations. These comments were a rich source of data in explaining some of the results obtained.

A teacher questionnaire administered in 2003 to 220 public and independent secondary schools in and around Durban, was used as a pilot. The piloting of a questionnaire is crucial in determining whether respondents will understand directions provided and also in determining the amount of time it takes to fill a questionnaire (Fink & Kosecoff, 1985). This pilot questionnaire served two other purposes. Firstly, it served to “map the field” and thereby identify schools where investigations were taking place. Secondly, based on the analysis of the data collected, and comments from teachers who responded to it, certain revisions were made to the questionnaire. The questionnaire was restructured so that it

became more focussed in addressing the research questions. The content validity was established by having it reviewed by researchers in science education. According to Cohen et al., “to demonstrate this form of validity, the instrument must show that it fairly and comprehensively covers the domain or items that it purports to cover” (p. 109). The questionnaire was reviewed by researchers at Michigan State University, which the researcher visited as a result of a collaboration between the National Research Foundation of South Africa and the National Science Foundation of the United States. Comments made by these researchers provided valuable information in restructuring the questionnaire. Three major enhancements were made. Firstly, in addressing the question on the extent of learner autonomy, it was decided to group items so that data could be gathered on the autonomy learners have at each stage of the investigation. Secondly, the teacher questionnaire of 2004 also included an additional section which focused on the support strategies used by teachers when learners are doing investigations. Thirdly, the wording of certain items was also changed so as to enhance the clarity and reduce the ambiguity.

3.3.2 Classroom observations

Classroom observations were conducted at five schools drawn from the sample which had been surveyed in the quantitative data collection of the study. In observing these lessons, the researcher elected to be detached from the lessons, and thus acted as a non-participant observer. The observations were carried out as unobtrusively as possible. The advantage of the classroom observation is that the subjects are observed in their natural surroundings rather than an artificially created experimental environment. In these classroom observations, the researcher focused on two aspects. The first aspect in trying to gauge learner autonomy in the investigation process, looked at the decision-making which took place during the investigation process. The investigation was tracked in this regard by identifying a priori the following units of observation, Who identifies the variables to investigate ? Who decides what question to investigate ? Who plans the investigation ? Who conducts the investigation ? Who draws the conclusions ? These units of observation were derived from literature on the models of scientific investigations described in Chapter 2. According to Schumacher and McMillan (1993) it is important to establish units of observation “since it is impossible to observe everything that occurs” (p. 257). The second aspect focused on the type of strategies used by the teacher in supporting learners doing

investigations. This was an inductive process and involved observing and then describing how teachers supported learners who were doing investigations.

In order to provide a rich description of what transpired during the lesson it was decided to use both descriptive and narrative systems of observation. According to Evertson and Green (1986) “this approach to integrating multiple perspective analysis in a single project has been undertaken by researchers from a wide variety of disciplinary groundings and perspectives interested in the study of teaching-learning processes” (p. 165). Weinstein (as cited in Evertson and Green, 1986) points to the value of such diversity, by stating that “By investigating several perspectives in each study, we will improve our understanding of the social reality of the classroom” (p. 306).

In one observation, a descriptive system of observation was used. A descriptive system of observation was employed by having preset categories which relate to the two aspects of learner autonomy and teacher support. Evertson and Green (1986) state that “descriptive systems are generally concerned with obtaining a detailed description of observed phenomena in order to explain developing processes, and to identify generic principles by exploring specific processes” (p. 172). A permanent record of this observation was obtained by video- and audio-recording the classroom observation. This record provided a basis for an in-depth analysis of the units of observations which were selected a priori.

In the other four classroom observations, where the teachers chose not to have their lessons video- or audio-recorded, a narrative system of observation as described by Evertson and Green (1986) was used. In such a system, the researcher is the primary instrument of observation, and captures in everyday language what is observed. A critical incident record was made of the unfolding events. Such a recoding system is used to gain “specific information in descriptive form that bears on question or questions of interest” (p. 171). The critical incident record, therefore, “can be viewed as a constrained system that records a specific slice of reality, one defined in advance and guided by a specific framework or theory” (p. 178). The researcher made written fieldnotes which focused on the actions of the teacher and learner, and the teacher-learner interactions which took place. The quality of this descriptive data could have been improved if all 5 teachers had allowed their lessons to be video-taped and audio-taped.

Interviews with teachers and learners from the schools where the classroom observations took place validated the findings of the questionnaires and classroom observations. In these interviews, the teachers were also asked to explain some of their responses to the questionnaires and some of their actions during the classroom observations. The teachers were sensitive about interviews being audio-recorded, and so written notes were made.

The trustworthiness of the data collected through the observations was established through triangulation. According to Guba and Lincoln (as cited in Cohen et al., 2000) in qualitative research the notion of 'trustworthiness' replaces the more conventional views of reliability and validity. There was triangulation as the data from the observations was compared with the data collected from the interviews and questionnaires. In order to ensure the validity of the observations the units of observation were identified apriori and then reviewed by researchers in science education for their unambiguity and appropriateness to the purposes of the observation.

3.3.3 Learner questionnaire

In 2004 a questionnaire (Appendix B) was administered to learners at the 5 schools where classroom observations took place. The questionnaire in seeking validation of the findings of the teacher questionnaire were structured similar to the teacher questionnaire. Learners were assured of the confidentiality of the information provided and that the questionnaire was not a test, so there were no 'right' or 'wrong' answers. In order to focus the learner on the questionnaire and to assist them to recollect what an investigation entails, it was decided in the introduction to describe the investigative process to the learners by means of an example. The learner questionnaire had two sections and consisted of 35 items. Section A requested personal and school information. In this section the learners were also asked to describe an investigation. In section B, learners were asked to respond to statements which related to the degree of autonomy they received in doing scientific investigations, the way in which teachers supported them in doing investigations, and their perception of the benefit of doing scientific investigations.

The questionnaire items were piloted in 2003 with a group of 60 learners to ensure that all instructions, questions and statements were clear and unambiguous. In order to clarify the definition of an investigation it was decided to describe an example of an investigation in

terms of the stages of the investigation. The content validity, was established by having it reviewed by researchers in science education.

3.3.4 Interviews

Teacher interviews were conducted in 2003 and 2004 with teachers who were involved in professional development and doing a B.Ed.Hons in science education at the University of KwaZulu-Natal (Edgewood campus). This group of 10 teachers represented a sample of teachers from schools throughout KwaZulu-Natal. The teachers were all attending lectures over the school holiday at the Edgewood campus. They were therefore accessible for interviews, and there was no need to travel to their schools which were some distance away from Durban. These interviews were audio-recorded. Table 3.1 provides a demographic description of these teachers.

The interviews focused on their perceptions of scientific investigations as a teaching and learning strategy and also the role of the teacher when an investigation is being conducted. The interviews were structured and guided by a few focusing questions on an interview schedule (Appendix C). The same questions were posed to all interviewees so that comparable data across all subjects could be obtained. In this way the reliability was enhanced as Silverman (cited in Cohen et al., 2000) reports, “one way of controlling for reliability is to have a highly structured interview with the same format and sequence of words and questions for each respondent” (p. 121). At the beginning of the interview, all respondents were assured of the confidentiality and anonymity of the data collected. The interviews were later transcribed for analysis because according to Schumacher and McMillan (1993) mechanically related data such as a tape recording increases the reliability.

Table 3.1 Demographic description of teachers interviewed

Teacher	Male/female	Age	Qualification	Type of school	Average class size	School resources
Teacher 1	Male	35	Teaching diploma	State secondary school	35	Adequately resourced
Teacher 2	Female	40	Teaching diploma	State secondary school	30	Adequately resourced
Teacher 3	Male	28	Teaching diploma	State secondary school	31	Well resourced
Teacher 4	Male	37	Teaching degree	Independent school	25	Well resourced
Teacher 5	Female	45	Teaching degree	Independent school	28	Well resourced
Teacher 6	Male	34	Teaching diploma	State secondary school	40	Poorly resourced
Teacher 7	Male	43	Teaching diploma	State secondary school	42	Poorly resourced
Teacher 8	Female	30	Teaching diploma	State secondary school	35	Adequately resourced
Teacher 9	Male	36	Teaching diploma	State secondary school	52	Poorly resourced
Teacher 10	Female	40	Teaching diploma	State secondary school	50	Poorly resourced

3.3.5 FFS Expo for Young Scientists

The FFS Expo for Young Scientists at the University of KwaZulu-Natal (Durban campus) provided an opportunity to collect data relating to open investigations in the form of projects from learners. Having been a judge at previous expos, it appeared such projects were open-ended in that learners drive the investigation process from the start by choosing their own topic to drawing the conclusion. The support for the learners come mainly from family members. From the researcher's experience this represented a special category of investigations as very few investigations of this type take place at school. The FFS Expo is an annual competition for learners in secondary schools throughout KwaZulu-Natal.

Learners enter projects which are judged according to criteria such as originality of the idea, the scientific method, clarity of presentation, skill in presentation of data and material, thoroughness of research, depth of knowledge, visual appeal of the poster, and the ability to communicate ideas verbally. The projects which are entered often relate to the curriculum at school. With the introduction of the new outcomes-based curriculum, learners are required to do at least two full investigations (Department of Education, 2002a). After these projects are assessed, the learners are then encouraged to enter projects which are of a high standard for the expo. In other cases, learners enter projects on their own initiative. A questionnaire (Appendix D) focussing on such investigations was developed and administered to a sample of 20 Grade 9 learners at the expo in 2004. The learners were chosen so that their projects were representative of all categories of Grade 9 entries for the expo. This questionnaire was piloted with 4 learners at the 2003 expo to ensure that all questions were clear and unambiguous. The questionnaire was semi-structured and sought information relating to the project that learners had entered. In certain cases where the project was done by a group of learners, the learners in the group jointly filled in the questionnaire. In the questionnaire, the learners were asked to describe their project and to explain the support they received in doing it. Thereafter, these learners were interviewed. The interviews were audio-recorded. The interviews homed in on the responses to the questionnaire, and sought further clarification of these where necessary. The interviews were later transcribed.

3.4 DATA ANALYSIS

This section describes the procedure of transforming the data collected from the questionnaires, interviews and observations into assertions. The section also discusses the principles upon which the data analysis procedure is based.

3.4.1 Data corpus

The relationship between the research questions and the source of the data collected is shown in Table 3.2.

Table 3.2 The relationship between the research questions and the source of data

	Question 1 What is the degree of learner autonomy ?	Question 2 What are the perceived benefits of learners doing investigations ?	Question 3 What strategies are used by teachers in supporting learners doing investigations ?	Question 4 What factors affect the degree of learner autonomy ?
Classroom observations	5 (2004)		5 (2004)	5 (2004)
Teacher interviews		3 (2003) 7 (2004)	3 (2003) 7 (2004)	3 (2003) 7 (2004)
Learner interviews		10 (2004)	10 (2004)	
Science expo learner interviews		20 (2004)		
Learner questionnaires	126 (2004)	126 (2004)	126 (2004)	126 (2004)
Teacher questionnaires	55 (2004)	55 (2004)	55 (2004)	55 (2004)
Science expo questionnaires	20 (2004)	20 (2004)		

3.4.2 Principles followed in data analysis

The study employed a mixed method data analysis which comprised both quantitative and qualitative analytical techniques. Onwuegbuzie and Teddlie (2003) maintain that “a mixed methods data analysis allows the researcher to use the strengths of both quantitative and qualitative analysis techniques so as to understand phenomena better” (p. 353). This was certainly the case in the study where answers to the research questions posed required that both quantitative and qualitative data be collected and analysed. Onwuegbuzie and Teddlie (2003, p. 375) describe seven stages which can be used to guide the data analysis process in mixed methods research (Table 3.3).

Table 3.3 Stages of mixed methods data analyses process (Onwuegbuzie & Teddlie, 2003)

Stages	Definition
1. Data reduction	Reducing quantitative data (e.g. descriptive statistics, exploratory factor analysis) and qualitative data (e.g. exploratory thematic analysis, memoing)
2. Data display	Reducing quantitative data (e.g. tables, graphs) and qualitative data (e.g. matrices, charts, graphs, networks, lists, rubrics, Venn diagrams)
3. Data transformation	Qualitizing and /or quantitizing data (e.g. possible use of effect sizes, exploratory factor analysis).
4. Data correlation	Correlating quantitative data with qualitative data
5. Data consolidation	Combining both data types to create new or consolidated variables or data sets.
6. Data comparison	Comparing data from different data sources.
7. Data integration	Integrating all data into a coherent whole or two separate sets (i.e. quantitative and qualitative) of coherent wholes.

Note: From “A framework for analysing data in mixed methods research” by A. J. Onwuegbuzie & C. Teddlie (p. 375), In A. Tashakorri & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioural research* (pp. 351-383), 2003, Thousand Oaks: SAGE.

It should be noted that while these seven stages are somewhat sequential, they are not linear. Some stages in this process may be by-passed. For example, to proceed from the data reduction to the data integration stage only two steps may be used. An analysis may involve data reduction to data display to data integration. This was the case in the current study where the data collected underwent the stages of data reduction, data display, data comparison and data integration.

3.4.3 Data transformation

This section describes how the stages of data reduction and data display in the mixed method data analysis process were used to transform the data collected into a form from which assertions were generated.

The quantitative data in the form of the responses to the teacher questionnaire and the learner class questionnaire were analysed statistically using the SPSS version 11.0 for windows software program. The given responses to the questionnaires were coded and then using the SPSS programme, frequency tables was generated. This table indicated the most and least frequently chosen responses as a percentage. For example, the frequency of the teacher responses to the support strategies indicated the common strategies that teachers use in supporting learners who are doing scientific investigations. In this way the patterns of responses were established. In most instances where descriptive statistics was presented, the five categories were collapsed into three, e.g. never or seldom, sometimes and often or always. This was done because very few respondents explored the extremes of the scales, i.e, never or always. Given that there were now only three categories generated, more sophisticated statistical analysis techniques could be used. Cross-tabulations, correlations and chi-squared test were conducted to establish whether or not there was a relationship between variables. For example, a cross-tabulation was done of the data collected in the teacher questionnaire relating to the average class size and the frequency with which learners conduct the investigation on their own to reveal a possible relationship between these two variables. The general trends that were quantitatively established were used as a basis for qualitative data analysis, which according to Schumacher and McMillan (1993) is “primarily an inductive process of organizing the data into categories and identifying patterns (relationships) among the categories” (p. 479).

The data collected from the interviews and classroom observations were analysed qualitatively. The interviews with teachers and learners were transcribed verbatim. Extracts of the observed lesson which was video-taped was also transcribed verbatim. Written notes were taken for the other lessons observed. The other data for qualitative analysis were the comments made by teachers on the questionnaires.

A classification scheme was developed in order to give structure and thereby make the qualitative data more meaningful. The classification system was developed by starting with predetermined categories which were derived from the research questions. These categories were degree of learner autonomy in scientific investigations, teacher perception of learner autonomy, learner perception of autonomy granted to them, teacher support strategies, and the factors affecting the balance between learner autonomy and teacher

direction. While collecting and reading the data, these categories were broken down into smaller subcategories.

The classification system was then applied to the transcripts of the interviews and classroom observations using the NVIVO computer programme (Bazeley & Richards, 2000). The data were coded by means of nodes. Nodes contain reference to text from documents. By browsing through the text documents, the researcher noticed excerpts that seemed significant. These were then coded to a node. Coding enabled the researcher to find quickly all the relevant data associated with each research question. For example, in addressing the question relating to the perceived benefits of learners doing scientific investigations, the relevant text from the interviews was coded to a node (called 'benefits'). This node was browsed whenever the researcher wanted to 'get a feel' for what teachers thought about learners doing their own investigations. Later, the coding was revised and 'teacher perception' was turned into a tree node with the various perceptions as its children. In this way, the chunks of data representing words and actions were clustered, sorted and systematically arranged. Through this analysis, a summary table was constructed. The table summarized the common themes which arose from the interviews and classroom observations, and was used in subsequent analysis.

3.4.4 Generating assertions

This section describes how the stages of data comparison and data integration are followed in generating assertions. The results of the analysis of the quantitative data collected from the questionnaires were compared with the common themes of the qualitative analysis of the interviews and classroom observations which were featured in a summary table. After the results of the qualitative and quantitative analysis were compared with each other, a relationship between these inferences emerged. In this way the two types of data were integrated into a coherent whole. For example, the analysis of the data collected in Section C of the teacher questionnaire relating to teacher support strategies was compared with the interview and observation data coded for teacher support strategies. The integration of the quantitative and quantitative data led to data interpretation, which resulted in certain assertions being generated. According to Gallagher & Tobin (1991) these assertions are the answers to the research questions and as such are concise statements that represent patterns in the data analysed. In analysing the data it was noted that in certain cases the data did not

unanimously support the assertions generated. As suggested by Gallagher and Tobin (1991), this counter-evidence was indicated.

The findings of the study arising from the implementation of the research methods described in this chapter are reported in chapters 4 and 5. In Chapter 4, the case studies of classroom investigations, and a sample of science expo projects are described. The purpose of this is to set the stage for Chapter 5 by orientating the reader towards the different types of investigations which take place by providing a complete description within a classroom context. In Chapter 5, a full analysis of all the study data including the questionnaire survey and interviews is presented.

CHAPTER 4

TYPES OF SCIENTIFIC INVESTIGATIONS

The RNCS (Department of Education, 2002b) of South Africa promulgates to a large extent the investigative approach in the teaching and learning of science. Learning outcome one of this curriculum focuses entirely on scientific investigations. However, as scientific investigations did not feature strongly in the previous curriculum, there is much confusion and disagreement amongst educators about what an investigation entails. In order to orientate the reader towards the different types of scientific investigation which were identified in Section 2.8.3, five investigations which were observed during the fieldwork are described in terms of the degree of autonomy which learners have. A description of these 5 classroom investigations was considered integral to the study as they allow the assertions which are generated in Chapter 5 to be seen in context. Thereafter, science expo projects which are another type of investigations are described.

The classroom observations revealed that investigations differed with regard to the degree of learner autonomy and the extent of teacher control through the stages of the investigative process. The framework (Table 2.6) which classified investigations as either structured, guided or open was used to describe the types of investigations which were observed.

Of the five investigations which were observed, one was open, three were guided, and one was a structured investigation. In the following sections each of these investigations are described in detail, with a focus on the degree of autonomy learners have at the different stages of the investigation. For example: Do learners choose the investigation question? Are learners involved in the planning stage of the investigation? Do learners conduct the investigation? Do learners draw their own conclusions from the investigation?

In addition, a sample of four investigation projects which were submitted to the FFS Expo for Young Scientists held in August 2004 at the University of KwaZulu-Natal (Durban campus) is described. These projects were used as exemplars of the range of support that learners received in doing projects for science expos.

The investigations described in this chapter do not in any way claim to be representative of what is taking place in all Grade 9 science classrooms. These investigations provide the reader with detailed descriptions of real investigations and illustrate how teachers plan investigations that either promote or restrict learner autonomy. The description of these investigations provide a context for further findings of the study in Chapter 5, and also add to the evidence provided in that chapter. In order to protect the privacy of all the participants, the names of the participants and the schools have not been mentioned. Instead, pseudonyms are used.

4.1 MISS ESSOP'S CLASS: AN OPEN INVESTIGATION ON PULSE RATE

The first case provided a rich description of an open investigation in a Grade 9 class in which the teacher provided the topic and the learners formulated the question, did the planning, conducted the investigation and drew their own conclusion. This case description was constructed by employing a narrative system of observation. Miss Essop, the teacher of the class, chose not to have the lesson video- or audio-recorded. The researcher therefore observed and made written field-notes of what unfolded in the classroom.

4.1.1 Contextual information

The observation took place in a Grade 9 class at a state all boys' secondary school. The school is situated in a middle class suburb. The school has a reputation for producing good matric results. The previous year, the school achieved a 100% pass rate in the external senior certificate examination. The school is well-resourced and has four science laboratories. Miss Essop informed me that in order to maintain a high standard of education, the school fees were higher than many other state schools at the time of observation. The average class size was twenty four, and the particular class observed had twenty three learners. There were six Natural Science classes in Grade 9 and the learners are graded according to their academic ability. The class observed was the 'C' class, i.e. middle achieving learners in this school. Miss Essop had eighteen years' teaching experience in Natural Science and Biology. She possesses a Bachelor of Science degree with majors in Botany and Environmental Education, and a higher diploma in education. The topic that was covered was the cardio-vascular system. The teacher explained to me

that in the previous lesson the class was introduced to the concept of pulse rate, and the learners had measured each others' pulse rate.

4.1.2 A description of what happens in Miss Essop's class

The lesson took place in a biology laboratory. This was a typical laboratory with water and gas outlets arranged the perimeter of the room and movable learner tables in the middle. Apparatus was stored in cupboards and chemicals in a room at the front of the laboratory. The learners sat at their work benches in groups of four. One group had three learners. There were six groups. Miss Essop explained to the class that they were going to do an investigation on pulse rate. She told the class that they were to use the scientific method to design an investigation involving pulse rate. She reviewed the scientific method with the class. She described the scientific method as a stepwise process often followed by scientists in order to investigate an issue. She then referred them to a previous worksheet in their science files where the stages in experimental design was described. The worksheet (Appendix F) showed the following steps in the scientific method:

- Step 1: Hypothesis
- Step 2: Experimental design
- Step 3: Experimentation
- Step 4: Analysis
- Step 5: Presentation

The teacher informed the learners that the investigation was to be completed in two lessons. In the present lesson they should do the planning of the investigation, and the next lesson they would conduct the investigation and collect their data. In the third lesson, the learners in groups would do a presentation of their findings to the class. In their presentations, the groups were allowed to use a poster, the over-head projector or computer PowerPoint to describe their findings. The learners were also told that they would need to submit a report on their investigation in a booklet. This report should be structured according to the steps of the scientific method described in the worksheet mentioned.

Miss Essop explained and wrote on the board that in planning their investigation they would need to focus on the following questions:

1. What is the aim of the investigation ?

2. What is the hypothesis ?
3. What procedure will be followed ?
4. What apparatus is needed ?
5. How will the data be collected ?
6. How will the results be presented ?

The learners were told that as the investigation was open, they would need to formulate their own question relating to pulse rate. Once the question had been decided, they were to discuss and write down how they intended investigating the question. This introductory part of the lesson took approximately twenty minutes.

As the learners engaged in their group discussions, the teacher moved around the class listening in on the group discussions taking place. She frequently stopped at a group and asked learners to identify the independent, dependent and extraneous variables in their hypothesis. She asked probing questions which sometimes made learners rethink what they had decided. For example, in the following exchange where a group of learners had chosen to investigate the effect of drinking coffee on the pulse rate, it can be seen how the teacher through the use of these probing questions, helped the learners to gain greater clarity about what they will be investigating.

- Miss Essop: Okay, tell me what your hypothesis is ?
- Follett-Smith: We want to investigate the effect of drinking coffee on the pulse rate.
- Miss Essop: Yes, but is this your hypothesis. Do you remember what the hypothesis is ?
- Ruan: It is a something you say which may be true. That's what you want to investigate.
- Miss Essop: Good. Now, can we try again. Yes, Follett-Smith
- Follett-Smith: Coffee causes the pulse rate to increase
- Miss Essop: Can, we identify the variables in this hypothesis.
- Ruan: The independent variable is the amount of coffee and the dependent variable is the pulse rate.
- Miss Essop: I need you to explain to me how you will investigate this.
- Ruan: We will choose a group of people. We will take their pulse before and after the coffee.
- Miss Essop: In making the coffee will you add different quantities of coffee to the water ?
- Ruan: No, it will be two teaspoons for all.
- Miss Essop: Then I want you to have a look at your independent variable. You said it is the amount of coffee. That doesn't seem right does it ?

Follett-Smith: No, we will need to change that to drinking coffee.

Miss Essop: So, what is the extraneous variable ?

Follett-Smith: The number of spoons of coffee.

The teacher had similar exchanges with other groups. Where two groups had formulated the same hypothesis, one group was asked to choose another hypothesis. The teacher later told me this was to prevent copying and also to ensure that more factors affecting pulse rate could be identified. By the end of the lesson, each group had formulated an hypothesis to investigate and a plan for the investigation. The following hypotheses were formulated, drinking coffee causes pulse rate to increase; as more coffee is drunk the pulse rate increases; drinking tea causes the pulse rate to decrease; drinking Energade causes the pulse rate to increase; running up stairs increases the pulse rate; coughing continuously causes the pulse rate to increase. The learners were told to bring all the materials necessary to conduct the investigation in the next lesson. Hot water would be provided to the groups using coffee and tea. This part of the lesson took approximately thirty minutes.

In the second lesson, the groups began conducting the investigation. The groups appeared to be working as a team with each member of the group designated a certain role. In one group, I noticed a learner coughing continuously for a period of time, after which a second member of the group took his pulse, while a third member had a stop watch, and the fourth member recorded the pulse rate in a table. The teacher went to each group, observed what was being done, and sometimes asked learners to explain what they were doing. The teacher also offered suggestions in the form of questions when it was noticed learners were not controlling the extraneous variables which they had identified in their plan. For example, in the Energade experiment, where the group had decided to use a learner as a control subject, and a learner as the experimental subject, the control subject was not given an equivalent volume of water to drink. The teacher after noting this, intervened and asked learners if this was fair test. The learners then reviewed what they were doing and made the necessary changes. After drawing a table of results, the groups drew a graph on the graph paper to represent their results. The teacher once again paid particular attention to what the learners were doing. On occasions she questioned the learners about the suitability of the scale they had chosen for the graph. Thereafter, the learners stated their conclusion to the investigation. By the end of this fifty minute lesson all groups were complete.

In the third lesson each group did a presentation of their findings to the class. Each member in the group described an aspect of the investigation. Four groups used a poster and two groups did a PowerPoint presentation to describe their findings. After each group did their presentation, the other learners asked questions and made comments. The questions related mainly to the procedure that was followed. For example, the group who had done the investigation on the effect of coughing on the pulse rate, were questioned about why they had only conducted the experiment twice. This was pointed out to them by other groups as a flaw in their investigation, as the findings could not be reliable if the experiment has only one subject and the experiment was performed only twice. Groups also demanded scientific explanations for the findings of the investigations. It was observed that the groups were not always in a position to offer an explanation for the findings. When such a situation arose the teacher intervened and made comments or asked guiding questions so learners were able to explain their findings. The teacher wrote down the findings of each investigation on the board. The presentations took up the whole lesson. All groups had completed the presentations.

4.1.3 Follow-up after lesson in Miss Essop's class

The learners had autonomy through all stages of the investigation. Each group was responsible for formulating a hypothesis of an investigation which related to pulse rate. The learners planned how they were to conduct the investigation, and collect data. Finally, after collecting and analyzing the data, the learners drew their own conclusions. The teacher played a supportive role by asking questions which encouraged the learners to reflect upon what they are doing, and offering suggestions when necessary.

In order to gain a more complete understanding of what transpired during the investigation the teacher and some learners were interviewed after the investigation. The teacher was asked to explain why the learners were given such autonomy in the investigation. The teacher in her explanation referred mainly to the enjoyment which the learners experience when working on their own. The following excerpt from the interview with this teacher underscores this:

I have noticed that an investigation is always something that my learners look forward to. I think it is because this is something that they have to do mostly on their own. They are now placed in a position where they can decide how good or poor their product will be.

They also enjoy working in a group so that the work may be shared. (Miss Essop, interview)

Miss Essop was also asked about how predominant this approach was in her teaching. She remarked that as far as possible, learners were given the opportunity to do investigations which were open. However, due to the time constraints and the pressure of covering content, most of the investigations in her class were guided.

The learners who were interviewed from this class corroborated what the teacher had said about the enjoyment which they derived from doing the investigation on their own. The following comment by a learner from this class supports this.

Science used to be a real drag last year. It was boring watching the teacher do the experiments and stuff. This year I find science more interesting because we can do things on our own. (Learner interview, Miss Essop's class)

The investigation described in Miss Essop's class would be classified as a typical open investigation according to the framework being used.

4.2 MR BOTHA'S CLASS: A GUIDED INVESTIGATION ON RESISTANCE

A guided investigation in Mr Botha's Grade 9 class was observed and a narrative of what took place is presented. In such an investigation, the teacher provides the topic and question to be investigated. The learners then plan what they will do, conduct the investigation and draw their conclusions. As the teacher chose not to have the lesson video- or audio-recorded, the researcher relied solely on field-notes and memory to record what transpired in class.

4.2.1 Contextual information

The lesson was observed at a state all boys' secondary school. The school draws learners from an affluent feeder area. Thus, the school is well-resourced and the governing body employs eighteen educators over and above those paid by the government. Historically, the school is strong academically, and its learners have performed well in the Grade 12 senior certificate examination. The school has six fully fitted and well stocked science laboratories. The researcher was informed that it is policy of the school that the class sizes should not exceed thirty learners. The class observed had twenty four learners. The school

had eight Natural Science classes in Grade 9, and the learners were graded according to their academic ability. The class observed was the 'B' class. Mr Botha has fifteen years' teaching experience in Natural Science and Physical Science. It was his third year teaching at this particular school. He possesses a Bachelor of Science degree with majors in mathematics and physics, and a higher diploma in education.

The lesson observed took place in a science laboratory. There were seven tables, each designed to accommodate four learners distributed throughout the laboratory. Before the lesson, the teacher explained to me that it was going to be an investigation on electricity. The learners had the task of practically identifying all factors which affect the resistance in a circuit. It was the third practical lesson on electricity. In the two previous lessons, the learners had dealt with current strength, resistance and potential difference. They had drawn circuit diagrams and connected circuits. The teacher told me that the learners from these lessons had gained sufficient expertise to connect the components in an electrical circuit. The learners had been working in groups of four during the previous practical lessons, and they would continue in the same groups for this lesson. When questioned about the composition of the groups, Mr Botha explained that he had nominated six responsible learners as group leaders and they then chose the members in the groups. He told me this was the best way to get groups where all members 'got along' and worked harmoniously.

The length of each teaching period was 50 minutes. However, for the observed lesson the teacher informed me that he had made arrangements with the mentor teacher to also use the mentor period (thirty minutes) for the investigation. The investigation lesson would therefore extend for one hour and twenty minutes.

4.2.2 A description of what happened in Mr Botha's class

At the start of the lesson, the learners organized themselves into groups at their tables. After greeting the learners, the teacher drew the attention to what was written on the board: "Task: To identify factors which affect the resistance in a circuit." The teacher then initiated a class discussion on electrical resistance. He asked the learners, "What do we understand by resistance?" The majority of the learners almost instantaneously raised their hands. The teacher pointed to a learner who answered, "difficulty of flow." The teacher

nodded his head and pointed to another learner. This learner explained, “something which opposes the flow of charge.” The teacher asked, “Do you all agree with this definition?” The class answered almost in unison, “Yes sir”.

The teacher then questioned the class about the ammeter and what it was used for. Through further follow-up questioning the class came to realize that the ammeter reading could be used as an indicator of resistance in the circuit. From this class discussion, the learners learnt that the lower the ammeter reading, the higher the resistance in the circuit. Mr Botha told the class that they had the task of discovering the factors which affected the resistance in a circuit. He explained that they were to investigate as many factors as they could in the available time. He handed out a worksheet with guiding questions on them (Appendix G). The worksheet included the following:

1. I think this will affect resistance _____.
2. How will I investigate it ?
3. How does it affect resistance ?

The learners were expected to answer these questions for each of the factors they were going to investigate.

On the instruction of the teacher, the group leaders collected the electricity packs from the teacher’s table. The groups were instructed by the teacher to brainstorm ideas and then devise a plan of action. They were required to write down this plan on the worksheet provided. During these group discussions, the teacher walked about the class and listened in on the exchanges between learners. After a few minutes he went to each group and asked them to describe their plan. In this exchange, he asked many questions, and these questions forced the learners to reflect very carefully on their plan for the investigation.

The following excerpt illustrates this questioning:

- | | |
|-----------|--|
| Mr Botha: | Okay, I see you guys have chosen thickness of conductor as a factor which would influence the resistance. Tell me, why have you chosen thickness ? |
| John: | We are all pretty confident that if you increase thickness it will make it easier for the current to pass through. |
| Mr Botha: | What about the resistance ? |
| Justin: | It would therefore have less resistance. |
| Mr Botha: | Good. Now explain to me Kajee, how the group intends investigating this. |
| Kajee: | Sir, we decided to make it easier for the charge. We must offer it another path. The light bulbs must be connected in parallel. |

- Mr Botha: So are you saying that thickness equates to having resistors in parallel. What if you had three in parallel.
- Kajee: It will be more thicker.
- Mr Botha: Okay, how will you show this relationship between thickness and resistance.
- [The teacher looks at Sooriah.]*
- Sooriah: Use the ammeter.
- Mr Botha: Tell me more.
- Sooriah: Connect the ammeter in the circuit to measure current strength.
- Mr Botha: Yes, but how will this enable you to investigate resistance ?
- [Sooriah does not answer and shakes his head. The teacher then redirects the question to John. John answers.]*
- John: A higher reading means smaller resistance.
- Mr Botha: Okay, do we have that ?

The teacher adopted a similar questioning technique with the other groups. After getting the go ahead from the teacher, the groups then proceeded to open the electricity packs and began connecting a circuit. In a short time, the room became very lively. There was lots of cross-talk both within and between groups. I observed that three groups investigated length, two groups investigated the thickness of the conductor, and one group investigated the type of metal as a factor affecting resistance. I heard exchanges such as the following taking place within the groups:

Both light bulbs should come on. What's happening ? Where's the current going ?
Check the circuit. There must be a gap. It could also be the battery."

At another table:

Something is wrong with the ammeter. The needle is wrong. What could this mean ?
Reverse the red and black wires. The current is going the other way.

The teacher interacted with the groups and asked questions and offered advice when necessary. On one occasion I observed the teacher returned to the group, where the learners were investigating the thickness of the conductor as a factor affecting resistance. The teacher looked at the circuit the group had connected. The teacher then questioned the learners about the circuit.

- Mr Botha: Tell me what you have done so far.
- Kajee: We first took one light bulb and measured the current passing through. We then decided to increase the thickness by having two light bulbs in parallel. Now we want to measure the current strength.

- Mr Botha: Can I have a look at your circuit diagram for this ?
- [The group produces a circuit diagram which they had drawn in the planning stage of the investigation. It was a diagram where there are two light bulbs in parallel, and an ammeter in series with one of the light bulbs. The teacher continues with his questioning.]*
- Mr Botha: I want you to look carefully at your circuit diagram you have drawn and the one you have connected. Are they the same ? Trace the flow of current. Is it the same Justin ?
- Justin: Yes sir.
- Mr Botha: Look at the position of the ammeter. What is it measuring in the connected circuit.
- Kajee: The current passing through this light bulb.
- Mr Botha: Is that what you want ? Yes, John,
- John: No, I think we need the total current.
- Mr Botha: Good. Do you know what needs to be changed in the circuit.
- [The learners answer 'yes'. The group then reconnects the circuit with the ammeter in series with the parallel combination of resistors.]*

Mr Botha interacted in a similar way with the other groups. He constantly walked around, checking that the groups were making progress. He asked questions, and made suggestion when deemed necessary. With the teacher's guidance and facilitation, each group appeared to be on the right track.

Ten minutes before the end of the lesson (they had been working for 60 minutes) the teacher asked the groups to stop working. He quickly ascertained that each groups had investigated at least one factor. The teacher then asked each group to give a report back of what they had learnt through the investigation. Each group then shared their findings with the rest of the class. The groups explained how each factor affected the resistance in the circuit. For example, one group stated that as the conductor becomes longer, the resistance increases. The groups which had investigated the same factor arrived at similar findings. After each group had given a report back, the teacher summarised their findings on the board.

4.2.3 Follow-up on lesson in Mr Botha's class

The learners were asked to design an investigation to identify the factors which affected the resistance in a circuit. In the planning stage the learners decided on what factor to investigate. They then formulated a hypothesis based on this. The learners were

responsible for carrying out the investigation and collecting data. They drew their own conclusions. The teacher facilitated their progress through the investigation. The class discussion at the beginning of the lesson orientated the learners towards the investigation. Without telling them directly, but through skilful questioning, the teacher guided the learners to what resistance was, and how the ammeter could be used to indicate the relative amount of resistance in the circuit. In the planning stage where the learners decided on the factor they would investigate and how they would go about doing it, the teacher was always on hand to ask a clarifying question or to offer a suggestion to get the group on track. When the learners were carrying out their plan and collecting data, the teacher was again present in a supportive capacity.

In the interview which followed the investigation, Mr Botha was questioned about the role which he had played during the investigation. He described himself as a guide who would provide direction to the learners in leading them to the desired outcome. The teacher described this role as follows:

As you can see the learners did a lot on their own. But they were not left alone. I was around to make sure they were on the right track. I guided them throughout the investigation so that they moved in the right direction. (Mr Botha, interview)

The learners who were interviewed all commented positively about their experience of conducting the investigation on their own. A learner interviewed expressed this viewpoint as follows: “We liked playing around with the circuit. It was great fun as we could try different things and change the parts if we liked. This was much better than just looking at the diagram.”

The lesson in Mr Botha’s class illustrates a guided investigation where the teacher decided the topic and provided the investigation question. The learners then planned the investigation, collected data and drew their conclusions mostly on their own.

4.3 MR PILLAY’S CLASS: A GUIDED INVESTIGATION ON CIRCUITS

This section describes another case of a guided investigation in a Grade 9 class. The description is based on a classroom observation involving a descriptive system of

observation. The lesson was video- and audio-recorded. The researcher also made written field-notes of what unfolded in the classroom.

4.3.1 Contextual information

The investigation lesson observed took place in a Grade 9 class at a state all boys' secondary school, which is situated in a suburb where the majority of the learners come from middle income homes. The school has a reputation for producing good matric results. Many of its learners achieve university entrance passes with some excelling. The previous year, two learners from this school were placed in the top thirty of learners in KwaZulu-Natal in the external senior certificate examinations administered by the national Department of Education. The school is well-resourced and has six science laboratories. The average class size at the time was twenty six, and the particular class observed had twenty five learners. There were eight Natural Science classes in Grade 9. The learners were graded according to their academic ability. The class observed was the lower set 'E' class.

Mr Pillay, the teacher of the class, had eleven years' teaching experience in Natural Science and Physical Science. He possessed a Bachelor of Science degree with majors in mathematics and chemistry, and a higher diploma in education. From the discussion with him prior to the observation, Mr Pillay stated that he always had a passion for practical work. He explained that practical work was something that he thoroughly enjoyed doing himself, and so whenever possible he engaged his learners in practical work. He regularly entered his learners in science expositions such as the FFS Expo for Young Scientists.

The lesson observed took place in a science laboratory. There were six tables, each designed to accommodate four. These tables were arranged in rows. The length of each teaching period was fifty minutes. The teacher told me beforehand that the aim of the investigation was to experimentally determine the relationship between current strength and potential difference across a resistor. The teacher informed me before the lesson that the learners did have prior knowledge of drawing circuit diagrams. They knew that the ammeter should be connected in series and the voltmeter in parallel to the resistor. He had shown them these connections in a circuit that he had connected. He also told me that although the learners had no previous experience connecting circuits he had taken 'great

pains' to explain the connections and also how to take readings from the ammeter and voltmeter. This was going to be the first investigation where the learners would apply this knowledge.

4.3.2 A description of what happened in Mr Pillay's class

As the learners entered the laboratory, Mr Pillay directed them to the tables and asked them to sit in their practical groups. He then handed out two identical worksheets (Appendix H) per group. Mr Pillay explained to the learners they were to do an investigation on the relationship between current strength and potential difference. He then asked the learners to read through the worksheet. As they were doing this, he asked the class what a hypothesis was. A number of learners raised their hands to answer. He pointed to a learner, Steven and got the following response, "It is like you think it will happen." The teacher told Steven that he had "the right idea." He then redirected his question to Martin who answered as follows, "A hypothesis is a guess you would make. Before a scientist experiments, he will guess what will happen." Mr Pillay went on to tell the class that they would now need to formulate a hypothesis concerning the relationship between current strength and potential difference. Thereafter, they would have to plan how this hypothesis would be investigated by describing the procedure they would follow. The teacher told the learners that they should only conduct the experiment once he had approved their plan. He told them one worksheet should be filled 'in rough' as the investigation was being planned. The second worksheet should only be filled in after the plan for the investigations had been finalized, and the investigation had been conducted. This worksheet would then be submitted as their report on the investigation.

The groups began discussing what their hypothesis, and plan for the investigation would be. In planning the investigation, the discussion centred around how the circuit would need to be connected. The learners attempted to draw a circuit diagram on the worksheet. The teacher visited each group while they were doing this. Where the circuits were incorrectly drawn, Mr Pillay asked questions about the connection of the components. If the answers were unsatisfactory, he referred learners to their notes on electrical circuits. He suggested to the learners that on the circuit diagrams they indicate the polarity of the components. All groups had chosen a light bulb as a resistor in their circuits. Once the teacher had approved the group's circuit diagram, he asked a member from the group to collect a box of

electrical components. The box contained batteries, connecting wires, a circuit board, light bulbs, a switch, a rheostat, an ammeter and a voltmeter. Most groups completed this part in about fifteen minutes.

The groups then set about connecting their circuits. The teacher moved about the laboratory, asking questions about their connections in the circuit and making suggestions when necessary. The questioning was more deliberate and probing when learners had done something wrong. This was evident from the following excerpt where a group of learners had connected the voltmeter in series with the light bulb, and the light bulb did not glow. The teacher did not tell the learners that they had incorrectly connected the voltmeter, but instead through guiding questions and suggestions, the learners come to realize the error they have made.

- Mr Pillay: Okay, what seems to be the problem here ?
- Johnson: The bulb is off.
- Mr Pillay: Have you checked to see that your circuit is complete ? Are there any gaps in your circuit ? Is your circuit closed ?
- [The learners answer, "yes sir" in unison]*
- Mr Pillay: Okay, I want you to look closely at your connection of the voltmeter. What is the voltmeter doing in this circuit ?
- Kelly: Measuring volts.
- Mr Pillay: What do you mean by that ?
- Kelly: The voltage.
- Mr Pillay: What is voltage ?
- [The learners are unable to answer.]*
- Mr Pillay: I want you to get out your notebooks and look up what voltage is.
- [The learners page through their notebooks and then Johnson answers.]*
- Johnson: It is the energy transfer per Coulomb of charge.
- Mr Pillay: Explain this to me in your own words.
- Johnson: How much energy the current supplies to the circuit ?
- Mr Pillay: Good. Now let's go back here. Why do we have this voltmeter in the circuit ?
- Visharlan: To measure the energy transfer across the bulb.
- Mr Pillay: Now to measure this energy transfer across the bulb, how should the voltmeter be connected. In series or parallel ? Yes, Vishalan ?
- Visharlan: I think in parallel ?

Mr Pillay: Good. Now look at what you have done here.

[The learners then make the changes to the circuit and the bulb now glows.]

After taking three sets of readings, the learners recorded them in the table on the worksheet. Thereafter, the learners had a brief discussion in their groups about the relationship between current strength and potential difference. All groups had stated that as the voltage was increased, the current strength in the circuit increased. The teacher again went to the groups and helped them understand the conclusion they had reached. He asked the groups to explain why the current strength increased when more cells were added in series. Once more the teacher used questioning which attempted to probe their understanding of the concepts, current strength and potential difference. The following excerpt where the teacher interacted with another group of learners serves to illustrate this.

Mr Pillay: Explain this conclusion you have reached. Why do you think the potential difference and current have both increased together ?

Marnitz: The one depends on the other.

Mr Pillay: Yes, but why did the current increase ?

[Marnitz looks perplexed and is unable to answer. The other learners in the group are also unable to answer.]

Mr Pillay: I want you all to look at the meanings of current strength and potential difference. What do these things mean ? Kelvin ?

Kelvin: Current strength is amps and has to do with the speed of charge.

Mr Pillay: Fantastic. Now why is the charge moving faster when we add more batteries ?

Kelvin: More in the circuit. The current is moving faster.

Mr Pillay: Is that clear ?

[The learners answer "yes sir" in unison]

4.3.3 Follow-up on lesson in Mr Pillay's class

In the above investigation, the learners were given the investigation problem which identified the variables in the investigation. They formulated a hypothesis based on this. They devised a plan to investigate the relationship between current strength and potential difference by drawing a circuit diagram. After the circuit diagram had been checked by the teacher, the learners connected the circuit and took ammeter and voltmeter readings. They

entered these readings on a table. Based on the results of the investigation, they drew a conclusion which addressed the hypothesis. The investigation can therefore be classified as guided. The teacher played a supportive role in facilitating the learners' progress through the investigative process. Through the use of skilful questioning, he encouraged the learners to reflect upon what they had done, and to rethink decisions they had made. Mr Pillay also explained that there were certain skills in this investigation which needed to be modelled. He mentioned how he had spent some time showing the learners how to decide which scale to use on the ammeter and voltmeter, and how to take readings.

After showing them how to take these readings they were given a worksheet with the ammeter and voltmeter gauges drawn. On these gauges different readings were shown. They had to do give these values of the readings (Mr Pillay, interview).

This excerpt reflects that although the learners had the autonomy in collecting data, the teacher provided sufficient guidance.

4.4 MRS REUBEN'S CLASS: A GUIDED INVESTIGATION ON COMBUSTION

In this section the third guided investigation in a Grade 9 class is described. As the teacher, Mrs Reuben objected to the lesson being video- or audio-recorded, the researcher made field-notes to construct a picture of what took place.

4.4.1 Contextual information

The observation took place at a state secondary school. The school is co-educational and there are about the same number of boys and girls. The school draws learners from predominantly middle income homes. A fair percentage of the parents are professional people. The school is situated in a residential area, that lies next to a densely populated poor suburb. About 10% of learners from this suburb attend this school. Compared to surrounding schools, the school is well-resourced, but not as well as Mr Pillay's school. The school fees are also higher than the surrounding schools. The school had four science laboratories. The school places a strong emphasis on the academic performance of the learners. Learner participation in sport is low. The school has an outstanding reputation for its learners producing good results in the matric senior certificate examination. The matric results in science had been particularly good. As a result of this, there is always a deluge of

applications for a place in Grade 8 at this school. The average class size in grade 8 and 9 was forty two, and in Grades 10, 11 and 12 it was thirty eight. The guided investigation was observed in a class with forty learners. There were seven Grade 9 classes and the learners were graded according to their performance in Grade 8. The class observed was a “C” class. The teacher, Mrs Reuben had twelve years’ experience teaching Natural Science. She had a teaching diploma with majors in Physical Science and Mathematics. The teacher informed the researcher that the management of the school subscribed very strongly to the OBE approach. The principal often invited subject advisors to address subject departments about OBE and the curriculum changes in the FET phase. All teachers were therefore strongly urged to adopt a learner-centred approach in the classroom.

Mrs Reuben informed me prior to the lesson that the class would be conducting an investigation to show that one of the products of combustion of a candle was carbon dioxide. It was brought to my attention that combustion reactions had been covered in the previous lesson, and learners possessed the knowledge that during combustion a substance reacts with oxygen. The learners were also taught that carbon dioxide turned clear limewater milky. The teacher told the researcher that due to the overcrowding in the laboratory, the learners would be working in a covered area outside the laboratory. The teacher explained further that such areas had been created throughout the school to alleviate the overcrowding situation.

4.4.2 A description of what happened in Mrs Reuben’s class

As the learners arrived for the lesson, the teacher asked them to stand in two lines of boys and girls. The teacher then placed learners into groups by calling out the names of members in each group. There were four groups of seven learners and two groups of six learners. The groups were then directed to the tables which were set outside. The teacher later explained to me that she composed the groups so that learners who were overly talkative in class could be separated. The teacher informed the learners that they were to design and then carry out an experiment to show that carbon dioxide was a product of combustion. She also told them they would be assessed for the investigation and impressed upon them the need to take the task seriously. They were expected to complete the investigation within two lessons. Each lesson was of fifty minutes duration. The learners were told that the present lesson would be used for planning, and the investigation would

be conducted in the next lesson. The next lesson was going to be in three days' time. The groups would be responsible for bringing the apparatus to be used. The groups were told to inform the teacher in advance should they not be able to provide the apparatus. The teacher handed out a worksheet which included the following questions and instructions to guide learners in planning the investigation, conducting the investigation and drawing conclusions

1. Brainstorm ideas in your group.
2. Decide what apparatus you will use.
3. Describe how you will do the investigation.
4. Draw the apparatus you will use.
5. Describe what happened.
6. Write an equation for the combustion of the candle.
7. What did you conclude ?

The teacher read the worksheet and told the learners that each group would need to hand in a worksheet at the end of the investigation.

The groups began brainstorming. This was the planning stage of the investigation. The learners were told that they should have a plan by the end of the lesson. As the groups engaged in discussion on how to conduct the investigation, the teacher sat at her table and marked tests from a previous lesson. The teacher sat at the table for ten minutes. During this time it was observed that a few learners visited other groups. They appeared to engage in conversation which was unrelated to the task given. The teacher shouted at these learners to return to their group. When questioned at the end of the investigation about this period when learners were left on their own, Mrs Reuben explained that learners should be given some space to 'talk things through.' After this period of time, the teacher went to each group and asked to see what they had written on their worksheet. At this point, three of the six groups had written the plan and the other groups were still in discussion about what to do in the investigation. At the groups where the learners had already formulated the plan, the teacher used probing questions which enabled the learners to clarify their plan. If their plan was inadequate, the teacher asked them to reconsider these deficiencies. She also made suggestions where necessary.

The following excerpt illustrates how the teacher probed a group's plan. The group was made up of seven members with Trevern as the group leader.

- Mrs Reuben: Guys tell me what you will do.
- Trevern: Ma'am, we will burn the candle. This gives CO₂. We then take something burning like a match. If it goes off it proves the candle gave CO₂.
- Trevern: Okay so will you hold the burning match close to the candle flame?
[The learners all answered "yes ma'am."]
- Mrs Reuben: Okay, I want you to think about this before you conduct your experiment. How do things burn and what is needed for burning?
[The learners reflect on this question and engage in a group discussion. Thereafter teacher returns to the group.]
- Mrs Reuben: Have you thought about this ?
- Vijay: Ya, we know that oxygen is needed for burning.
- Mrs Reuben: Good. You are saying that the match that's burning will go off in air when held near the candle ?
- Vijay: Ya.
- Mrs Reuben: Think about this....in air. Yes, Suren ?
- Suren: I am not sure....but with the oxygen in the air it will carry on burning.
- Mrs Reuben: Good. So what do you think you need to do ?
- Suren: Collect the gas in a container.
- Mrs Reuben: Yes, now I want you to design this and show me what you will do.
[After a discussion, the group leader calls for the teacher.]
- Mrs Reuben: Okay Trevern what's your plan ?
- Trevern: We think we need to have a bottle to store the CO₂. We can put the candle in the bottle...light it and then quickly put the match there.

The teacher had similar exchanges with other groups. In an interaction with another group, the learners explained to the teacher they would collect the gas evolved through combustion in a container. They would then place an ant in the container and seal the container. The learners suggested that if the trapped ant died it would prove that the gas produced would have to be carbon dioxide. The teacher questioned the learners about whether it would be the lack of oxygen or the trapped carbon dioxide that would kill the ant. The learners had a rethink about their plan and then proposed another container should be used as a control. A second ant would be placed in this container which would then be sealed. The learners would compare the times it took for the ants to die. The teacher made no comment regarding the killing of the ants. The teacher did not appear concerned about

the learners choosing to use an ant in the investigation, nor did she try to persuade them to change their plan.

By the end of the lesson all groups had formulated a plan to conduct the investigation. The learners were asked to bring their own material for the investigation. The teacher told the learners she would provide chemicals should they be required. In the next lesson, the groups conducted the investigation. The teachers observed what the learners were doing and intervened either when help was solicited or she felt the learners were making no progress. She asked guiding questions or offered advice. The researcher followed the progress of the Trevern's group who in the previous lesson had formulated a plan where they would place the burning candle in a bottle and then put a burning match into the bottle. It was noted that the match did not extinguish immediately.

The following exchange shows how the teacher asked the group to review their plan and consider another procedure to test for the presence of CO_2 .

Mrs Reuben: What do you think is the problem ?

Trevern: There is not enough CO_2

Mrs Reuben: Why not ?

Trevern : It is escaping.

Mrs Reuben: I want you to think of another way to show that the gas formed here is CO_2 . You can look at your notebooks.

[Trevern's group engages in a discussion. After a few minutes, Mrs Reuben returns to the group. The learners have a sketch of the apparatus for their investigation.]

Mrs Reuben: Okay this looks interesting. What do we have here ?

Trevern: We realized that limewater is another way to test for the CO_2 . The bottle can be filled with limewater. Then if you put the burning candle it will turn milky.

Mrs Reuben: Try it out.

[After visiting other groups, the teacher returns to Trevern's group. They are now carrying out the investigation. The learners prepare a solution of limewater in a bottle. A burning candle is made to stand in the bottle. The researcher observes that the limewater does not turn milky as they had expected] Mrs Reuben questioned them on this.

Mrs Reuben: Why do think there is no change to your limewater ?

Vijay: Maybe there is no carbon dioxide.

Mrs Reuben: Are you sure ?

[The teacher redirects the question to Trevern]

Mrs Reuben: What do you think Trevern ?

Trevern: I think the problem is not enough gas. Maybe some escapes.

Mrs Reuben: So what can you do ?

Trevern: Need to cover it up quickly.

[The group tried this. This time the limewater did turn milky.]

The teacher played a similar role when visiting other groups. For example, in the group where the learners were comparing the times for the ant to die in the container filled with carbon dioxide and the control container with the normal air, the teacher intervened and questioned the learners about the different sizes of the container. The learners came to realize that size would be a variable that would need to be controlled in order to make the test fair. At the end of the lesson, all groups handed in their worksheets.

4.4.3 Follow-up on lesson in Mrs Reuben's class

The teacher defined the investigation task for the learners. The learners planned and carried out the investigation. The teacher supported the learners by asking questions which encouraged the learners to reflect on and justify their plan. When groups were making no progress in conducting the investigation the teacher asked them to review their plan. The teacher also made suggestions which enabled the learners to reformulate their plan.

The investigation in Mrs Reubens class, although guided, represented a different scenario compared to the guided investigations in Mr Botha's and Mr Pillay's class as the class size was much bigger. There were forty one learners in the class. To accommodate the large number of learners, certain actions needed to be taken. Firstly, the class was moved outside for the lesson. The teacher explained this as follows:

The large class hasn't hindered me at all. I think investigation can still be done. It does make it uncomfortable in the lab so they were asked to do it outside. The cleaners were helpful in setting up the tables. The students need room to move around. In the lab it is dangerous to have overcrowding in the event of an accident. You would see that there are mainly seven pupils per group. (Mrs Reuben, interview)

Secondly, the learners were made to work in groups of six and seven whereas in Mr Botha's and Mr Pillay's class where a guided investigation was also being carried out, the learners were placed in smaller groups of four. Thirdly, the learners were asked to bring their own apparatus for the investigation. In offering a reason for this, the teacher explained that there was insufficient apparatus for all the groups, and also she felt that by learners bringing their own apparatus it would encourage some creativity in them. The

above investigation therefore illustrates a guided investigation carried out in a large class of learners with few resources.

4.5 MRS NAIDOO'S CLASS: A STRUCTURED INVESTIGATION ON DENSITY

In this case, a structured investigation is described. According to the classification framework for types of investigations, in a structured investigation, the teacher provides the question to be investigated together with a plan to be followed. The learners conduct the investigation and draw their conclusions based on the analysis of results. The investigation observed is described according to a narrative system of observation. Mrs Naidoo, the teacher of the class, chose not to have the lesson video- or audio-recorded. The researcher therefore observed and made written field-notes of what transpired in the classroom.

4.5.1 Contextual information

The researcher observed a Grade 9 class at a state secondary school. The school is co-educational and has about the same number of boys and girls. The school is situated in a densely populated suburb. The area is economically diverse, with both low and middle income people. The school has one science laboratory. The laboratory is inadequately resourced and has only the bare essentials. Much of the apparatus for this investigation had been borrowed from neighbouring schools.

At this school, the average class size was thirty six. The particular class observed had thirty eight learners. The teacher informed me that the Grade 9 classes were not graded, and every effort was made by the management to ensure a fair distribution of ability. She explained this was a decision taken in consultation with the entire staff, and was done to engender a good working relationship between class teachers. In this way, no teacher was privileged to have a 'good class,' while others teachers were 'saddled' with a poor class. The teacher had twelve years' experience teaching both Natural Science and Physical Science. She possessed a teaching diploma with Mathematics and Physical Science as her teaching subjects.

The lesson took place in a science laboratory. The room had six rows of wooden work benches. As the learners entered the laboratory, the teacher directed the learners to the work benches. At four benches, there were six learners each and at two benches there were seven learners each. It appeared these groupings for practical work had been followed from previous lessons. This was later confirmed by the teacher. The teacher also informed me that as the class was mixed ability, she ensured when forming the groups, that each group had at least two learners who were “bright”.

4.5.2 A description of what happened in Mrs Naidoo’s class

After the learners were seated at their places, the teacher explained to the class they were to do an investigation on the density of objects. The aim was to find out what floats and sinks in water. From this, the learners were to formulate a rule for floating and sinking. The teacher passed out a worksheet to each learner (Appendix I). The worksheet had a number of sub-headings dealing with the aim for the investigation, a list of apparatus and materials needed, the procedure to be followed, a results table with headings, and a question which related to the aim of the investigation.

The teacher told the class she would demonstrate to them the use of the triple beam balance and how to take readings from the measuring cylinder. All the learners gathered at her work bench situated at the front of the laboratory. They stood in a semi-circle formation. The teacher then chose a mass piece and showed the learners how to measure its mass with a triple beam balance. She added water into a measuring cylinder and explained to the learners how its volume should be read. She emphasized that volume readings needed to be taken at the bottom of the meniscus for water. She also mentioned certain precautions that needed to be adhered to. For example, she told them that the pan on the triple beam balance must be thoroughly cleaned before use.

After the demonstration the learners returned to their work benches. Mrs Naidoo asked two members from each group to collect the apparatus and materials from the front of the laboratory. The teacher told the learners they had forty minutes in which to complete the investigation. She emphasized they should read the instructions carefully before doing anything.

The groups began using the triple beam balance and measuring cylinder as instructed. The teacher went around the class checking to see that the learners were using the apparatus as she had instructed them to do so. She did this by observing learners, and also by asking them to show her how a reading was taken when she suspected it was inaccurate. In the following exchange the teacher observed that a group of learners had not been taking readings on the measuring cylinder at the bottom of the meniscus. She questioned them about this:

Mrs Naidoo: What did we say about the curvature of water ?

Mithi: It curves down.

Mrs Naidoo: Yes correct. We call this the meniscus and it is a concave meniscus. Now, what did I say about this ?

Sacchin: You need to take it on the line.

Mrs Naidoo: What line is this ?

Mitha: The top line.

[The teacher draws the curvature formed by water.]

Mrs Naidoo: Now look at this. Where do we take the reading ?

Logan: Here at the bottom.

Mrs Naidoo: Fine. Is that what you were doing ? Now go back and do all these volumes again.

[The teacher watched the learners take readings. Once she was convinced they were on the right track she moved to another group.]

At times when learners asked for help on taking readings, she again demonstrated to them the use of the apparatus. The teacher also questioned the learners on what they were trying to achieve by taking these measurements. A problem arose when learners were unable to measure the volume of the piece of wood using the displacement of water due to its flotation. The teacher suggested that learners push down on the piece of wood with their fingers until it is immersed in the water. She warned them that their fingers should barely touch the water when doing so. The groups seemed focused on getting through the worksheet in the allotted time. Although, there was very little conversation taking place in the room, exchanges such as the following were heard.

Jenny: What are we supposed to do next ?

Kuvan: Use the other object.

All groups completed the table by the end of the allotted time. The teacher went to each group and looked at their table of results. The teacher focused on the floating and

sinking of the objects and asked the groups to work out a rule which enabled one to determine whether an object will float or sink in water. She used guiding questions to elicit the rule from a group which could not work out the rule. This is illustrated as follows.

- Mrs Naidoo: We have three things. We have the mass, volume...what else ?
- Cindy: We found the density.
- Mrs Naidoo: Good so we have calculated the density. Now some object float and other sink. What do you think determines this ?
- Natalie: It must be the size.
- Mrs Naidoo: What do you mean by size ?
- Natalie: The mass.
- Mrs Naidoo: Now look at your table. Compare the glass and the piece of wood. Which has the bigger mass ?
- Learners: The wood.
- Mrs Naidoo: But did this sink ?
- Learners: No.
- Mrs Naidoo: So what makes an object sink ?
- Sita: The density.
- Mrs Naidoo: When will the object sink in water ? Remember water has a density of 1g/cm^3 . Please answer Natalie.
- Natalie: If the density is bigger.
- Mrs Naidoo: That's right.

The teacher then asked the learners to look at the board. On the board she had drawn the table from the worksheet with the last column on sinking and floating filled in. She then told the learners, "This is what you should have got. Okay, now explain to me what we have learnt about floating and sinking objects." She pointed to a learner who had raised her hand. She answered, "If an object has a higher density than one it will sink." The teacher nodded her head and then asked the learners to hand in their worksheets.

4.5.3 Follow-up on lesson in Mrs Naidoo's class

The teacher gave the learners a worksheet. On the worksheet, the aim of the investigation was stated. The learners were not asked to formulate a hypothesis. The worksheet also described in detail the procedure that needed to be followed. The learners therefore were not involved in the planning stage of the investigation. The learners conducted the investigation by following the instructions on the worksheet. The use of the apparatus had

been demonstrated to them. They entered their results in the table provided, and drew their own conclusions by studying the results on the table. This is clearly an example of a structured investigation.

After the investigation, a group of three learners from Mrs Naidoo's class were interviewed. In these interviews the learners were questioned about other types of investigations they had done. From their answers it was obvious that they only had exposure to structured investigations. The learners also indicated that while doing these investigations, the teacher was always on hand to make sure that they followed the instructions correctly. The following excerpt illustrated this:

Mrs Naidoo always gives us what to do on the worksheet. Then we do it on our own. Mrs Naidoo helps us while we do it so we don't make mistakes. This way we do the right thing. Sometimes she does it on her own and we watch it. (Learner interview)

This excerpt and the observation of the lesson reflect that although the learners had the opportunity to conduct the investigation on their own, the teacher at all times maintained a degree of control over what the learners did.

After the investigation, the teacher was questioned about why the investigation was structured. She referred to the lack of experience and confidence of learners in doing scientific investigations. The following excerpts from the interview illustrated this point:

I am hopeful that at some time in the future my learners will be able to do an investigation where they do their own plan. At this point in time it is something very new to them. They lack the necessary experience in how to go about planning.

They are still used to the old system. Not all schools...not all primary schools are doing the OBE...are doing OBE type teaching...they wait...learners wait until you tell them what to do. So, they are still waiting to be told what to do. They are not confident enough. (Mrs Naidoo, interview)

Compared to the open investigation and the guided investigations described, this investigation reflected greater teacher control and less learner autonomy.

4.6 SCIENCE INVESTIGATIONS FOR EXPOS

In the past, learners entered and submitted projects to science expos as a co-curricular activity. The learners did these projects at home. Generally, these projects were not assessed at school and so did not form part of the assessment for school science. In most

cases this was the only exposure learners had to scientific investigations. These investigations done for the science expo were open as the learners did them entirely on their own. However, as a result of the strong emphasis on investigations in the RNCS (Department of Education, 2002b), this type of investigation done for the expo can no longer be seen to be divorced from the school science curriculum. Such projects now form an integral assessment component of the new science curriculum.

Every year, learners enter science projects to the FFS Expo for Young Scientists held in August at the University of KwaZulu-Natal (Durban campus). It is sponsored by the FFS Refineries and coordinated by the science teacher organization, KASTE (KwaZulu-Natal Association for Science and Technology Education). It is well supported and draws over six hundred entries from throughout KwaZulu-Natal. The learners can chose to do a project related to any field of science.

The researcher visited the FFS Expo for Young Scientists in 2004, having done a preliminary visit in 2003. The researcher focused on projects submitted by Grade 9. Due to a large number of entries, only twenty learners were asked to fill in a questionnaire (Appendix D) and then these learners were interviewed. This sample of twenty learners was drawn so that it was representative of the different categories of entries that were submitted. Some of the projects were photographed (Appendix E) to illustrate the type of projects that learners do for expos. In this section, the researcher focussed on four typical projects that were submitted by learners and used these as exemplars of the nature of support that learners have in doing expo projects. These investigations which were classified as open were different to the open investigation that took place in Miss Essop's class, as the learners also had autonomy in deciding the topic they chose. The empirical evidence used to describe this support was collected from the questionnaires that these Grade 9 expo participants filled in and the interviews conducted with them. The science expo projects under consideration were titled as follow: Food aid for AIDS; Alternative materials for paper making; Tumeric magic and; Are you being milked for your milk ? Pseudonyms have been used to identify the different learners.

4.6.1 Food aid for AIDS

This project was an individual effort by a Grade 9 learner, Susan. The project was a

construction of a solar dryer used for drying fruit and vegetables. The investigation question which led to this construction was, “How can fruit and vegetables be preserved for AIDS sufferers in rural areas ?” In this construction metal foil was used to concentrate the sunlight onto an open container which had fruit and vegetable in it. The poster which accompanied the solar heater on display, described the plan, the data collected and the conclusion reached. In designing the construction, the learner did research by looking at books and visiting internet sites. She also did some testing of various materials for heat retention. The learner collected data to compare the effectiveness of the solar dryer to ordinary exposure to sun in preserving fruit and vegetables. The learner then used her data collected to conclude that the solar dryer was an effective way to preserve food and vegetables. The learner also displayed samples of fruit and vegetable to show the effectiveness of the device.

In the interview, the learner described the circumstances under which she entered her project and the type of support she received. The teacher gave the learner the entry forms and other relevant information which came from the organizers. The teacher encouraged the learner to participate in the expo however it was not compulsory for them to do so. The expo project was therefore not used for assessment in Natural Science. This link between learner participation in the expo and the encouragement from the teacher to participate is illustrated when Susan states in the interview that, “He (the teacher) did not force us to participate. He told us it would be a nice experience and that we would see lots of interesting projects at the expo”. Susan explained in the interview that the idea for the project stemmed from her personal interest in AIDS:

I was doing research for an English oral on the AIDS activist Nkosi Johnson. I was very touched by his plight. I also read about the dietary requirements for patients living with AIDS. I then realized that most AIDS sufferers in South Africa lived in rural areas and did not have access to fresh fruit and vegetables everyday. I then began looking into ways in which fruit and vegetables can be preserved. That’s how I got the idea of constructing a solar food drier. (Susan, interview)

The support that she received was primarily from family members at home. Susan explained that her elder sister helped with the design for the solar food drier, and her mother assisted with its construction:

After choosing what I wanted to do, I went to my teacher and asked if it will be okay. She said that I should go ahead with it. I read books on solar ovens and I also did a search on the internet of such things. My sister was a great help as she had done a solar oven at school. I incorporated all those ideas and came up with this design. My mother helped me

by buying the materials that I needed to construct it and she also assisted me with the construction of the food drier. (Susan, interview)

The teacher support was minimal. When asked about the help she received from the teacher, the learner responded as follows:

Before starting with it, I asked her if it was okay to do. She said it was fine. When it was completed I showed it to her. She said it was an original idea and that my poster was outstanding. (Susan, interview)

The above case therefore illustrated that the learner was responsible for choosing the topic, formulating the plan, collecting data and drawing a conclusion. This shows complete autonomy in the investigation. The support which she received was from family members.

4.6.2 Alternative materials for paper making

The objective of this project was to explore alternative materials for paper making. At the display, there were samples of paper made from straw, bugweed and palm. The poster stated the research question, described the plan, the procedure for paper making, the results collected and the conclusion reached. The research question was, “Which of straw, bugweed or palm is the best alternative to paper ?” In the plan the learner, Katherine explained the procedure for paper-making and how the different papers would be compared. The results showed the data collected in comparing the quality of the papers made of their materials in terms of strength and absorption. The conclusion reached was also stated. Although it was not compulsory for the learners to participate in the science expo, the teacher encouraged them to do so. This is exemplified when the learner stated in the interview that, “The teacher told us projects is what science is all about. You get to do real science. It can be anything that has fascinated you”.

The idea for the project emanated from the learner’s concerns about the environment. She was encouraged by her father who worked for SAPPI. Katherine explained this as follows:

My father works for Sappi and I have always been interested in paper making. I wanted to know if we could make paper with other things besides pine and it would be better for the environment. We use pines that are not indigenous to the country. (Katherine, interview)

When the learner was asked to explain how she came to know about the procedure for changing the straw, bugweed and palm leaves into paper, she indicated that her father offered her suggestions on how to do it. She also explained that she assessed information from the internet on papermaking:

I did a lot of research on my own on how they made the paper. I looked on the internet on how they made paper and my dad helped me simplify the process of pulping the paper. The real factory they use pressure cookers and much bigger machines. (Katherine, interview)

Katherine mentioned that the teacher had commented on the project before it was displayed at the expo. These comments were all positive and so there was no need to make any changes to the project.

This expo project like the previous project showed the learner having much autonomy over all stages of the investigation. The initial idea for the project and the investigation question was the learner's. The support which she received here was more extensive as her father had expert knowledge of paper making as this related to his job. As with the previous expo project, the teacher involvement was minimal.

4.6.3 Indicators of maize silage quality

This project was a joint effort by two learners, Jack and Piet, and investigated the factors which influence the quality of maize silage. They both live on a farm and their fathers are farmers. Silage is food for the cows in winter and so the quality of the silage is important. Their display was made up of a poster which had the research question, a description of the plan, the results collected, and the conclusion made. There were also samples of silage collected during the investigation. The research question was, "What factors affect the quality of maize silage." In the plan the learners described four samples of the silage which were taken from different locations in the pit and the tests which were conducted on the silage. The tests included a smell test and a chemical test where the pH was taken. The learners indicated that they chose the project as they felt it was very relevant to their present circumstances. Piet explained this as follows:

Both of our dads are farmers. We just thought that we may as well do a project on silage. We knew that there were lots of different pits to put silage into. We wanted to know how to make the best silage. Jack's brother who is at Cedara also thought that we should do something in silage. Also, at home we have lots of information on it. (Piet, interview)

The information that was needed to conduct the test on the silage was obtained primarily from the internet. Jack's brother who is a student at an agricultural college, was always on hand to render assistance whenever it was necessary. In the following excerpt from the interview, the learners explain how the testing of the silage requires specialized scientific knowledge:

Jack: Well, we wanted to do as many tests as we could. The first one we decided to do was smell because you can smell if something is off or sweet. Sample one had a sweet hay-like smell. That was because it had been hot. Sample two had a pleasant lactic acid smell because it is moist but not too moist. Sample three which is on the side had a strong offensive, rancid smell. Sample four because it was so slushy and beginning to rot, had a rotten smell. pH is important because it shows you what bacteria you have got in your pit. You get your bacteria that convert sugar to starches and you get your bacteria that ferment it. You want that bacteria to die off at a certain stage. When the oxygen is finished they must die off. The pH level shows you that they have died off and they have fermented at the right stage.

Interviewer: How did you learn about all these tests ?

Piet: We did lot of research using the internet. We got into sites on agricultural science. Jack's brother is studying at Cedara (agricultural college). He was always available to help. He gave us good advice on the type of tests that could be used on the silage. He allowed us to use his books on agriculture.

The learner when asked about the involvement of the teacher in their project work, answered that he guided them when they approached him for help. The teacher helped them become more focussed on the problem they were investigating. The teacher also gave them advice about the tests they were planning to do on the silage. The following response from Piet illustrates this:

He just guided us. We went to him from time to time. We wanted to cover all the aspects maize...like planting, crop spraying, preparation of the land...so we had a general idea and the teacher took us down a definite path. Also, we were a bit confused on what test we should perform on the silage. The teacher helped us a little bit on what test we could do. (Piet, interview)

This project showed how the first hand experience and knowledge of a topic led to an investigation question. Both learners worked on a farm and so the topic of silage was something that interested them. They could also draw knowledge from their fathers who were both farmers and a brother who was studying agricultural science. The teacher support was also evident as the teacher guided them when they needed help.

4.6.4 Are you being milked for your milk ?

In this project the learner, Mishka investigated the relationship between the cost and the quality of full cream pasteurised cow's milk. At the display she had containers representing the six brands of milk that were used in the investigation. There was also a poster which included the research question, the plan, results in the form of table and graphs, and the conclusion made. The research question was, "Is the cost of the milk related to its quality.

In the plan Mishka described how she had used six samples of different brands of milk. Through a chemical analysis she compared the composition of each brand of milk. Mishka explained in the interview that the idea for the project was her own and came from her observation that different milk brands had a different pricing:

Milk is used by millions of people everyday. The prices of milk vary but I wanted to know if quality also varied. The idea was to determine whether there was a relationship between cost and quality of milk. So many different brands of milk had different prices. (Mishka, interview)

The learner received substantial out-of-school support on the project. The scientific knowledge of the chemical tests that would be conducted on the different samples of milk was acquired by accessing the internet and reading encyclopaedias and journals on biochemistry. The following excerpt from the interview describes the extent of support that the learner received from a laboratory assistant at Durban Metro Laboratories in conducting these tests:

My father is a doctor and he works for the Ethekwini municipality and he introduced me to a friend who is a lab assistant at the Durban Metro Laboratories. She gave me a booklet telling me about the different tests and how to go about doing them. She also told me how to use certain pieces of equipment for the tests. (Mishka, interview)

While doing the project the Mishka did not go to the teacher for any help. The learner merely made a suggestion about the poster for the project. The learner described this as follows:

The teacher told us at the beginning that this was our project. She looked at the chart for the project after I had done it. She wanted all the information on the chart, so I changed it. (Mishka, interview)

The learner once again had autonomy over all stages of the investigation. The idea for the project was also her own. She received much support in conducting the tests for the investigation from an expert in the field. There was little support from the teacher.

4.7 COMMENTARY

In this chapter, a range of different types of investigations both for school and a science expo have been described. The investigations were classified according to the degree of autonomy learners had over the investigation and the extent of teacher control. Five investigations at school were described. The investigation in Miss Essop's class was

typical of an open investigation where learners has autonomy over all investigation stages. The investigations in Mr Botha's , Mr Pillay's and Mrs Reuben's classes were described as guided as the teacher in these cases provided the investigation question. The investigation in Mrs Naidoo's class was structured and reflected less learner autonomy than the other two as here the teacher also provided the plan to be followed. This illustrates a range of different types of investigations, providing different levels of autonomy which actually take place in schools.

Four science expo projects were described. The four cases reflected that learners have complete autonomy over the investigation stages when doing expo projects. The initial idea for the project came from the learner and appeared to be stimulated by a certain interest that the learner had in a particular field of science. The support was derived mainly from family members. This out-of- school support learners received from their parents was also highlighted in a study conducted by Syer and Shore (2001) which showed that high school students who participated in a science fair, used their parents as a resource for a wide variety of activities, including help with the idea, editing, connections to labs or mentors, purchasing materials, setting up the project, transportation, advice, designing the experiment or display board, gathering information, and creating graphs and charts. In doing the expo projects that were described, learners received only limited support from their teachers. Once learners decided what they wanted to do, they sought the opinion of the teacher on it. The teacher made suggestions when necessary. After the projects had been done, the teachers commented on them, and where necessary changes were made. Two points stand out which make expo projects different from classroom investigations. Firstly, where teacher support was provided, it was limited to making suggestions. The learners were in complete control of the investigations. Secondly, alternative resources to the teacher were consulted, in particular the internet and help from family members.

CHAPTER 5

ANALYSIS AND INTERPRETATION OF RESULTS

The previous chapter provided a detailed description of five investigations at school. These investigations were classified as either open, guided or structured and were described in terms of the autonomy learners had and the extent and nature of teacher support. Science expo projects were used to describe cases where learners in addition to having autonomy in all stages of the investigation also chose their own topics. The fine-grained descriptions of these investigations have therefore illustrated the different degrees of autonomy learners experience in doing investigations.

This chapter presents the findings of questionnaires administered to and interviews conducted with a larger group of teachers and learners. It presents the findings which have emerged as a result of the analysis of data collected from questionnaires and interviews conducted with teachers and learners. Sections 5.1 to 5.4 are devoted to each of the four research questions. In each case, an assertion is made in addressing the question and then supporting and counter-evidence is provided and discussed. The research questions were addressed by analyzing and interpreting the data collected from the teacher questionnaires filled in by 55 teachers in 2004, and the 126 learner questionnaires. These learner questionnaires were administered at the five schools where investigations were observed. The data from the learner science expo questionnaires were excluded from this analysis as it represented an extreme case of learner autonomy. The teacher sample although not representative of the population does represent teachers who actually carried out investigations. In addition to the teacher questionnaire, excerpts from the teacher interviews were quoted in order to elaborate and clarify these findings. Data collected from the pilot questionnaires were not generally included in the statistical and descriptive analysis. However, where respondents made comments which were significant, these have been used.

The sample is made up of teachers from both state and independent schools, small schools and large schools, experienced and inexperienced teachers. The majority of the teachers (67%) who responded to the questionnaire had more than ten years' experience teaching science (Figure 5.1).

In general teachers were confident in their ability to teach science according to the new curriculum (80% indicated they felt confident) and in particular investigations (78% indicated they felt confident).

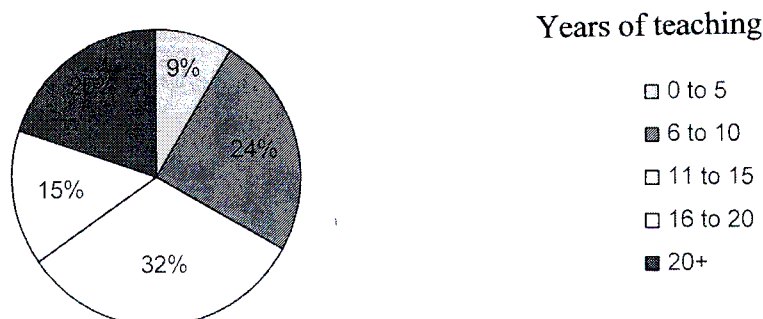


Figure 5.1 Percentage of respondents for each category of teaching experience

Most teachers had attended some form of training for the new science curriculum. A small number of teachers (9%) had not attended any OBE workshops but others had attended from one to ten workshops (Table 5.1).

Table 5.1 Frequency with which teachers attended OBE workshops

Number of workshops attended	Frequency	Percent (%)
No workshops attended	5	9
1 to 5 workshops attended	38	69
6 to 10 workshops attended	12	22

Table 5.2 Responses to the place where learners do the investigations

The place where learners do most of the work	Frequency	Percent (%)
Mostly in school during science lessons	24	43,6
Mostly at school after hours	4	7,3
About equally at school and at home	20	36,4
Mostly at home	7	12,7

The teachers were mainly from well resourced schools, as about 78% indicated their schools had resources for science teaching. It is interesting to note that although the schools were well resourced a significant number of investigations were done at home or partly at home (Table 5.2)

Of the four investigation types carried out, 35 % were explorations, 30% explanations, 23 % comparisons and 12% constructions. This shows that most investigations are explorations and explanations. Although there is a significant number of comparisons, the number of constructions is relatively small.

The average class size in Grade 9 at schools who responded to the questionnaire was 31 learners. A small number of teachers (about 13%) indicated that the average class size in Grade 9 at their school exceed 40 learners (Figure 5.2).

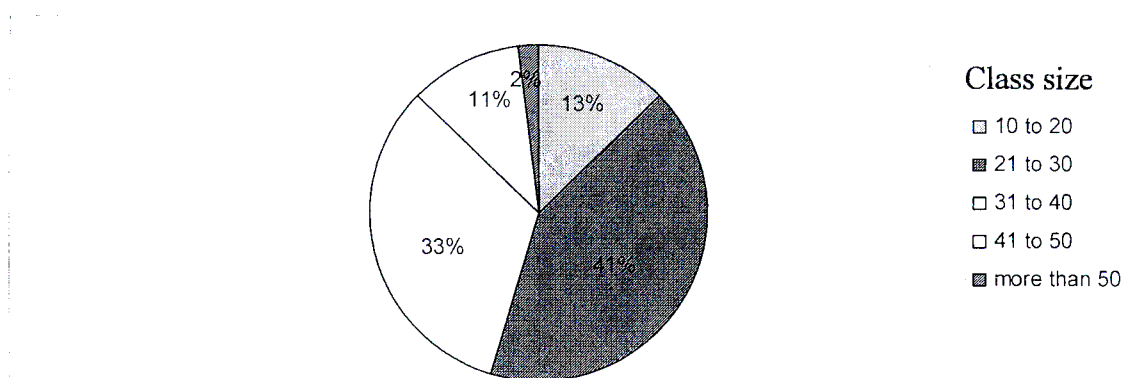


Figure 5.2 Percentage of respondents for each category of class size

5.1 LEARNER AUTONOMY IN SCIENTIFIC INVESTIGATIONS

The new outcomes-based curriculum in South Africa encourages a learner-centred approach to education. Research Question One explores this learner-centredness by considering how much autonomy learners have in doing scientific investigations. The framework described in Section 2.8.3 was used to analyze learner autonomy. This framework focused on the four stages of formulating the question, planning the investigation, collecting data and drawing a conclusion. Research Question One was, “What are the degrees of learner autonomy in the implementation of scientific investigations?” The following assertion was generated with regard to this question:

Assertion One: Learners have varying degrees of autonomy across the different stages of scientific investigations. In general, autonomy increases from little autonomy at the start when formulating the investigation questions to significant autonomy when drawing conclusions.

This general assertion was constructed from a number of sub-assertions which are individually discussed below.

5.1.1 Choosing the question

Sub-assertion 1a: Learners have limited autonomy in choosing the investigation questions.

In general teachers were confident in their ability to teach science according to the new curriculum (80% indicated they felt confidence) and in particular investigations (78% indicated they felt confidence).

Table 5.3 Responses to questions dealing with autonomy in choosing investigation questions

Summary table	Item	Responses n = 55		
		Never or seldom(%)	Sometimes (%)	Often or always(%)
Item 16	I give the question	14,5	25,5	60,0
Item 17	Learners decide on variables	45,5	40,0	14,5
Item 18	Learners formulate question	54,5	45,5	0,0

From Table 5.3, in 60% of the cases, teachers often or always give learners the question. Only 15% of the teachers never or seldom give the question, which implies that they allow the learners to determine the question. In addition, the analysis of the questionnaire given to learners shows that about 70% of the learners reported that they are either “often” or “always” given the investigation questions by the teacher (Table 5.4). These findings reflect that to a large extent, teachers give learners the investigation questions.

Table 5.4 Frequency with which learners receive the investigation question (item 9, learner questionnaire)

The teacher gives us the investigation question	Number of learners (N=126)	Percent (%)
Never or seldom	10	7,9
Sometimes	27	21,4
Often or always	89	70,7

In supporting this assertion, eight of the ten teachers who were interviewed indicated that they always gave the learners the investigation questions. Two main reasons were forwarded for this. Firstly, they believed learners in Grade 9 have limited knowledge of variables and therefore were unable to construct useful questions. Mrs Naidoo, a teacher whose lesson on a structured investigation was described in Section 4.5 explained that, “At the Grade 9 level, learners are still coming to grips with such things as independent, dependent and extraneous variables. To make up investigation questions is therefore a little beyond them.” Another teacher referred to a classroom experience where he had given learners a project to do on an investigation of their choice:

I decided to give my learners an investigation as a project. I told them they would be assessed and the best entries would be entered for the science expo. Although we had done investigations in class where I told them what to do, the efforts I got were disappointing. The investigation question was poorly phrased and lacked focus. The learners showed confusion about variables. Consequently, the experimental design was flawed. So as you can see, because the question was problematic, the entire investigation suffered. (Teacher 1 interview)

Secondly, remarks by five of the teachers interviewed and comments made by seven teachers on the questionnaire raised concerns about whether the required content would be addressed if learners posed their own investigation questions. The following responses attest to this:

I have tried this sometimes. If I give them a certain scope and ask them okay ask a question on this, I find that their questions are not related to the concepts I want to teach. It is unrelated to my syllabus. (Teacher 2 interview)

Giving learners complete autonomy is a pipedream, while teachers are required to teach the syllabus in class. When learners do their own investigation they often do things which have no learning value and are completely unrelated to the work that needs to be covered. (Teacher comment in questionnaire)

While the majority of teachers who were interviewed and who responded to the questionnaire held the above views, some had different ideas. One idea which was repeated by a few of the respondents and interviewees dealt with ownership. Miss Essop who

“often” asked learners to formulate their own questions in the investigation, believed that learner-generated questioning placed the learners in control of their learning. She also expressed the view that learners gain a sense of ownership, and this is motivational and inspires them to complete the task. She explained this as follows:

I would introduce them to a section and explain the scientific language related to it ... I mean the terms and so on. In groups the learners discuss what could possibly interest them in this section. They come up with the questions. Most times the questions are good and relate to what I want them to learn and the apparatus we have allows them to investigate it. Through this approach I feel they are in charge of their learning. They decide what they want to make of it. They are prepared to persevere even if there are problems. It definitely motivates because it is their own. (Miss Essop, interview)

The evidence from the teacher and learner questionnaires, and the interviews which were conducted with the teachers was consistent with the assertion that the investigation question is mostly given to the learners by the teacher. The main reasons for this strategy appeared to be the lack of confidence in the ability of the learner to construct questions, and the need to stick to the curriculum.

5.1.2 Planning the investigation

Sub-assertion 1b: The learners have limited autonomy in the planning stage of the investigation. When learners are given the opportunity to plan investigations, these are simple investigations which are similar to ones they have already experienced.

The focus of the planning stage is on generating the procedure for the investigation. In this stage of the investigation, the learners identify the materials to be used, verify the type of variables involved (control, independent, dependent), and determine how the variables can be manipulated, controlled, and measured (Chin, 2003). Items 19, 21 and 23 of the teacher questionnaire gathered data on the degree of autonomy learners have in planning investigations.

From Table 5.5 it appears that learners on more occasions than not are given a plan to follow. In this plan learners are told what data to follow, the apparatus to use and step-by-step instructions.

Table 5.5 Responses to questions dealing with autonomy in planning investigations

Summary table	Item	Responses n = 55		
		Never or seldom(%)	Sometimes (%)	Often or always(%)
Item 19	Learners decide on the method to use	41,8	30,9	27,3
Item 21	Learners decide what apparatus to use	38,1	34,5	27,3
Item 23	Learners follow step-by-step instructions	20	52,7	27,3

This is supported by data from the learner questionnaire where 54% of the learners indicated that they either “never” or “seldom” decide what method to follow (Table 5.6).

Table 5.6 Frequency with which learners can decide what method to follow (item 13, learner questionnaire)

The learners decide what method to follow	Number of learners (N=126)	Percent (%)
Never or seldom	68	54,0
Sometimes	38	30,0
Often or always	20	16,0

A factor common to the responses of seven of the ten teachers who were interviewed in explaining why learners are not being given the opportunity to plan the investigation, was that the learners lack the necessary experience and expertise in investigative work. This is reflected in the following comment made by a teacher:

I am hopeful that at some time in the future my learners will be able to do an investigation where they do their own plan. At this point in time it is something very new to them. They lack the necessary experience in how to go about planning. (Teacher 1 interview)

This lack of readiness would appear to be as a result of a lack of experience in doing investigations rather than a lack of capacity to do an investigation. The following comment made by a teacher on the questionnaire expresses this point of view:

Although the curriculum specifies that learners should be given more responsibility in doing things, I believe they still need to be told what to do. They need a lot of direction. It is not that I don't have confidence in their ability, but they lack the practice of doing it. It is unreasonable to suddenly spring it upon learners that they must design an investigation on their own. They need guidelines on what is required. For example, they should be given a list of apparatus they can use, and then they can plan around that. (Teacher questionnaire)

The interviews with the teachers have also suggested that when learners are asked to plan an investigation, these are simple fair testing investigations which are similar to the ones

they have already experienced. These fair testing investigations were described in the classification of investigation types in section 2.3. The following excerpts from interviews with teachers are indicative of this.

My learners are quite capable of strategizing how to do simple, basic investigations. Here they would investigate a relationship, say between two things. When the investigation becomes too complex, they do struggle a lot. (Teacher 2 interview)

From what I have seen so far, definitely they are capable of doing a basic cause-effect investigation on their own. They can identify variables such as dependent and independent variables. Sometimes, however, they ignore the control variables. I have to ask them if it really is a fair test. (Teacher 3 interview)

For some investigations, learners are given a bigger role to play in the planning. These would be investigations where they have done something similar in the past. If it is something that is more involved and where they have to consider more control variables, they are given guidelines to follow. (Teacher 4 interview)

The above teacher responses would suggest that the number of variables which need to be controlled is an important factor in deciding whether learners are asked to plan the investigation. This was the case in Miss Essops's where an investigative lesson was observed (section 4.1.2). Here the learners, after formulating a hypothesis, planned their investigation. The investigations they planned involved the manipulation of one variable and the measurement of another variable. These investigations were all simple fair tests which did not entail the control of many variables.

The interviews with learners also showed that they have few opportunities to plan investigations. The following excerpts illustrate this:

Our teacher mainly gives us the worksheet where we follow a procedure on it. He would tell us okay step do this step do that. (Learner interview).

We often work in groups and follow the directions from the teacher. Sometimes he writes this on the board. But most of the time he gives us a sheet of paper. He tells don't start until you know what to do. So we spend time reading the instructions. (Learner interview)

Hardly ever do we decide what we want to do. The teacher tells us almost all the time. There is a worksheet with instructions to follow. We follow this. (Learner interview)

This evidence supports the assertion that learners are given limited autonomy in planning the investigations. The opportunities to plan the investigation are restricted to simple investigations which are similar to something they have already experienced.

Data collected from the teacher questionnaire showed however, that 16% of the respondents "often or always" allow the learners to decide what method to follow. A

similar percentage of learners chose this option on their questionnaire. The following comments made by two teachers would suggest learners can be given the opportunity to decide what method to follow once they have gained sufficient experience and expertise at scientific investigations:

Yes I eventually do allow my pupils to plan their investigations. But this is a gradual process. I start off at the beginning of the year by showing and explaining the nuts and bolts of investigations. I give instructions they should follow. They do a number of these investigations. Once I realize they are ready I let them design an investigation. (Teacher 4 interview)

It is about reaching a stage when they are ready. Otherwise it is a muck up to let them decide a procedure. Once they come to terms with it, they are given many chances to plan the investigation. (Teacher 5 interview)

It would therefore appear with greater exposure to investigations in the classroom learners will gradually be given more opportunity to plan investigations on their own.

5.1.3 Collecting data

Sub-assertion 1c: Often, learners have a large degree of autonomy in collecting data

The data collected through the teacher questionnaire show that once learners have been given the question and plan to follow, they have a significant degree of autonomy in collecting data. Table 5.7 which summarises the responses to autonomy in conducting the investigations, shows that about half the teachers allow learners to conduct investigations on their own.

Table 5.7 Responses to questions dealing with autonomy in conducting investigations

Summary table	Item	Responses n = 55		
		Never or seldom (%)	Sometimes (%)	Often or always (%)
Item 22	Learners conduct investigation on their own	21,8	30,9	47,3
Item 24	I do investigations and learners observe	58,2	21,8	20,0

The above finding was supported by the analysis of the learner questionnaire where about 50% of the learners indicated they either “often” or “always” conducted the investigation on their own (Table 5.8).

Table 5.8 Frequency with which learners conduct the investigation on their own (item 17, learner questionnaire)

We conduct the investigation on our own without being told by the teacher what to do	Number of learners (N=126)	Percent (%)
Never or seldom	27	21,4
Sometimes	35	27,8
Often or always	64	50,8

In addition, in all five investigations observed and described in Chapter 4, the learners worked in groups and collected data on their own. In Miss Essop's class, each group controlled a factor such as coughing and then measured the pulse rate. The learners recorded the data on a table. The learners in Mr Botha's class in investigating the factors affecting the resistance in a circuit, connected the circuit, took ammeter readings, and tabulated their results. Similarly, the learners in Mr Pillay's class investigated the relationship between current strength and potential difference by connecting a circuit, and taking ammeter and voltmeter readings. The readings were recorded on a table. The learners in Mrs Reuben's class collected data on their own to show that one of the products of combustion was carbon dioxide. In Mrs Naidoo's class, the learners used the triple beam balance and a measuring cylinder to determine the mass and the volume of the objects respectively, which they recorded on a table. These investigations illustrated the autonomy which learners had in manipulating apparatus and collecting data. The teacher played a supportive role in guiding the learners through this stage.

Some idea of the value attributed to giving learners autonomy at this stage was given by two teachers who commented that science is an activity so learners ought to be actively involved in the learning of science. Their comments were:

The nature of science means that learners must do and be active. (Miss Essop, interview)

Science is not an absorbing subject. By nature it is practical and activity-based. Theories are only good if they can be proved by experimentation. Learners only learn science by doing. (Mr Botha, interview)

It would appear that when investigations are done in class, teachers are quite prepared to give learners the opportunity to manipulate the apparatus and collect data because of their beliefs that learners should be active when doing science.

5.1.4 Evaluating data and communicating findings

Sub-assertion 1d: Learners are often given responsibility for evaluating data and drawing conclusions

In general the learners appear to have substantial autonomy in evaluating the data and drawing conclusions after the data have been collected. From Table 5.9 it can be seen that in almost 70% of the cases the teachers reported that learners draw their own conclusions.

Table 5.9 Responses to questions dealing with autonomy in drawing conclusions

Summary Table	Items	Responses n = 55		
		Never or seldom (%)	Sometimes (%)	Often or always (%)
Item 25	Learners make own conclusions	9,1	23,6	67,3
Item 26	I tell the learners what the conclusions are	72,7	18,2	9,1

This finding is supported by data from the learner questionnaire where almost 60% of the learners responded that they often or always made their own conclusions in the investigations without the teacher's help (Table 5.10)

Table 5.10 Frequency with which learners make their own conclusions from the results (item 25, learner questionnaire)

We make our own conclusions from the results without the teacher's help	Number of learners (N=126)	Percent (%)
Never or seldom	12	9,5
Sometimes	39	31,0
Often or always	75	59,5

In all five investigations which were observed the learners were given the autonomy to draw their own conclusions. The learners in Miss Essop's class by analyzing the data collected on the pulse rate, drew a conclusion relating to how the factor investigated affected the pulse rate. The learners in Mr Botha's class formulated their own conclusion concerning the factors which affect the resistance in a circuit. After collecting and tabulating data, the learners in Mr Pillay's class arrived at relationship between current strength and potential difference. In Mrs Reuben's class the learners concluded that one of

the products of combustion was carbon dioxide. For the investigation in Mrs Naidoo's class, the learners drew a conclusion about which objects float in water.

Even where the teacher demonstrates the investigation to the learners, it appears that in some cases, learners are still given the opportunity to draw their own conclusions. In analyzing the responses to questions 24 and 25 of the questionnaire it is noted that in 5 cases where the teacher demonstrated the investigation, the learners were allowed to draw their own conclusions. A teacher interviewed stated that due to a lack of apparatus at his school he often demonstrated the experiment, but he always gave learners the opportunity once all the data had been collected to analyze it and draw the conclusions:

Due to a lack of resources at this school, our learners seldom do them (investigations) on their own. If I do the investigations, they still learn the science by giving the conclusions once they have seen a pattern in the results. (Teacher 6 interview)

From the data collected it can be inferred that in most science classes where investigations are taking place, the learners are given the opportunity to draw their own conclusions in the investigation rather than being told what the conclusions are.

5.1.5 Commentary

The evidence presented in addressing Research Question One points to the fact that most investigations fall into the category of structured. In such an investigation, the learners are presented with a question to which they do not know the results, but they are given a procedure to follow to collect data and draw the conclusions.

In this study learners were seldom given the opportunity to formulate their own questions in doing scientific investigations. This finding is similar to that of a study conducted by Bradley (2005) with a sample of Australian junior secondary science students, where low levels of student-initiated activity were found in science practical work. The reasons given by the Australian study why learners were not allowed to formulate their questions are consistent with the explanations offered by the teachers surveyed in the present study, namely, the limited knowledge that learners possessed about variables, and secondly the concern about whether the content specified by the curriculum would be covered. This issue about variables was also evident in research conducted by Gott and Duggan (1995). This research yielded the finding that students find investigations dealing with multiple and continuous variables more difficult than those involving single categoric variables.

Rop (2002) expands on the second reason by explaining that:

Although an original or inquiry question asked by an engaged student might be an indicator of student scientific thinking and understanding, it nonetheless creates an interruption to the normal flow of things. Such an interruption may threaten the teacher's feeling of control of classroom events and therefore his ability to cover the content of the curriculum. (p. 718)

The analysis of the literature has shown there is much merit in asking learners to generate their own question for an investigation. Chin, Brown and Bruce (2002) hold the view that questioning lies at the heart of scientific inquiry and meaningful learning. Allowing learners to generate their own investigation questions stimulates curiosity and encourages thinking about relationships among questions, tests, evidence, and conclusions (Keys, 1998). Another finding of the data analysis is that learners have limited autonomy in planning the investigation. This finding is similar to that of the survey of maths and science education in the United States conducted in 2000 by Horizon Inc. for the NSF which showed that only 12% of teachers indicated students were asked to design or implement their own investigation (Smith, Banilower, McMahon & Weiss, 2002). Furthermore, a finding of the AKSIS project conducted in the United Kingdom, teachers found that students experienced particular difficulty in planning investigations (Watson, Goldsworthy & Wood-Robinson, 1998).

From the current study it appears that the familiarity of the investigation to the learners and whether a similar investigation was done in class, are important factors in determining the amount of autonomy that learners receive through the planning stage of the investigation. Welch et al. (1981) observe that a very high percentage of students (sometimes more than 80%) at each age level (nine-, thirteen-, and seventeen-year-olds) can correctly design procedures for performing certain familiar experimental tests, but far fewer students (sometimes less than 25%) can do this for other less familiar experimental tests. Sund and Trowbridge (1973) believe this situation is understandable and explains that if students have not had experience in learning through inquiry, their lessons should be considerably structured. After they have gained some experience in carrying out an investigation, the structure should be lessened.

While restricted in the question generating and planning stages, it would appear that learners are given much more autonomy in the remaining stages of manipulating apparatus, generating data and drawing conclusions.

5.2 BENEFITS OF LEARNERS DOING THEIR OWN INVESTIGATIONS

The role of scientific investigations in the school science curriculum was explored earlier. The RNCS (Department of Education, 2002b) states that scientific investigations which are described in Learning Outcome One must feature prominently in the Natural Science curriculum. This leads to the question as to whether there are benefits of learners doing their own investigations as perceived by teachers and learners. This is expressed in Research Question Two which asks, “What are the perceived benefits of learners doing their own scientific investigations ?” The perceived benefits are stated in Assertion Two.

Assertion Two: When learners are actively involved in doing their own investigations teachers and learners believe that it has a positive impact on their learning of science. The three potential benefits reported, are that it is motivational, it facilitates conceptual understanding, and leads to the development of scientific skills.

For the purposes of this section, the phrase “doing their own investigations” used in the above assertion refers to learners having responsibility for at least collecting the data and drawing a conclusion i.e. two stages.

5.2.1 Interest in science

Sub-assertion 2a: When learners do their own investigations they become motivated and show a keener interest in science

Evidence from the data which is summarized in Table 5.11 shows that about 80% of the teachers who responded to the questionnaire “agree” with the statement that “when learners do their own investigations, they develop more of an interest in science than when they do investigations set by the teacher”. In interpreting this data against assertion one, which refers to the autonomy learners have in the stages of the investigations, one may infer that this interest in science is considered to be derived when learners are given autonomy in manipulating apparatus to collect data, and then drawing conclusions.

Table 5.11 Teacher belief that investigations develop in learners an interest in science (item 36, teacher questionnaire)

When learners do their own investigations, they develop more of an interest in science than when they do investigations set by the teacher	Number of teachers (N=55)	Percent (%)
Disagree	4	7,3
Unsure	6	10,9
Agree	45	81,8

In supporting this data, a teacher explained that learners derive much enjoyment from investigations as it is a practical activity as opposed to a theoretical lesson in science where they are not involved in activities such as manipulating apparatus and collecting data.

They enjoy...I don't find it difficult to teach them. They are very motivated...they enjoy the lesson. If it's practical then it's 100%. If it's a bit of a theory lesson and factual then it is not as exciting as the other one. (Teacher 5 interview)

The following response by a teacher again refers to the interest learners show in science when given the autonomy in collecting their own data and drawing their own conclusions:

I have noticed that an investigation is always something that my learners look forward to. I think it is because this is something that they have to do mostly on their own. They are now placed in a position where they can decide how good or poor their product will be. They also enjoy working in a group so that the work may be shared. (Teacher 4 interview)

In supporting this teacher perception that investigative work does make the learning of science more interesting, Table 5.12 shows that 65% of the learners who filled in the questionnaire hold the view that they "often" or "always" find science more interesting when they do their own investigations.

Table 5.12 Learner belief that science becomes more interesting by doing investigations (item 34, learner questionnaire)

Do you find science more interesting when doing your own investigation than one set by your teacher ?	Number of learners (N=126)	Percent (%)
Never or seldom	9	7,1
Sometimes	35	27,9
Often or always	82	65,0

These responses were explored further at the interviews with the learners. When asked to elaborate upon how their autonomy in doing investigations makes science more interesting, the learners had the following to say:

Science used to be a real drag last year. It was boring watching the teacher do the experiments and stuff. This year I find science more interesting because we can now do things on our own. The experiments, especially the electricity stuff is really good. I enjoy connecting circuits and playing around with light bulbs and seeing how the brightness changes. (Learner interview)

Science becomes more exciting. We now work in groups to do our investigations. The teacher allowed us to do the chemistry experiments. We were able to test for acids and bases. This was lots of fun because we brought stuff from home. We did it ourselves rather than the teacher telling us about these things. (Learner interview)

The data collected provide convincing evidence that the majority of the participants believe that by doing investigations themselves learners are motivated.

5.2.2 Conceptual understanding

Sub-assertion 2b: When learners do their own investigations, teachers and learners believe that it facilitates the understanding of science concepts.

Evidence in support of this assertion is shown in Table 5.13 where it is reflected that about 65% of the teachers who responded to the teacher questionnaire of 2004 were of the view that ‘when learners do their own investigations, it helps them develop a better understanding of science concepts than following a teacher’s step-by-step instructions.’

Table 5.13 Teacher belief that learners develop a better understanding of science concepts by doing investigations (item 38, teacher questionnaire)

When learners do their own investigations, it helps them develop a better understanding of science concepts than following a teacher’s step-by-step instructions	Number of teachers (N=55)	Percent (%)
Disagree	7	12,7
Unsure	12	21,8
Agree	36	65,5

When teachers in the interviews were asked to explain the benefits of learners doing their own investigations in terms of conceptual understanding, they indicated that learners were able to grasp the concepts more easily and that this conceptual understanding was more pervasive and general and not specific to a particular situation. This perception is evident in the following excerpts from the teacher interviews:

I think the learners definitely get a better understanding. And, I think it breaks away from rote kind of learning. The learners get a better idea of the science concepts because they are

actually dealing with them rather than having to learn them off by heart like parrots.
(Teacher interview 3)

I think that the only way a child learns properly and internalizes is if they learn it themselves rather than me just churning out the information and they giving me back the information. If they have had practice in doing something related to the work, I definitely think that they...they learn the work forever. And so therefore although I taught a fair amount of content-based chalk and talk, I try to make the lessons hands-on as possible.
(Teacher interview 4)

In Section 4.3 a guided investigation was described in Mr Pillay's lower set "E" class. In the interview he explained how the weaker learners in particular, by doing the investigations, came to understand their work better:

For the weaker groups I definitely think that with this system...*(OBE)* the content makes sense to them because it's live for them in every lesson or almost every lesson. I think they are benefiting on the learning ability...they are doing better. They feel that they can achieve the work...it is not too much for my brain. So I think they gain from the point of view of the content it comes easier to them. The top ones gain because of the pleasure they gain from their learning. So those gains are at a totally different level. (Mr Pillay, interview)

In supporting this sub-assertion, about 50% of the learners who responded to the questionnaire indicated they either "often" or "always" understood their work better when they did their own investigations (Table 5.14). In addition, about 41% of the learner indicated that they "sometimes" understood their work better.

Table 5.14 Learner belief on understanding their work better by doing investigations (item 33, learner questionnaire)

Do you understand your work better by doing your own investigations ?	Number learners (N=126)	Percent (%)
Never or seldom	10	7,9
Sometimes	52	41,3
Often or always	64	50,8

This question was followed up in the interviews with the learners. In the following excerpts of the learner interviews, the learners explained how by becoming involved in the investigation, they developed a better understanding of their work. Furthermore as shown in the second excerpt below, this involvement can stimulate further questions:

Learning becomes more practical. You no longer just watch and see what is going to happen. By doing, it starts to make more sense to us. (Learner interview)

Since we started with these investigations I feel the work is becoming more easier to me. The experiments make me ask more questions about what's happening. Before I just

watched the teacher show us. (Learner interview)

There were some dissenting views on the whether by doing their own investigations it aids conceptual understanding. Evidence from the data summarized in Table 5.13 shows that about 13% of the teachers surveyed did not believe that learners understand concepts better by doing investigations than when the teacher gives them step-by-step instructions. These teachers believed that when learners are not given instructions they lose focus of the conceptual learning that is supposed to take place, and the learners instead develop misconceptions. A teacher explained this point of view as follows:

I have no hassle with them doing it on their own, but this can lead to a whole lot of confusion at the same time. If you want them to learn something, it can happen that if they do something wrong in the experiment then the incorrect finding is reached. As a teacher you now have a problem explaining to them this is not what we wanted. (Teacher 7 interview)

The data collected reveal that teachers and learners believe that when learners do investigations by collecting data, analyzing data and drawing conclusions, they develop a better understanding of their work.

5.2.3 Practical skills in science

Sub-assertion 2c: When learners do their own investigations the perception is that they develop skills in science

The data collected through the teacher questionnaire showed there was strong support by the teachers for the statement, ‘when learners do their own investigations, it leads to the development of their scientific skills’. Table 5.15 shows that 80% of the teachers who responded to this questionnaire “agree” with this statement.

Table 5.15 Teacher belief on the development of scientific skills in learners by doing investigations (item 39, teacher questionnaire)

When learners do their own investigations, it leads to the development of their scientific skills	Number (N=55)	Percent (%)
Disagree	3	5,5
Unsure	8	14,5
Agree	44	80,0

Some interviews with teachers provided evidence in support of this sub-assertion. In these interviews, the teachers explained how by learners doing their own investigations, they develop skills in science:

It allows students to develop more skills...that is what science teaching is all about...investigative skills, observation skills, problem solving...allowing them to develop more insights into problem solving. (Teacher 8 interview)

By doing the practical work themselves, they become competent at skills like taking measurements, for example reading the thermometer, they can handle apparatus, record observations and so on. I think overall it make them more confident in what they are doing. This you only get by doing. Skills are not something you can teach by showing or demonstrating. They have to do it themselves. (Teacher 4 interview)

In each of the five investigations that were observed, there was evidence that the learners were using these skills. For example, in the open investigation in Miss Essop's class, the learners demonstrated the skill of formulating a hypothesis. The one group which was observed closely, formulated the hypothesis that drinking coffee increases the pulse rate. The learners after collecting their data, plotted a graph. Thereafter, they demonstrated the skill of inference by drawing a conclusion. In Mr Botha's class where a guided investigation was observed, the learners where able to manipulate apparatus, i.e. connect the ammeter and then take measurements. Similarly, in Mr Pillay's class where another guided investigation was observed, the learners with some support from the teacher were able to connect the circuit, and then take ammeter and voltmeter readings. Upon tabulating their results, they were able to infer a relationship between the current strength and potential difference. The learners in Mrs Reuben's class were able to set-up and manipulate apparatus to show that carbon dioxide was a product of combustion. The learners developed similar skills in Miss Naidoo's class where a structured investigation was conducted. After demonstrating its use to them, the learners were able to use a triple beam balance to measure the mass of objects. The learners also learnt how to use the measuring cylinder to measure volume. It was evident that in all cases learners had the opportunity to develop some process skills.

A small percentage of teachers (about 5%) disagreed with this statement. A teacher in the interview when asked to elaborate upon his choice, felt that he could impart these skills to the learners by illustrating these skills through demonstration of practical work, and also by the teacher setting a task which focuses only on one skill. The teacher expressed this in the following way:

There are other ways that they can acquire these skills. I feel it can be dangerous for learners to learn a certain scientific skill by doing an entire investigation. How is the teacher going to keep an eye on what they are doing? He can't keep track of them at all times. This can be particularly dangerous in chemistry work where they sometimes work with acids. To teach a skill I much rather demonstrate it to them. This way I can explain to them in detail. I then give them a little task where they can practice the skill. For example, on measuring volumes I can give them different volumes of water and ask them to use a measuring cylinder to determine the volumes. (Teacher 6 interview)

From above analysis the general perception is that when learners do scientific investigations, they have opportunities to develop process skills.

5.2.4 Commentary

In this section, evidence has been provided to support the assertion that even when learners have a limited degree of autonomy such as in collecting data, analyzing data and drawing conclusions, the teachers and learners perceive that scientific investigations have a positive impact. There are three perceived benefits to learners doing scientific investigations.

Firstly, there was a common belief amongst the teachers that learners show a keener interest in science when they are given the opportunity to do scientific investigations. Learners therefore become motivated by doing the investigation themselves rather than observing the teacher demonstrate it to them. This is a generally accepted finding of other research conducted. Studies conducted on the contribution of doing investigations to learners have led to similar findings to this study. According to Raubenheimer (1996) the findings of research conducted by the Assessment of Performance Unit (APU) of the United Kingdom reveals that children enjoy and are eager to be involved in science activities such as investigations. Edwards, Luft, Potter and Roehrig (1999) report that investigational work by learners does help to stimulate their interest in science. In a learner survey by these researchers, 75% of the learners agreed with the statement, "I find it more interesting to make my own conclusions than to answer set lab questions." Further research by Gibson and Chase (2002), showed that a 2-week summer science program which used an inquiry-based approach helped middle school students, who had a high level of interest in science, maintain their interest during their years in high school. According to the NRC (2005) in its publication, *America's Lab Report: Investigations in High School Science*, "as a result of laboratory experiences that make science 'come alive,' students may become interested in learning more about science and see it relevant to everyday life" (p. 91). It

would therefore appear that although learners have a limited degree of autonomy in doing investigations such as in collecting data, analysing data and drawing conclusions, it is highly motivational to their learning of science. This is important because learner achievement in science depends upon how well motivated the learners are to do science.

Secondly, teachers believe that learners understand scientific concepts better when they are actively involved in doing scientific investigations. The National Science Education Standards (NSES) formulated by NRC (1996) provides support for this finding by explaining how by doing inquiry, the learners develop conceptual understanding:

When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations, in this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills. (p. 2)

Empirical support has also been provided for this finding. Westbrook & Rogers (1996) undertook research involving Grade 9 learners to analyze the impact student-initiated experiments would have on the development of the concept of flotation. The students designed and conducted experiments to test each of their hypotheses, collected and analyzed the data, wrote lab reports, and presented the information to the class. The results of this research suggested there was a link between the student's involvement in developing laboratory activities and subsequent understanding of particular aspect of the concept of flotation.

Furthermore, a study carried out by Edwards, Luft, Potter and Roehrig (1999) found that the conceptual understanding demonstrated by learners to be greater when they engage in extended-inquiry investigations rather than just memorizing facts or complete verification laboratories. This perception that the doing of scientific investigations contributes to conceptual understanding, fits with the constructivist view of learning which indicates that learners need to be actively involved in the learning situation if learning is to occur deeply and enduringly (Driver & Bell, 1985).

A third perception concerning the benefit of doing scientific investigation was that it leads to an improvement in the learner's process skills. This is supported by the finding of a research study conducted by Mech (1990). The study aimed at determining which of two

teaching approaches, inquiry or illustrative, is more effective for the teaching of microscope skills to junior secondary school biology learners, concluded that the inquiry approach is more effective in promoting understanding of how the microscope works and in promoting the effective use of the microscope. It is clear that if learners are given the opportunity through investigations to use and practice skills, they have a better chance of developing them.

5.3 TEACHER SUPPORT OF LEARNERS DOING SCIENTIFIC INVESTIGATIONS

Assertion Three: Teachers support learners in progressing through the stages of the scientific investigation in the following ways, asking learners questions at all stages of the investigation; offering learners suggestions when they are making no progress in the investigation; giving learners a prompt sheet which helps focus them on the stages of the investigation; instructing learners in the use of practical techniques.

In this section, the strategies used by teachers in supporting learners doing scientific investigations will be described by analyzing data collected through the teacher questionnaires, class observations and interviews. This information was sought in response to Research Question Three which states, “How do teachers support learners doing scientific investigations ?” The analysis of the data collected led to Assertion Three.

Teacher support strategies describe the guidance that the teacher gives learners in order to facilitate their progress when they are doing scientific investigations. The form that this support from the teacher assumes is critical and must not be confused with teacher control. Teacher control describes the degree to which a teacher determines what is done and how it is done. Teacher support on the other hand, refers to the strategies used by the teacher in guiding the learners through the stages of the investigation.

The following comments by teachers in the teacher questionnaire underlie the importance and need for support when learners are doing investigations:

Investigations are done at a very juvenile level- some pupils do extremely well (they have the aptitude), some are clueless. A certain level of guidance is definitely needed. If you just leave them and never correct them they may develop the wrong scientific skills. (Teacher questionnaire)

Pupils are not sufficiently trained to work independently, hence the majority of them fall short in activities involving scientific investigations. The teacher will be a facilitator who gives them some direction. (Teacher questionnaire)

Learners doing open investigations does not mean that teacher should sit back and watch. Learners do not possess any experience or expertise of this. Teachers will need to be involved and guide them all the way. If this doesn't happen it will be a very frustrating experience for them (*learners*). (Teacher questionnaire)

Assertion Three was generated from a number of sub-assertions which are described as follows.

5.3.1 Asking questions

Sub-assertion 3a: Teachers in supporting learners, ask questions at the different stages of the investigation to probe their understanding which at times makes them reconsider what they are doing.

The teachers ask learners questions at all stages of the investigation. In helping learners clarify the investigation question, they ask questions which focus on the relationship between the variables in the investigation. This emerged from the analysis of the data collected from the teacher questionnaire, where 60% of the teachers who responded to the questionnaire indicated they “often” or “always” helped learners to clarify the investigation question (Table 5.16).

Table 5.16 Frequency with which teachers help learners to clarify the investigation question (item 28, teacher questionnaire)

I help the learners to clarify the investigation question	Number (N=55)	Percent (%)
Never or seldom	5	9,1
Sometimes	17	30,9
Often or always	33	60,0

The following responses elicited from teachers interviewed helps to explain how teachers support learners to clarify the investigation question:

Most investigations involve dependent and independent variables. If they (learners) are to correctly write the research question they will need to know what is meant by these variables. When they are discussing what question they want to do, I would go to the groups and ask them to spell out exactly what these variables are. Sometimes they confuse them. I then have to intervene ask them to rethink it. (Teacher 2 interview)

Very often the pupils are not clear about what they want to investigate, so I ask them to explain to me in simple language what they want to achieve through the investigation. The problem that often crops up when investigating two variables is that they ignore the controls... I mean the control variables. Again by asking them to explain what they want to do, they become more aware of it (control variables). (Teacher 3 interview)

The findings from the teacher questionnaires and teacher interviews were supported by data collected through the learner questionnaire. It is seen from Table 5.17 that about 68% of the learners indicated that the teacher helped them to clarify the investigation question.

Table 5.17 Frequency with which the learners indicated the teacher helps them to clarify the investigation question (item 12, learner questionnaire)

The teacher helps us to clarify the investigation question	Number of learners (N=126)	Percent (%)
Never or seldom	5	4,0
Sometimes	36	28,5
Often or always	85	67,5

The excerpt on pages 67-68 which relates to an exchange which took place in Miss Essop's class on the pulse rate investigation, provides an example of how the teacher by employing probing questions, enabled the learners to think through more clearly the relationship between variables they intended investigating. This excerpt shows how the teacher had supported the learners at the initial stage of the investigation by asking questions which forced the learners to verbalize and rethink the hypothesis they had formulated. This was crucial as an investigation question or hypothesis which is misinterpreted or poorly formulated will lead to learners conducting an investigation which lacks foundation.

Questioning as a support strategy is also used by teachers in guiding learners in the planning stage of the investigation. This is illustrated in the excerpt on page 83 from the guided investigation in Mrs Reuben's class to show that one of the products of combustion of a candle is carbon dioxide. The teacher used probing and insightful questioning in guiding the learners through the planning stage of the investigation.

Teachers often question the learners about what they are doing in conducting the investigation. The analysis of the teacher questionnaire shows that in response to this support strategy, about 67% of the teachers collectively indicated that they either “often” or “always” questioned the learners while they were conducting their investigation (Table 5.18).

Table 5.18 Frequency with which teachers ask learners questions while conducting the investigation (item 31, teacher questionnaire)

When learners are conducting the investigation, I ask them questions so they may reflect on what they are doing	Number of teachers (N=55)	Percent (%)
Never or seldom	2	3,6
Sometimes	16	29,1
Often or always	37	67,3

This questioning support strategy is illustrated in the excerpt on pages 78-79 from a guided investigation described in Mr Pillay’s class where learners investigated the relationship between current strength and potential difference across a light bulb in a circuit. Here the teacher employs this strategy in assisting a group of learners who are experiencing difficulty in connecting a circuit diagram. This exchange between the teacher and the learners shows how the teacher by redirecting the learners to a concept already studied, is able to get them to reflect on and rethink their connections in the circuit. The teacher did not tell or show the learners what to do. Instead, the teacher checked on the conceptual understanding of the learners by asking the learners to explain in their own words the concept of “electrical potential difference.” This was crucial in deciding whether a series or parallel connection of the voltmeter would be correct.

Teachers also asked learners to review their plan if the findings of the investigation were not correct. Analysis of data collected from the teacher questionnaire showed that about 64% of the respondents collectively either “often” or “always” asked learners to review their plan if the findings of the investigation were not correct (Table 5.19).

This support strategy was evident in the observation which took place in Mr Botha’s class. A group of learners who had investigated the effect of temperature of on the resistance in the circuit, had erroneously concluded that resistance in a circuit is lower at a higher

temperature. Upon questioning the learners on the procedure they had followed the learners discovered the flaw in their plan. In conducting the investigation the learners had failed to control other variables such as the length of the conductor and its thickness. By reviewing their plan, the learners were able to redo the investigation and arrive at the correct finding.

Table 5.19 Frequency with which the teacher asks learners to review their plan (item 34, teacher questionnaire)

If the findings of the investigation are not scientifically correct, I ask learners to review their plan	Number of teachers (N=55)	Percent (%)
Never or seldom	9	16,4
Sometimes	11	20,0
Often or always	35	63,6

A teacher interviewed, explained why teachers should intervene at this stage, by stating that incorrect findings should not be allowed to hang in suspension. He explained as follows that through probing questions, the learners should be made to review what they had done wrong:

The teacher should not accept an incorrect finding. This will lead to misunderstanding in science. He must quiz them about their plan. They need to see where they had gone wrong. If there is time they must go back and do the investigation again. (Teacher 3 interview)

A teacher in an interview revealed that when learners have reached an incorrect finding, she uses this as an opportunity to engage learners in a group discussion rather than using probing questions to get them to review their plan. In the following excerpt she explains how the learners themselves provide reasons and explanations about why the findings were not what was expected:

When we go through them in class if they found difficulty with or something or if we feel they have gone wrong, myself and especially the other members of the class I would rather coax them rather...to try and give them the answer. There seems to be problem... something not what we expected. Can any of you suggest why...the results were unexpected. Sometimes the class will come up with things. The class will say something like because that's not fair. So often the class will correct anything the groups did wrong...because they actually give the information to the others. They take out the fallacies and the arguments. (Teacher 8 interview)

The data presented show that teachers used a questioning strategy in enabling the learners to understand more clearly the question or hypothesis they intend investigating, in re-

thinking some of their actions when collecting data, and in reviewing their plan when they reach incorrect findings.

5.3.2 Offering learners suggestions

Sub-assertion 3b: The teacher makes suggestions when the learners do not seem to be making progress in conducting the investigation

From Table 5.20 it is seen that the majority of the sample (69%) collectively indicated that they either “often” or “always” offered the learners suggestions when they were making no progress in the investigation. The following excerpt from an interview with a teacher reveals that in the teacher’s view offering suggestions is less instructive and more facilitative:

I would sit down and listen to their ideas. I made them verbalize, I wouldn’t just give them the answer. They had to give me some kind of logical deduction. If I then found a glitch in their reasoning I would say perhaps you should review that step and then come back to me. So I was reluctant to just give them the answer. They battled with this. They wanted the answer. They didn’t want to sit and have to work through it. (Teacher 4 interview)

Table 5.20 Frequency with which teachers offer learners suggestions (item 29, teacher questionnaire)

I offer learners suggestions when they are making no progress in the investigation	Number of teachers (N=55)	Percent (%)
Never or seldom	3	5,5
Sometimes	14	25,5
Often or always	38	69,0

Another teacher who was interviewed referred to the frustration which can develop when learners reach a “block” in the investigation. In such a case the teacher indicates that the intervention by the teacher in the form of suggestions will help to redirect the learners in the investigation:

I think for too there has been this misconception amongst everybody that science is a subject where everything is cut and dried, and pre-packed for consumption. The learners have no conception of the nature of science. That is, that science is a subject where there is a lot of uncertainty and loose ends. Learners soon come to realize this when they do their own investigations. Sometimes, things don’t work out as expected and frustration builds up. The teacher now has an important role to play in intervening and offering them some ideas so that further progress may be made. He (*teacher*) has to encourage them to try something new. (Teacher 5 interview)

In the guided investigation described in Mr Pillay's class in Section 4.3, a situation arose where a group of learners were not making further progress in the investigation, and where the teacher intervened to offer a suggestion. The learners had connected a circuit, with an ammeter in series to the circuit and a voltmeter in parallel across a light bulb. The needles on the measuring instruments however showed a deflection to the left of zero. The learners appeared to be confused. The teacher facilitated their progress by suggesting the learners mark the polarities on all the components in their circuit diagram they had drawn. The learners were then asked to go to their circuit and check to see that the wires went to the correct terminals on the components. After they made the necessary changes to their circuit, the problem was rectified with all the needles on the correct side of zero for each device.

It is evident from this analysis of data collected that in general the teacher will offer a suggestion when learners do not know what to do next in the investigation. It appears that in offering a suggestion, the teacher does not tell the learners what to do, but rather offers a hint, makes comment or asks a question which gets them on track again.

5.3.3 A prompt sheet

Sub-assertion 3c: Teachers give learners a prompt sheet which helps to focus learners on the stages of the investigation.

A prompt sheet may include questions or broad headings to direct the learners through the stages of the investigation. Data collected through the teacher questionnaire showed that just over half the respondents collectively indicated that they either "often" or "always" gave learners a prompt sheet. Furthermore, about 25% reported that they "sometimes" gave learners a prompt sheet (Table 5.21).

Table 5.21 Frequency with which teachers give learners a prompt sheet (item 30, teacher questionnaire)

I give learners a prompt sheet which helps to focus them on the stages of the investigation	Number of teachers (N=55)	Percent (%)
Never or seldom	13	23,6
Sometimes	14	25,5
Often or always	28	50,9

The following comments by teachers who were interviewed refer to the use of prompt sheets in supporting learners doing scientific investigations:

I have used a worksheet, a prompt sheet if you like where learners are asked a number of questions to guide them and help them. Such as what are the variable you are investigating, what apparatus will you use, how will you measure the variables, draw a table, and what are your conclusions. I feel this keeps them on track. (Teacher 3 interview)

For learners who are attempting investigations on their own for the first time, a sheet where they are prompted is essential. I have found that a table with headings of the variables you want to measure does work. It tells the learners that you want to find the relationship between these variables. (Teacher 4 interview)

The above excerpts show that teachers find prompt sheets useful in that they give structure to the investigation and serve to guide and focus the learners through the stages in the investigation.

For the guided investigation on the relationship between current strength and potential difference in a circuit described in Section 4.3, Mr Pillay gave the learners in his class a worksheet which served as a prompt sheet (Appendix H). This prompt sheet comprised of questions and instructions which acted as cues to focus learners on the stages of the investigation. This prompt sheet was not like a traditional worksheet such as the one used in Mrs Naidoo's class (Section 4.5) where learners were given a list of instructions to follow (Appendix I)

Whereas the above prompt sheet related to all the stages of the investigation, the following prompt sheet (Table 5.22) used by another teacher for the same investigation concentrated only on the planning stage of the investigation. The format of this prompt sheet is similar to that offered by Harlen (2001) and was described in Section 2.7. The responses given to each question or prompt were those offered by a group of learners who were observed doing the investigation.

Table 5.22 Prompt sheet for the planning stage of the investigation

PROMPT	RESPONSE
What is your investigation question	How do the current strength and potential difference relate ?
What will you change in the investigation ? (the independent variable)	The number of cells
Why will you change this ?	It changes the voltage in the circuit
What will you keep the same in the investigation ? (the controlled variable)	The light bulb
Why will you keep this the same ?	To make sure the resistance stays the same. So other things like temperature remains the same. Also the connecting wire will be the same.
What will you measure ? (the dependent variable)	The current strength
How will you measure this ?	By means of an ammeter
How will you arrive at your conclusion ?	We will see how the current changes when the number of cells changes.

From the questionnaire data, it can be inferred that prompt sheets are used frequently in classes where investigations are taking place. From the interviews and observations it becomes clear that a prompt sheet is an important instrument that can be used to help learners provide structure to an investigation.

5.3.4 Instructing learners in the use of practical techniques

Sub-assertion 3d: Teachers give learners instruction in the use of practical techniques when they lack the necessary expertise

In conducting scientific investigations, learners need to be proficient in the use of practical techniques. These practical techniques include the correct use apparatus, for example a measuring cylinder in the measurement of volume. The analysis of the data collected provided evidence that teachers do instruct learners in these practical techniques by demonstrating the techniques to the learners. An overwhelming majority of about 96% of the teachers collectively indicated that they show learners how to use apparatus they are not familiar with (Table 5.23).

Table 5.23 Frequency with which teachers show learners how to use apparatus (item 32, teacher questionnaire)

I show learners how to use an apparatus they are not familiar with	Number of teachers (N=55)	Percent (5)
Never or seldom	0	0,0
Sometimes	2	3,7
Often or always	53	96,3

When learners were not familiar with the apparatus they would use in the investigation, the teacher demonstrated its use to them. This was evident from the interview with teachers, and also in the investigations which were observed. In the guided investigation observed where learners investigated the factors affecting resistance, Mr Botha explained to me in the two lesson leading up to the investigation he had discussed the functioning and the connections of the voltmeter and ammeter in the circuit:

This was the first time that learners had seen an ammeter and a voltmeter. It was therefore necessary to connect the circuit and show them how they were connected. I also spent some time showing them how to read the scales and take readings. I think now they were ready for the investigation. (Mr Botha, interview)

Similarly in Mr Pillay's class where learners investigated the relationship between current strength and potential difference the teacher had spent much time in demonstrating to learners the connections of the ammeter and voltmeter in the circuit, and also how to take readings from these devices. For the structured investigation in Mrs Naidoo's class where the learners had to investigate the floating and sinking of objects, the teacher demonstrated to the learners the use of the triple beam balance and how volume readings should be taken from the measuring cylinder.

A variety of reasons were given for showing learners how to use an apparatus, but the most common related to the safety aspect. Teachers stated that learners could endanger themselves if they were allowed to tinker with equipment which was unfamiliar to them. The following comment from a teacher interviewed underlines this:

There is no doubt that the learners safety must be placed above all else. If learners are allowed to mess about with say with a bunsen burner, this could spell disaster. They would endanger not only themselves but the also the entire class. I will allow them to use such apparatus only under very controlled conditions and after I have demonstrated its use to them. (Teacher 7 interview)

The evidence collected also showed that once the teacher had demonstrated the use of apparatus, it was common for teachers to plan practical exercises for learners so that they

acquired experience and expertise in the use of commonly used apparatus. The following excerpts from the teacher interviews revealed this:

In order to do practical work such as an investigation by themselves, the learners firstly need to be taught how a piece of equipment works. For example when they do an investigation to compare the density of different materials, I give them exercises where they learn how to measure mass using a mass balance. If it is a liquid they are looking at, then they will need to know how to use a measuring cylinder and take readings. The learners only go onto the investigation once I am satisfied they are confident in the use of the apparatus. (Teacher 8 interview)

In experiments where reading needs to be taken it is paramount that students know how to read the correct values. Take for example the ammeter and voltmeter used in the Ohm's Law experiment. If they (learners) take incorrect readings the whole experiment falls flat. They need to be able to take a reading say between 2 and 3 volts when there are 10 intervals between the numbers. I drill this and they practice it extensively. (Teacher 4 interview)

Overall, it would appear that teachers provides support by making sure learners can use apparatus by demonstrating its use to them and also providing exercises where they could practice and gain experience in how to use it.

5.3.6 Commentary

One of the primary purposes of the study was to describe the strategies used by teachers in supporting learners doing scientific investigations. The study reveals that although autonomy may be transferred to learners in doing scientific investigations, teachers believe that they have a pivotal role to play in supporting these learners through the investigative process. Rotheram (1984) states that scientific investigations, especially open investigations are most demanding and involves the learner in asking his own questions, designing his own experiment, carrying it out and reaching his own conclusions. He therefore makes the point that the teacher needs to employ a support strategy such as a flow chart, in scaffolding the learner's execution of the investigation. The evidence collected in this study suggests that teachers employ a variety of strategies in supporting learners throughout the stages of the investigation in which they reduce control and allow more autonomy.

Firstly, teachers use probing and insightful questioning at all stages of the investigation in forcing learners to reflect upon what they are doing. When formulating their own questions, the teacher supports them in ensuring that the question they pose is clear and

focused. The teacher also ensures that the learners are capable of investigating the questions they have posed. The NRC (1996) makes this point by saying that the teacher must ensure that the knowledge and procedures needed to answer the question posed are accessible and manageable, as well as appropriate to the students' development level. The finding of this study show that teachers intervene in particular where learner are formulating a question for an investigation involving the relationship between variables. The teachers in this study have identified this as an area where learners need support in defining the independent, dependent and control variables. Brook et al. (1989) observe that in formulating an investigative question, learners need to have a good grasp of the notion of a variable. Setting up an experiment requires explicit definition of the variable or variables which form the focus of the investigation and of other variables which need to be controlled. The teacher also asks questions in supporting the learners when they are manipulating apparatus to collect data. When learners reach an incorrect conclusion, the teacher asks them questions so that they review what they have done. Sometimes when this happens teachers use this as an opportunity to engage other learners in a class discussion where they point out possible sources of error. Harlen (2001) maintains that in this discussion which follows the presentations of findings, the teacher's opinion, if offered, should not be judgemental, but rather be a part of the general pooling of ideas. Furthermore, he writes that the principal aim should be to develop the habit of self-criticism and reflection on the procedures. When children become used to reviewing their work, they will not require someone else to help them reflect on what they did, but will do so spontaneously

The type of questions posed by the teacher in supporting the learner's progress through the stages of the investigation is different from that in a traditional teacher-dominated classroom where the teachers' questions have the purpose of controlling the social situation (Lemke, 1990). In an activity which is more learner-centred with aspects of learner autonomy, the teacher is encouraged to ask a "productive" type of question which calls for reflection and analysis that promote a view of science as a dynamic search for answers. Such questions by the teacher provoke thought, are based on students' experiences, and call for creative thinking (King, 1994). After perceiving the student's difficulty, he has to formulate a question which will be a challenge yet give guidance to the student (Sund & Trowbridge, 1973). This type of questioning was certainly prevalent in the lessons that were observed.

Secondly, teachers provide support by making suggestions when learners are making no further progress in the investigation. Roth (1994) referred to such investigations as “blind alleys”. Roth (1994) maintains that such “blind alleys” constitute a necessary part of the normal learning experience in a science laboratory/classroom, and they help students in developing an understanding and appreciation of the nature of scientific inquiry as a tentative enterprise under construction. However, if learners are unable to cope with this uncertainty, teacher support may be necessary (Roth, 1995). The teachers in this study made the point that if the investigation is open, this intervention should not be confused with interference. The learners should still be allowed to maintain control over the investigation, and the support should be more in the form of suggestions and guiding questions.

A third support strategy widely used by teachers is to give learners a prompt sheet which helps to focus their attention on the different stages of the investigation. This finding is similar to that of the AKSIS Project (Watson et al., 1998). According to the second interim report (1998) of the AKSIS Project teachers used prompt sheets in 78% of investigations at the KS2 (age 7 to 11) and 75% at KS3 (age 11 to 14) to help students structure work and support their decision-making in open situations. Although the present study did not explore in detail the benefits of using prompt sheets, a study undertaken by Gabel (2001) found that the learners who were given written prompts while doing the investigation, exhibited a gain in science inquiry skills and maintained a positive attitude towards science. Despite the effectiveness of prompt sheets in supporting learners, Watson et al. (1998) caution that prompt sheets can straight jacket students thinking, resulting sometimes in students carrying out procedures routinely without understanding the purpose of it.

A fourth support strategy identified is the explicit instruction in the use of practical techniques. To a large extent teachers believe that if learners are to do scientific investigations on their own, they need to possess certain practical skills, especially in the use of apparatus. Teachers share the view that learners need to receive deliberate instruction in these skills rather than allowing these skills to develop intuitively. The underlying reasons given for this are safety and accuracy when taking measurements. Wellington (1989) agrees with this when he writes that scientific techniques do require rules for their execution and for safety. It may therefore be irresponsible and undesirable to allow children learn scientific skills and procedures implicitly by trial and error. Sund and

Trowbridge (1973) illustrates this point by explaining that one could not learn very much about how a force causes a mass to accelerate, unless careful measurements of distance, time force, and mass are made. To learn the interrelationships between all these factors requires that the skill of measurement be quite highly refined. It would seem necessary to know how to use a meter stick or measuring tape, to read the units correctly, to read a stopwatch, to operate a beam balance correctly, and to measure force with spring balance or some other method. Millar (1991) reaffirms that these practical techniques will need to be taught explicitly. Thereafter, the students need to have opportunities to practice the skills required for a particular inquiry situation (Sund & Trowbridge, 1973). These “controlled prelab” activities will reduce the probability that learners will take incorrect measurements using an apparatus (Beasley, 1985). These activities were reported by teachers who were interviewed.

5.4 FACTORS THAT AFFECT THE DEGREE OF LEARNER AUTONOMY

In chapter 4, three types of investigations were described according to the degree of autonomy the learner had at the stages of the investigation. In this section, the factors which affect the degree of autonomy that learners have will be identified and explained.

In doing so, this section deals with the presentation and analysis of data related to Research Question Four which asks, “What factors affect the degree of learner autonomy ?” Assertion Four addresses this research question.

Assertion Four: **The factors which appear to influence the degree of autonomy learners have in doing scientific investigations include class size, availability of resources, the time available for investigations and teacher competence.**

For the purposes of this section, the phrase “doing investigations” used in the above assertion refers to learners having responsibility for at least collecting the data and drawing a conclusion i.e. two stages.

5.4.1 Class size

Sub-assertion 4a: Learners have more autonomy in doing investigations in a smaller class.

A factor mentioned by all ten teachers interviewed was the number of learners per class. The teachers hold the view that open investigations where learners have autonomy in all phases of the investigations can only take place if class sizes are contained. When asked what the maximum class size would be for learners to do their own scientific investigations, all teachers stated a class not exceeding 25 learners.

A cross-tabulation was conducted in order to explore a possible relationship between class sizes at schools and the autonomy of learners doing investigations. Data extracted from the teacher questionnaire was used to conduct a cross-tabulation of item nine where teachers were asked about their average class size and item twenty two which relates to the amount of autonomy learners have when conducting scientific investigations (Table 5.24).

Table 5.24 Cross-tabulation of the average class size and the frequency with which learners conduct the investigation on their own (teacher questionnaire)

The learners conduct the investigation on their own without being told what to do	The average number of learners in each class	
	30 or below	Above 30
Never or seldom	3	9
Sometimes	5	12
Often or always	22	4
Total	30	25

From the above cross-tabulation it is seen that of the twenty six teachers whose learners “often” or “always” conducted the investigation on their own without being told what to do, twenty two of them indicated that their average class size was thirty or below. Of the twelve teachers who indicated their learners either “never” or “seldom” conduct investigations on their own without being told what to do, six have an average class size above thirty. From this analysis it would appear there is a correlation between the class size and the autonomy learners have in conducting scientific investigations. The smaller the class, the more autonomy learners are likely to have in conducting scientific investigations.

It also appears that the preferred class organization when learners are doing scientific investigations is to have learners in small groups. This was indicated overwhelmingly in the data collected through the teacher questionnaire. Of the teachers surveyed through this questionnaire, about 64% of them organize their classes by having learners work in small groups when doing scientific investigations (Table 5.25)

Table 5.25 Class organization when learners are doing scientific investigations (item 13, teacher questionnaire)

How was the class organized most of the time ?	Number of teachers (N=55)	Percent (%)
Learners in one large class group	5	9,1
Learners in a number of small groups	35	63,7
Learners in pairs	8	14,5
Learners work by themselves	7	12,7
Total	55	100

The open investigation in Mrs Essop's class which was described in section 4.1 took place in a small class of learners. As a result of the smaller class, the teacher was able to relinquish more control of the investigation to the learner because she was able to monitor closely what learners were doing, and offer support when necessary. On the other hand, in Mrs Naidoo's class where a structured investigation took place, there were 38 learners working in groups of six and seven. In the interview, Mrs Naidoo referred to the difficulty of learners doing their own investigations in a large class:

Teaching grade 9 is really exciting because there is so much opportunity for practical investigation. However, it is also exhausting because the teacher has to be constantly giving input. I think that to conduct investigations where the pupils formulate their own questions, choose their own apparatus etc. is only possible in smaller classes. The pupils will have to work in small groups of four. They will need the constant input from the teacher to see that they do not deviate too much. (Mrs Naidoo, interview)

Another teacher recounted in an interview his experience of teaching a class of over 50 learners:

I teach in a rural school where there are over 50 children in a class. There is not enough chairs and desks. When the CTAs came from the department, I did try doing the investigation with them. I did place them in groups. They were 7 in a group. So there were 8 groups. I took them outside. They had to do this thing about fitness. It was not a success as I had to run from group to group showing and explaining what was to be done. This was impossible. (Teacher 9 interview)

Although a small class is the ideal for investigative work, the following response from a

teacher shows that it is possible to do investigations in a large class. However, effective classroom management by the teacher and the structuring of the groups is required:

I think you would have to have your groups very well structured and you might need a lot more support than in a smaller group. I think you could. I don't think numbers restrict you, I think it's your management. If it is a mixed ability class you will have to ensure that the talent is distributed to all groups. Each group will need to have a strong group leader who will need to take charge. The teacher will have to have the learners under control. There will need to be strong discipline so that everybody works on the task. This will free up the teacher to walk around to the groups and offer help when needed. (Teacher 2 interview)

The analysis of the data collected has shown that class size is a factor which influences the degree of autonomy learners receive when doing scientific investigations. In cases where classes are small it would appear that learners have more autonomy in doing investigations. With a small class the teacher is more willing to relinquish control, and offer support to the learners.

5.4.2 Availability of resources

Sub-assertion 4b: Learners have more autonomy in doing investigations at schools which are adequately resourced

Teachers in poor schools have highlighted the lack of resources for science teaching as a major impediment to teaching open investigations. They claim that due to the lack of science equipment, they have no option but to demonstrate practical work to the learners. The analysis of the teacher questionnaires and teacher interviews revealed that this lack of resources at schools was seen as an impediment to learners doing their own scientific investigations.

A cross-tabulation was conducted in order to explore a possible relationship between the availability of resources at schools and the autonomy of learners doing scientific investigations. Data extracted from teacher questionnaire were used to conduct a cross-tabulation of item five where teachers describe their school in terms of the availability of resources and item twenty two which relates to the amount of autonomy learners receive when conducting scientific investigations (Table 5.26).

Table 5.26 Cross-tabulation of the availability of resources and the frequency with which learners conduct investigations on their own (teacher questionnaire)

The learners conduct their investigation on their own without being told what to do	No resources or poorly resourced	Has resources for science teaching
Never or seldom	5	7
Sometimes	5	12
Often or always	2	24
Total	12	43

The above cross-tabulation shows that of the forty three teachers who taught at adequately resources schools for science, more than half of them (twenty four) indicated they “often” or “always” had learners conducting scientific investigations without being told what to do. Furthermore, twelve of these teachers from adequately resourced schools for science indicated they “sometimes” had learners conducting scientific investigations without being told what to do. The cross-tabulation also shows that of the twelve teachers who taught at schools with no or poor resources for science teaching, five indicated that their learners “never” or “seldom” conducted an investigation on their own without being told what to do. This observation clearly indicates that teacher control predominates when the resources are inadequate for learners to do their own scientific investigations. While a correlation appears to be present between the availability of resources and autonomy in doing investigations, it is not implied that that this factor is a cause. Further studies would be needed to reach this conclusion.

The teacher interview responses to the question of how important is the availability of resources to the implementation of learner-centred investigations corroborated this finding from the questionnaire. The following response explains how due to very limited resources in the laboratory, the teacher is forced to demonstrate practical work:

This is a major hurdle at my school. We have only one laboratory which is very under-resourced. For something like the past ten years we have received nothing from the department. We have very limited supplies. Whatever we have we conserve and use chemicals etc. very sparingly. So you can see most of the work has to be demonstrations.
(Teacher 10 interview)

There were some teachers who explained how they were able to overcome this difficulty of lack of resources. The following excerpt illustrates how a teacher has managed to overcome this:

I am teacher at a state school situated in a low income area. The school fees are therefore set low at R400 a year. With this sort of budget you can imagine not much is available for the science budget. At my school the teacher does whatever experiments they feel are important. Sometimes he demonstrates and sometimes he would ask for volunteers to do it, while the other learners observe. Now with the new curriculum I realized this was all wrong and somehow we had to involve the learners. There are three high schools which are almost on the same road. So we always borrow stuff from each other. Then by doing groupwork, the learners get a chance to do the experiment. (Teacher 6 interview)

Overall, the data collected have revealed that the lack of resources at schools appears to affect the degree of autonomy learners have in scientific investigations. At schools where resources are inadequate, learners would appear to have limited opportunities to do investigations on their own.

5.4.3 Time available for investigations

Sub-assertion 4c: The number of investigations and the degree of autonomy given is strongly influenced by the content coverage and assessment.

The pressure to cover topics in the syllabus and the lack of school time for scientific investigations impinge upon the number of investigations done at school and more especially how much autonomy the learners have in doing these investigations. The following comments by teachers when interviewed reflect they are unable to give learners open investigations as they require too much time:

I definitely think there is a place for open investigations. But, if you look at the constraints that we have with regard to the syllabus and things like that, it takes a long time to do open investigations. Because with this expo project that we are busy working on now, it has taken about two months to get where we are now. And it took learners about three weeks just to get a topic. So, it takes a lot of time. (Teacher 3 interview)

I think time-table constraints... we are all run by bells and buzzers and all periods are demarked ...there is strict routine and you don't interfere with other peoples' time. There inflexibility in terms of staff, colleagues that I work with. Quite often there is not enough time when the learners are doing their own investigations. A few minutes taken from the next lesson becomes an issue. Our periods are only 40 minutes. This is not enough for the work we should be doing. (Teacher 5 interview)

Mr Pillay, in whose class a guided investigation was observed explained that if there were fewer topics to be covered he would get learners to do more open investigations:

Despite the new curriculum, I still find the number of topic to be many. I have a problem trying to strike the balance between teaching them the content and skills development...meaning I cannot develop the investigative skills as I would want. For sure if I am given more time I will let the learners do more investigations where they would design the whole thing on their own. (Mr Pillay, interview)

As a result of these time constraints, teachers seem to do practical demonstrations to illustrate concepts, laws and principles in science. The following comment by a teacher in the questionnaire reveals that due to the time constraints he is forced to resort to demonstrations where he illustrates concepts taught rather than allowing learners to investigate these themselves:

There is just no time for the learner to do practical work like investigations. Although this is not what science should be, I am forced to demonstrate much of the experiments.
(Teacher comment, questionnaire)

It also emerged that much of this pressure to cover the syllabus is being exerted on the teachers by the school management. A teacher who was interviewed revealed that her efforts at changing her teaching practice and implementing the investigative approach in her teaching had been frustrated by her school management and science department:

I have become extremely frustrated with my management at school. I come from a very traditional school where teachers have been very critical and cynical about the changes that have been introduced to the curriculum. They hold the view that teaching involves the transfer of a body of knowledge. They have not shown much regard for the OBE principles which underlie the new curriculum. At our first Natural Science department meeting this year I brought up the issue of introducing scientific investigations in our teaching and allowing learners to do their own investigations. I received little support from my colleagues. My H.O.D. told me that if this was something I wanted to toy with he would not stop me, but I would have to also teach the syllabus that the other teachers were following. (Teacher 2 interview)

The teachers in this study believe that the assessment policy of the school is a related factor in shaping the teaching approach being adopted in the classroom. Teachers firmly believe that what they teach and how they teach should adequately prepare learners for assessment. Furthermore, learner performance in high stakes standardized tests and examinations have traditionally been used by the school management and the education department as a yardstick for effective teaching.

The following comment by a teacher in the questionnaire shows an overwhelming obligation to cover a certain body of knowledge in preparing learners for summative assessments such as tests and examination:

The investigative approach that you speak of is something that I really believe in. However I teach at a school my science department emphasizes the content. We have to teach content as a preparation for Physical Science in Grade 10. In the traditional sense we have topics that we have to cover. There is little time for pupils to do scientific investigations. The tests and exams that they write is all based on these topics. (Teacher comment, questionnaire)

Some teachers in their comments in the questionnaire and in the interviews expressed the view that if learners are to do investigations in science, the assessment policy for science at their school will need to change. The following two excerpts represent this point of view:

Continuous assessment requires set tasks which include oral and other presentations, tests, exams, translation tasks, projects etc., thus time has to be planned to cover all the requirements. My learners can only do investigations if I able to give them a mark for assessment purposes. (Teacher comment, questionnaire)

The department requirements for OBE state that learners should do investigations. However, at our school we are not forced to assess for investigations. It (investigations) will only take if our principal or H.O.D. says okay I need a mark for investigations. (Teacher 8 interview)

The above comments show that there is a strong belief amongst teachers that they will allow learners to do their own investigations only if it is a requirement for assessment at their school. At all the schools where the investigations were observed, the teachers indicated that the learners would be assessed for the investigation. The mark scored in the investigation would then contribute towards the continuous assessment for the year. For example, Mr Botha explained that in terms of his school's assessment policy in science, the learners are required to be assessed for at least one investigation per term:

We try to follow the RNCS very closely. We are forced to assess for investigations. We try and do one for each section and the students are assessed for at least one per term. The report card is designed to show what mark is given for the outcomes. (Mr Botha, interview)

The pressure to cover a certain body of knowledge coupled with the focus on preparation for test and examinations means there is less time for investigations, and subsequently there are fewer investigations where learners have autonomy in doing them.

5.4.4 Teacher competence

Sub-assertion 4d: Learners have more autonomy in doing investigations at schools where teachers are themselves competent at investigations.

The investigative teaching approach which is a departure from the traditional teacher-centred approach of teaching science redefines the role of the teacher in the science classroom. Teacher competence is therefore a factor which has serious implications for the extent to which scientific investigations are being implemented and how it is being implemented.

The analysis of the data collected from the teacher questionnaire did not show any significant relationship between teacher competence and the autonomy that learners have in doing scientific investigations. As teacher competence is often associated with experience, a relationship between teaching experience and the number of investigations carried out was explored. In order to investigate the relationship between the number of years experience and the number of investigations carried out, the data were recoded. The number of investigations were coded into categories of 1 to 4 and more than 4, as the national curriculum (Department of Education, 2002a) suggests that learners do at least 4 investigations per year. The number of years teaching experience was coded into category 1 for 10 years or less and category 2 for more than 10 years, as a teacher with 10 years' experience was considered to have sufficient experience at teaching the traditional curriculum. A cross-tabulation of the number of investigations and the number of years teaching experience is shown in Table 5.27. There was no significant relationship between the teachers' years of experience and the number of investigations they did ($X = 0,43$, $df = 1$, $p = ,836$).

Table 5.27 Cross-tabulation of the number of years teaching experience in two categories and the number of investigations carried out

Number of years experience	Number of investigations in categories		Total
	1 to 4	More than 4	
Category 1	6	12	18
Category 2	11	25	36
Total	17	37	54

However, the teacher interviews did highlight teacher competence in teaching scientific investigations as a requirement if learners themselves are to be given the opportunity to do investigations. The following comments made by two teachers interviewed revealed that if scientific investigations are to take place in the classroom, the teachers firstly will need to possess sufficient expertise and experience at doing investigations themselves:

The teachers themselves will have to be exposed to this type of teaching. It's like coming to class and telling the learners go and do this and that while myself I have never done an investigation. I have never done any research. So as teachers we need to be upgraded and introduced to investigations. (Teacher interview 8)

As a science teacher I feel very insecure in teaching investigations. In my teacher training at college which was over ten years ago I received little or no exposure to investigations in

science. We did not learn about the scientific method. We learned the content of science and the traditional teaching methodology of the teacher explaining things and demonstrating practical work. We were not told about and did not do investigations where we identified variables to investigate and chose our own procedure. The little I know so far is through reading the curriculum booklets and the CTAs from the department. This is obviously not adequate. (Teacher 6 interview)

A teacher commented in the questionnaire about the inadequate training which was provided from the education department in Natural Science and more especially in the skill of doing scientific investigations:

I am aware that scientific investigations is a learning outcome in Natural Science, but what is in theory is not going to be reflected in practice. This is a pipedream that the department has. Two years ago I attended an OBE workshop in Natural Science. This was a joke. The facilitator took great pains at reading to us the jargon from the document. I am still waiting to receive something from the department on scientific investigations. I will admit to you that I don't know head or tail of this. Until I am an expert at this, how can I let my pupils conduct investigations (Teacher comment, questionnaire).

It is apparent from the above comments that teachers who feel they lack competence in scientific investigations see this as a barrier and are reluctant to implement the investigative approach in their science teaching.

All five teachers whose lessons on investigation were observed, stated when questioned that they felt competent in their ability to teach investigations. Mr Pillay in whose class a guided investigation was observed, mentioned he had taken the initiative to learn about investigations as this was not something which was covered in his formal teacher training:

When I did my HDE some eleven years ago, the investigative approach was not overly emphasized. So when I started teaching, although I knew about it, it was not something that was compulsory. Now with OBE, it has to be taught. I admit what I knew three years ago was limited. I decided to read further about investigations. I became a judge at the FFS expo. This really helped me as I met teacher who were teaching investigations. It was an eye opener for me. It gave me the confidence to go to my class and try it out. Now I have no fears about investigations. (Mr Pillay, interview)

Although the analysis of the data collected through the teacher questionnaire was inconclusive, the comments teachers made would suggest that teacher competence does play a role in determining the degree of autonomy learners have in doing investigations.

5.4.5 Commentary

The analysis of the data collected has shown that class sizes, availability of resources, syllabus coverage and time constraints, assessment and teacher competence are all factors which need to be considered if learner-centred investigations are to become a reality in

classrooms in South Africa. Although this may appear common knowledge, the data in support of it does reinforce the view that contextual factors cannot be ignored if learner-centred investigations are to be implemented.

It is clear that class size does affect the degree of autonomy learners have in doing scientific investigations. Learners have more autonomy in doing scientific investigations where there are a smaller number of learners per class. In offering an explanation for this, Maor and Fraser (1996) allude to the management problem which arises when the teacher has to contend with a large class in an inquiry lesson. They maintain that in large classes it is difficult to cater for and offer genuine inquiry experiences to students with different prior knowledge. The teacher support is constrained as the teacher finds it difficult to monitor the progress of all learners through the stages of the investigation.

Planning to involve learners in investigations must also take into account resource limitations. The lack of available resources has been identified as a significant factor when it comes to learner autonomy in doing scientific investigations. Rogan and Grayson (2003) maintain that schools which have better resources than others, are better placed to implement the new learner-centred curriculum. However, some teachers believe that although these limitations can be challenging, they can also be overcome. Schmidt (2003) maintains that commonly available materials can provide many creative inquiry activities. On the other hand, Rogan and Aldous (2005) have noted that in case studies conducted at schools in Mpumalanga, that even at some schools which had well-equipped laboratories, practical work was limited. Obviously resources are not the only factor to consider.

The teacher's obligation to cover a certain volume of content with a limited period of time, impacts upon the degree of autonomy learners receive in doing investigations. Despite the transformation of the science curriculum with the advent of outcomes-based education, teachers still feel an overwhelming obligation to "cover" the syllabus. As a consequence of this, teachers find it too time-consuming to allow learners much autonomy in doing investigations. Research however shows that the time spent developing inquiry investigations can lead to more in-depth student comprehension of science principles (Schmidt, 2003, p. 30). The NRC (2005) offers block-scheduling as a means by which more time can be made available in the school time table for investigations. The NRC reports that block scheduling is one approach schools have used to provide longer periods

of time to carry out practicals and incorporate discussion. In this approach classes meet every other day for longer blocks of about 90-100 minutes, instead of every day for 40 or 45 minutes.

The analysis of the data has reflected that if more learner-driven investigations are to become reality in most classrooms, the assessments requirements as prescribed by the education department and also the science departments at schools will need to give sufficient weighting to scientific investigations. Watson et al. (1998) in reporting on the findings of the AKSIS project noted that although teachers felt that pupil-decision-making is important they often feel constrained by the limitations imposed on them by assessment. Such teachers tend to make investigational activities more closed by structuring activities carefully to guide students to a particular product so that they may be assessed in terms of the prescribed assessment standards. The hope is that the curriculum reform in science education in South Africa with a shift from high-stakes examinations to continuous assessment will provide an opportunity for learners to carry out more investigations (Hobden, 2005).

If an investigative approach is to be implemented in the science classroom the teacher himself will need to be adept at scientific investigations if he is to offer learners adequate guidance when they are doing investigations. Many teachers avoid teaching science by inquiry because of their own lack of investigative experience and expertise. According to the NRC (2005) in a class where investigations are taking place, the teacher requires a deep understanding of scientific processes in order to guide in formulating a research questions and planning the investigation, as well as a deep understanding of science concepts in order to guide them toward subject matter understanding and other learning goals. If this is lacking it does contribute to the unsatisfactory experience of school science which learners commonly have (Reiss, 1993). Researchers such as Chaney, Hammer, Sander and Rivers (as cited in NRC, 2005) in exploring the teacher support in an investigative environment, suggest that for a teacher to ask the types of higher level and cognitively based questions that appear to support student learning, the teacher must have considerable content knowledge and science teaching experience. In South Africa, case studies conducted at schools in Mpumalanga showed that there was a positive relationship between the level of science practical work and the level of professional development of teachers (Rogan & Aldous, 2005).

The following chapter which is the concluding chapter, presents a summary of the findings made in the study, and their implications for teaching and learning of science. Some suggestions for further related research are also made.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to describe the implementation of scientific investigations in Grade 9 in terms the degree of learner autonomy and the extent of teacher support. In relation to learner autonomy, the study identified and described strategies that teachers use in supporting learners doing scientific investigations. The study also investigated the benefits of learners doing their own investigations, and the factors that affect learner autonomy. It needs to be noted that the purpose of the study was not to generalize about the implementation of investigations at all schools but to focus on the degree of learner autonomy and the support strategies used by teachers at schools where investigations were taking place.

The study adopted a mixed methodology research design which involved the collection of both quantitative and qualitative data. The quantitative data were collected by means of questionnaires which were administered to teachers and learners. The quantitative data were analyzed deductively using SPSS to generate frequency tables, and do correlations, cross-tabulations and Chi-square tests. Qualitative data were collected by means of classroom observations, teacher interviews and learner interviews. Inductive analysis of the text transcribed from the classrooms observations and interviews using NVIVO helped to identify common themes in relation to the research questions. The general trends that were quantitatively established were validated and explicated by the qualitative analysis. The data analyses resulted in certain assertions being made.

In this chapter, a summary of the findings, and conclusions, as well as a discussion of the implications for teaching and learning of science is presented. Some suggestions for further related research are also made.

6.1 SUMMARY OF FINDINGS

In answering the research questions certain empirical assertions were generated. According to Gallagher and Tobin (1991) these empirical assertions are “concise statements that present patterns and regularities that are arrived at inductively by reviewing data” (p. 84).

These empirical assertions are therefore the knowledge claims which represent the findings of the study. Four empirical assertions were generated in addressing the research questions.

The classroom observations of investigations illustrated that in real classrooms where investigations are being implemented there are a range of different types of investigations with varying degrees of learner autonomy. These investigations may be classified into structured, guided and open. In the structured investigation, there was more teacher control and less learner autonomy across the stages of the investigation. In the open investigation, the learner had almost complete autonomy. In the guided investigations, learners had more autonomy than in the structured investigation, but not as much as in the open investigation. The expo projects were different from the classroom investigations in two ways. Firstly, the learners have almost complete autonomy, from choosing the topic to drawing the conclusion. The teacher support is minimal. Secondly, the learners made extensive use of alternative resources such as the internet and family members.

Assertion One claims that the autonomy learners have in investigations, varies across the different stages of the investigation. On most occasions the teacher gives learners the investigation question and a plan to follow. Learners appear to have a large degree of autonomy in carrying out the plan and collecting data. Learners also appear to have substantial autonomy in evaluating data and drawing conclusions.

According to Assertion Two, when learners are actively involved in doing their own investigations, teachers and learners believe that it has a positive impact on their learning of science. The three potential benefits reported when learners do their own investigations, are that it is motivational, it facilitates conceptual understanding, and it leads to the development of scientific skills.

Assertion Three claims that when learners do have autonomy in doing investigations, teachers support them by asking questions, offering suggestions when they are making no progress, giving a prompt sheet which helps focus them on the stages of the investigation, and instructing the learners in the use of practical techniques.

According to Assertion Four, class size, availability of resources, the time available for

investigations, and teacher competence are identified as factors which influence the degree of autonomy learners have in investigations. Learners appear to have more autonomy in doing investigations at schools where classes are small, which are adequately resourced, where investigations are used in assessment, and where teachers are competent at investigations.

6.2 IMPLICATIONS AND RECOMMENDATIONS FOR PRACTICE

The RNCS (Department of Education, 2002b) specifies that through investigations, teachers should create opportunities for learners to demonstrate that they are able to work independently. However, a finding of the study reveals that at schools where investigations are taking place, learners have only limited autonomy in choosing the investigation question and planning the investigation. In light of the requirements specified by the RNCS (Department of Education, 2002b) for Natural Science, it is apparent that learners should be given increased opportunities for autonomy when doing scientific investigations.

A model of autonomy levels of investigations

Based on the review of literature and the findings of the study, the researcher proposes a model which can be used by teachers and curriculum planners to facilitate a transition towards investigations where learners have more autonomy. The model in Table 6.1, which is similar in structure to that proposed by Gabel (2001) shows a progression where learners have little autonomy at level 1, with a gradual increase of this autonomy, until level 5 is reached where learners have complete autonomy. The model identifies the autonomy level of learners based on whether the teacher or learner has responsibility for the stage of the investigation. For example, a learner is at autonomy level 3 if the teacher provides the topic and question, and the learner plans the investigation, collects data, analyses the data and draws a conclusion. An investigation done at autonomy level 5 would correspond to a science expo investigation, where the learner has autonomy over all stages of the investigation. It needs to be mentioned that although this was not encountered in the study, it is quite possible that the stages may be mixed so that both the teacher and learner may be jointly involved at a particular stage. Also, a teacher demonstration where the teacher does all stages and the learner only observes may be considered as autonomy level 0.

The model can be used in curriculum development programmes at schools where learners have limited autonomy in doing investigations.

Table 6.1 Model of autonomy levels of investigations

Investigation stages	Autonomy level				
	1	2	3	4	5
Choosing the topic	T	T	T	T	L
Formulating the question	T	T	T	L	L
Planning	T	T	L	L	L
Collecting data	T	L	L	L	L
Analysing data and drawing a conclusion	L	L	L	L	L

Note: T = Teacher controls and carries out
L = Learner has autonomy and responsibility to carry out

Firstly, the model labels the stages of the investigation and autonomy level of learners in investigations, and so provides a common language for teachers, curriculum planners and researchers to engage with the issue of learner autonomy. Secondly, the model can be used as an instrument to gauge and report on the autonomy level of learners at schools. Thirdly, once the autonomy level of learners has been gauged, the model can be used by professional development practitioners in structuring a developmental programme in the form of a series of investigation tasks which represent a progression towards autonomy level 5.

Factors affecting the degree of learner autonomy

The study in trying to explain the finding relating to the degree of autonomy learners have, identified certain factors which affect this autonomy. It was found that class size and the availability of resources affected the degree of autonomy learners had when doing scientific investigations. Learners were more likely to have greater autonomy where the class size did not exceed thirty, and at schools which had adequate science resources.

Teachers also indicated that the preferred classroom arrangement for the implementation of scientific investigations is that the learners work in small groups. These findings have implications for the context of the South African education system. The great majority of schools in South Africa are characterised by large class sizes and a lack of resources (Taylor, Muller & Vinjevold, 2003). It would therefore appear that in the present circumstances the implementation of scientific investigations in which learners are given more autonomy is severely hindered. It is also interesting to note that at schools where investigations did take place, a significant percentage of these investigations were done at home or partly at home, and the resources came from home. The teachers therefore rely on the learners' access to their own resources. A case in point of this situation is the researcher's school where learners were given the task of investigating the factors affecting resistance in an electrical circuit. In this case the learners were asked to bring their own batteries, connecting wires, light bulbs, different types of metal, and metals of different thickness. This has implications for equity in schooling, in that teachers cannot rely on learners from low socio-economic backgrounds to do investigations at home and bring resources to school. The department of education therefore cannot depend upon outside resources for the curriculum to be implemented. A possible strategy in dealing with the situation of large class sizes and poorly resourced schools is to establish resource centres in each school district so that learners from such schools can have the opportunity to do investigations at these centres. An example of such a centre is CASME (Centre for the Advancement of Science and Mathematics Education) at the University of KwaZulu-Natal. However, the researcher does not discount that learner-centred investigations can take place at schools where circumstances are unfavourable. It is recommended that further research be conducted to explore strategies that can be employed so that investigations do take place at poorly resourced schools with large class sizes. Those involved in curriculum implementation and review should take account of these factors, and perhaps adjust expectations until teacher to learner ratios in the classroom are reduced and resources become more available.

A further factor was the pressure of content coverage and assessment demands of the school. Investigative work can be time consuming and sometimes may extend over a number of periods on the timetable. Teachers have indicated that although the learning benefits of doing investigations is undoubted, they are reluctant to use this approach in their teaching as it means there is not enough time to complete all sections in the content.

While this may be the case, teachers need to realise that in outcomes-based education, the outcomes address not only knowledge, but also the skills, attitudes and values. The cornerstone of outcomes-based education is that it should be learner-centred and activity-based. It is incumbent upon teachers that learners do investigations as it is described in terms of the Learning Outcome One of the RNCS (Department of Education, 2002b). Consequently, those in charge of curriculum implementation should reduce content requirements to encourage more investigations taking place. In assessing learners, the assessment policy of the school must be aligned with the assessment principles used in outcomes-based education. According to the RNCS, assessment is a “continuous, planned process of gathering information about the performance of learners measured against the Assessment Standards of the Learning Outcomes” (p. 77). Continuous assessment is the chief method by which assessment should take place according to this curriculum. This is a departure from the traditional curriculum where assessment was primarily summative. The implication is that there will be less pressure in preparing learners for tests and exams and hence there will be more time for learners to do investigations. This can be achieved only on condition that there are no expectations to cover large amounts of content.

Teacher competence was identified as another factor. It is apparent that teachers who lack competence in scientific investigations avoid doing investigations, or if they do include investigations in the classroom, are reluctant to relinquish control and give learners autonomy in doing the investigations. If scientific investigations are to feature prominently in the science curriculum it is imperative that teachers-in-training do learn about investigations, and are given ample opportunity to do investigations on their own. For teachers-in-practice, it is recommended that the education department, in collaboration with the teacher training departments of tertiary institutions offer in-service training courses which focus specifically on scientific investigations. Teachers need to feel confident in their own ability if they are to implement investigations in their teaching.

Benefits of learners doing their own investigations

The study has found that teachers and learners believe investigations have potential benefits for the learning of science. Firstly, it was found that investigations are motivational. Given that all learners do Natural Science in the GET phase, whereas only a small percentage of learners choose to do Physical Sciences in the FET phase (Department

of Education, 2001), it is possible that by doing investigations in Grade 9, learners may be motivated to continue with science in Grade 10. This is one of the aims of the department of education and is one of the thrusts of its policy on science education described in the document, National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training (Department of Education, 2001). The department of education seeks to increase the enrolment of learners in Physical Science, as there is generally a poor output of graduates in Grade 12. Secondly, it is believed that investigations improve conceptual understanding. The TIMSS-R study (1999) reports that learners lack of understanding of science concepts contributes to their poor performance in science. The learners' understanding of science concepts may improve if they are given the opportunity to investigate these concepts experimentally. Thirdly, the contribution of investigations to science learning is that it leads to the development of skills in the laboratory. This is especially important in South Africa where in the past heavy emphasis has been placed on the teaching of content at the expense of skills, and now additional emphasis is being given to skills and attitudes.

A model of staged support from teachers

If learners are to progress to higher levels of autonomy which are described in Table 6.1, teachers need to offer support when necessary. The support strategies identified from the literature review and used by teachers in this study, can be implemented in supporting learners towards greater autonomy in doing investigations. The following is a staged development plan for increasing learner autonomy in investigations. In increasing learner autonomy, teachers need to firstly know about the prior experience and skills learners possess, the size of the class, the resources available, and the time available for the investigation. As a novice, the learner may have little or no experience of investigations. Before exposing learners to any investigations the teacher may give learners exercises in formulating questions, identifying variables, using apparatus, drawing graphs etc. The teacher may then model the stages of an investigation. As he is doing the investigation he could label the stages and explain what he is doing. The learners may be given some autonomy here in analysing the data and drawing a conclusion. At the next stage of autonomy, learners may be given the investigation question, and a plan with step-by step instructions. The learners would then have autonomy in collecting data, analysing data and drawing a conclusion. At this stage of autonomy, the teacher may support learners by

asking them questions so they reflect upon what they are doing, give instructions in the use of practical techniques, show learners how to use an apparatus they are not familiar with, and remind learners of precautions to be taken. When learners have had sufficient experience at this level of autonomy they may progress to a higher level where they may be given autonomy in planning an investigation. Here the learner would be asked to produce a detailed plan which outlines the steps they would follow. At this stage of the investigation, the teacher would support the learners by asking questions related to the steps they will take, the apparatus they have chosen, and precautions to be taken. At this stage the teacher may need to offer suggestions if the plan is inadequate. The teacher may also ask learners to revise the plan if the apparatus they have chosen is not available or if the investigation cannot be carried out in the time available. If learners are working in small groups the teacher can ask the group to identify the role the members will play when the investigations is being carried out. When learners are competent at this level of autonomy they may be given the opportunity to do an investigation at a higher level where they also formulate the investigation question. The teacher may support the learners here by asking learners to identify the independent, dependent and control variables. He would also offer advice on whether the question can be investigated with the available resources. After learners have done a number of investigations, they may be asked to do an investigation which given them autonomy at all stages. From the above it is evident that as learners gain more experience and expertise at doing investigations, they progress to a higher level of autonomy. Accompanying this, the teacher support is gradually withdrawn. This withdrawal of teacher support is represented in the following model (Figure 6.1). This model is similar to the model for a scaffolded inquiry constructed by Gabel (2001).

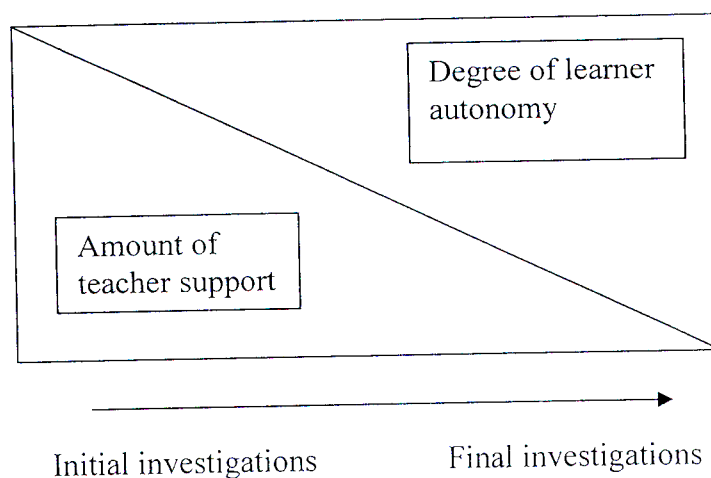


Figure 6.1 Model for teacher support with changing autonomy

The implementation of investigations based on the above model would describe a situation where learners who lack experience and expertise at investigations would have limited autonomy with a large amount of teacher support. As these learners acquire more experience and expertise by doing investigations, they will gain more autonomy and the teacher support will fade. The model of the autonomy levels already described, together with this model can serve as important tools in facilitating the implementation of investigations at schools.

6.3 IMPLICATIONS FOR FURTHER RESEARCH

Due to the prominent place given to scientific investigations in recent curriculum reform initiatives in South Africa, the findings of the study can be used to stimulate further research in this field because it has raised problems with current practice that need to be confronted by our science education community. When the researcher embarked upon this study, the FET curriculum was still in its draft stage. Since then the National Curriculum Statement for the FET phase has been produced. According to this statement the place of scientific investigations in the Physical Sciences curriculum is addressed in Learning Outcome One. With the advent of the FET curriculum, it has now become curriculum policy for learners in Grade 10 to do investigations. The assessment guidelines for Physical Sciences (Department of Education, 2005) suggests that learners do two whole investigations per year. With the limited autonomy learners have in Grade 9, it would therefore be interesting to study to what extent scientific investigations are being implemented in Grade 10 and the degree of autonomy learners have. Also, whether learners arrive in Grade 10 with the expected skills to do investigations, and whether there is some progression in terms of learner autonomy from Grade 9 to Grade 10.

The study has identified the availability of resources as key factors which affect the implementation of scientific investigations. Schools in South Africa vary drastically in terms of availability of resources. Generally, schools located in poor areas have little or no resources for science teaching. Schools in affluent areas are adequately or well-resourced. It has been found that where resources are inadequate, learners have very limited opportunities in doing scientific investigations. The reality of the South African situation is that a large number of schools are under-resourced. However, curriculum policy dictates

that teacher at all schools should be doing scientific investigations. An area of interest could be, What are the minimum resource requirements for learners to do investigations in the GET phase ? In view of these resource limitations at schools, teachers need to learn how to plan lessons on investigations by using materials that are available in the local community. Research into the use of such resources could provide guidance to teachers at under-resourced schools on how to overcome resource limitations in the implementation of learner-centred investigations.

Another factor that teachers have to contend with in the implementation of scientific investigations is large class sizes. In this regard, further research could explore whether the size of groups affect the investigation skills acquired by learners. This leads to the question of whether there is a critical group size in investigation work for which maximum learning can take place.

Another area of concern apart from these factors mentioned, is the slow pace of change in teacher beliefs. Although the merits of learners being actively involved in their learning is well known, the study shows that not all teachers are prepared to give learners autonomy in their learning. Further research needs to be carried out into why despite well known benefits, some teachers do not subscribe to learner-centred teaching approaches.

As scientific investigations are new to the science curriculum, teachers with limited experience and expertise at investigations are not necessarily competent to teach investigations. The study has identified teacher competence as a factor which influences learner autonomy in investigations. The model of autonomy level (Table 6.1) can be used in a longitudinal study to determine whether the autonomy level of learners increases as teachers become more competent to teach investigations.

The study has highlighted the idea of learner readiness in planning investigations. For example, teachers 4 and 5 explain that they allow learners to plan their investigations once they realize they are ready to do so (p. 106). Reaching this state of readiness is described as a “gradual process”. Research focusing on how expert teachers guide the development of this readiness and appraise for it, could yield important data to support the professional development of teachers in this area.

6.4 CONCLUDING REMARK

Scientific investigations form a core aspect of the science curriculum in the GET phase in South African schools. The implementation of scientific investigations at schools presents a new challenge to teachers as it signals a shift from a teacher-centred to a learner-centred approach. Teachers are now faced with a situation of relinquishing their traditional control in the classroom and using support strategies in facilitating the learners' progress towards greater autonomy. The study has highlighted that at schools where investigations are taking place, the learners have only limited autonomy. There are certain factors which affect the degree of autonomy learners have in doing scientific investigations. These factors if not addressed will no doubt impede progress towards greater learner autonomy in scientific investigations. Apart from describing and explaining the present situation, the other contribution of the study is that it firstly presents a model to gauge the current autonomy level of learners, and then a model which offers suggestions on how teachers can support learners towards greater autonomy. It is anticipated that both models would help teachers inform their practice in facilitating more open investigations where learners have more autonomy. The models may be seen as tools which teachers can use to consciously construct and choreograph an environment which support learner autonomy. The study and its findings therefore will aid teachers in narrowing the gap between what curriculum planners expect should happen in the classroom and the current state of affairs.

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APPENDICES

- A Teacher questionnaire
- B Learner questionnaire
- C Interview schedule
- D Science expo questionnaire
- E Science expo photographs
- F Worksheet of the scientific method given to Miss Essop's class
- G Worksheet given to Mr Botha's class
- H Worksheet given to Mr Pillay's class
- I Worksheet given to Mrs Naidoo's class

Questionnaire to Grade 9 Natural Science Educators

Dear Colleague

I am currently engaged in research on scientific investigations at the Grade 9 level for my Ph.D. at the University of KwaZulu-Natal. *My study focuses in particular on learners doing investigations and the guidance given to them by the teacher.* I believe that the findings of this research could contribute towards the curriculum reform initiatives currently taking place, and also inform our teaching practice.

In this regard, I would appreciate if you would complete the enclosed questionnaire. Please return the questionnaire to me in the stamped, addressed envelope provided. I wish to assure you that all information obtained will remain confidential and that no information released or reported will identify the school or participant. You are not required to provide your name, although it will assist me to follow up some of your responses and obtain clarification if necessary.

Should you have any queries please feel free to contact me.
Thanking you in anticipation of your co-operation.

Yours sincerely

Mr U.D. Ramnarain

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4092

Background information on Scientific Investigations

There is a wide variety of practical work in the teaching and learning of science. Different types include teacher demonstrations, teacher-directed experiments, learner experiments, fieldwork and investigations. The National Curriculum Statement (2003) for Natural Science states that investigations are to play a crucial role in the teaching and learning of science. The place of scientific investigations is addressed through learning outcome one which states that:

The learner will be able to act confidently on curiosity about natural phenomena, and to investigate relationships and solve problems in scientific, technological and environmental contexts.

According to this document, **three stages** may be identified in the investigative process.

These are:

- planning investigations,
- conducting investigations and collecting data, and
- evaluating data and communicating findings

A number of different kinds of scientific investigations have been recognized within classrooms. Learners carry out investigations which relate to:

- a *construction* where learners build something e.g. a model of a house with lights.
- a *comparison* where learners manipulate variables to find something out e.g. which washing powder works best?
- an *explanation* where learners do an investigation to find something out e.g. what factors influence the drying of clothes?
- an *exploration* where learners explore a phenomenon in order to understand it e.g. the bending of light through different media.

I would be most grateful if you would assist me in completing this questionnaire on scientific investigations.

Section A: Personal and School details

When given a choice, mark your chosen response by placing a cross in the appropriate block. Otherwise, indicate your response in the space provided.

1. How many years experience do you have teaching science?

0 to 5 years	6 to 10 years	11 to 15 years	16 to 20 years	20+ years
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2. How many departmental Outcomes-based Education (OBE) workshops in Natural Science have you attended? (if you did not attend any, please indicate 0)

3. How competent do you consider yourself to teach C2005 Grade 9 Natural Science?

very competent	Competent	unsure of my competence	I lack competence in some areas
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4. How competent do you consider yourself to teach learners the skill of doing investigations?

very competent	Competent	unsure of my competence	I lack competence in some skills
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5. How would you describe your school in terms of availability of resources for teaching science?

no resources for science teaching	poorly resourced	adequately resourced	well-resourced
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6. How many science laboratories or classrooms with facilities e.g. water, electricity, gas, storage etc. to do science investigations does your school have? (if no facilities, please indicate 0)

7. What percentage of your learners have English as their first language?

0 to 20%	21 to 40%	41 to 60%	61 to 80%	81 to 100%
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8. How many Grade 9 classes are there at your school?

9. What is the average number of learners in each Grade 9 class?

1 to 9	10 to 20	21 to 30	31 to 40	41 to 50	more than 50
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Section B

The following items relate to the *implementation of scientific investigations* in your Grade 9 class in 2003. Some of the terms used are explained in the introduction to the questionnaire.

When given a choice, mark your chosen response by placing a cross in the appropriate block. Otherwise, indicate your response in the space provided.

10. How many scientific investigations were conducted in a Grade 9 class in 2003? (if no investigations were conducted, please indicate 0)

NB: If no investigations were done in 2003, proceed to Section D.

11. How many of each type of investigation were carried out?(the different types are described in the introduction).

Indicate the number of each in the blocks below.

construction	comparison	explanation	exploration	other

12. What was the most common source of the questions that were investigated?

from the education department	from books on investigations	from science teaching colleagues	I made them up myself	learners suggested the questions
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13. During scientific investigations, how was the class organized most of the time?

learners in one large class group	learners in a number of small groups	learners in pairs	learners work by themselves
-----------------------------------	--------------------------------------	-------------------	-----------------------------

14. Where and when did learners do most of the work on the investigations?

mostly at school during science lessons	mostly at school after hours	about equally at school and at home	mostly at home
---	------------------------------	-------------------------------------	----------------

15. Where did the resources for the investigations come from?

mostly from the school's resources	mostly from my own resources	mostly from the learners' own resources	other
------------------------------------	------------------------------	---	-------

The following statements relate to how scientific investigations take place in your class.

Place a cross in the box that corresponds to your choice.

		NEVER	SELDOM	SOME-TIMES	OFTEN	ALWAYS
	In choosing the question...					
16	I give the learners the investigation questions.					
17	The learners decide on what variables to investigate.					
18	The learners formulate the question but I identify which variables are to be investigated.					
	In planning how to investigate the question...					
19	The learners decide what method to follow.					
20	The learners decide what data to collect.					
21	The learners decide what apparatus to use.					
	In carrying out the investigation and collecting data...	NEVER	SELDOM	SOME-TIMES	OFTEN	ALWAYS
22	The learners conduct the investigation on their own without being told what to do.					
23	The learners follow my step-by-step instructions.					
24	I do the investigation and the learners observe.					
	In drawing conclusions...					
25	The learners make their own conclusions from the results without my help.					
26	I tell the learners what the conclusions are.					
27	I help the learners understand the data collected so that they can reach the conclusion.					

Section C

The following statements relate to the strategies used in supporting learners doing scientific investigations. *Place a cross in the box that corresponds to your choice.*

		NEVER	SELDOM	SOME-TIMES	OFTEN	ALWAY
28	I help learners to clarify their investigative questions.					
29	I offer learners suggestions when they are making no progress in the investigation.					
30	I give learners a prompt sheet which helps to focus them on the stages of the investigation.					
31	When learners are conducting the investigation, I ask them questions so they may reflect on what they are doing.					
32	I show learners how to use an apparatus they are not familiar with.					
33	I refer learners to books they can look up in the library to assist them in the investigation.					
34	If the findings of the investigation are not scientifically correct, I ask learners to review their plan.					
35	When learners are doing the investigation, I choose to only observe what they are doing without intervening.					

Section D

The following statements relate to *your perceptions* of scientific investigations i.e. how you think investigations should be used in teaching and learning and their value for learning.

Please place a cross in the box that corresponds to your view.

		DISAGREE	UNSURE	AGREE
36	When learners do their own investigations, they develop more of an interest in science than when they do investigations set by the teacher.			
37	When teachers give students step-by-step instructions for an investigation, more learning takes place than when learners do their own investigations.			
38	When learners do their own investigations, it helps them develop a better understanding of science concepts than following a teacher's step-by-step instructions.			
39	When learners do their own investigations, it leads to the development of their scientific skills.			
40	In Grade 9, learners are capable of planning and carrying out their own investigations.			

	How often do you think...	NEVER	SELDOM	SOME-TIMES	OFTEN	ALWAY
41	Learners should decide what factors or variables to investigate.					
42	Learners should formulate their own questions to investigate.					
43	Learners should devise their own methods to investigate a problem or question.					

Do you have any comments you would like to make about investigations in Grade 9?
If so, please use the space below or attach a separate sheet of paper.

OPTIONAL: PLEASE WRITE YOUR NAME AND THAT OF YOUR SCHOOL IN THE SPACE PROVIDED.

NAME OF EDUCATOR: _____ SCHOOL: _____
SHOULD I HAVE ANY FOLLOW-UP QUESTIONS WILL YOU BE AVAILABLE FOR AN INTERVIEW? _____

Questionnaire for Grade 9 learners

This questionnaire asks about scientific investigations which take place in your classroom.

A scientific investigation is a practical activity which involves the following stages:

- defining the research question or hypothesis,
- devising a plan of action,
- conducting the investigation and collecting data, and
- drawing conclusions

EXAMPLE: I will now describe an investigation in terms of the above stages.

Consider a typical investigation which looks at the effect of water temperature on how fast sugar dissolves in water.

The variables of water temperature and time taken are identified to formulate a question and a hypothesis.

Research question: How does water temperature affect the time taken for sugar to dissolve?

Research hypothesis: The higher the water temperature, the faster the sugar will dissolve.

Devising a plan of action: The plan will focus on how to set up an experiment to accurately measure the time taken for sugar to dissolve in water at different temperatures, and how many measurements to make. A decision will also be taken on how to control and keep constant the interfering variables such as the volume of water and the mass of sugar added.

Conducting the investigation and collecting data: This involves setting up and carrying out the experiment to measure the time taken for equal amounts of sugar to dissolve when added to equal volumes of water at different temperatures. The data may be shown in a table with the headings water temperature (°C) and dissolving time (seconds).

Drawing conclusions: Here the results from the table will be analyzed by looking for a pattern or relationship that helps to answer the question or address the hypothesis posed initially.

I would be most grateful if you would assist me in completing this questionnaire on scientific investigations.

Instructions

1. Please respond to all items in both sections.
2. There are no 'right' or 'wrong' answers. This is NOT a test. All information provided will be confidential.
3. In order to mark your chosen response, please place a cross in the appropriate block. For example, if your favourite colour is green you will indicate it as follows:

red	blue	green X
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Section A

1. What is your age?

12	13	14	15	16	17
----	----	----	----	----	----

2. Do you use English as your home language?

yes	No
-----	----

3. How many science laboratories or classrooms with facilities e.g. water, electricity, gas etc. to do scientific investigation does your school have?

one	two	three	four	more than four
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4. How many learners are there in your natural science class?

1 to 9	10 to 20	21 to 30	31 to 40	41 to 50	more than 50
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5. How many scientific investigations have been conducted in your class in 2003?

one	two	three	four	more than four
-----	-----	-------	------	----------------

6. During the scientific investigations, how were you and your classmates organized most of the time?

we all worked together in one large class group	we worked in a number of small groups	we worked in pairs	we worked on our own
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7. Where did the resources such as the apparatus, chemicals etc. for the investigation come from?

mostly from the school	Mostly from my home	other
------------------------	---------------------	-------

8. Can you briefly describe one of the investigations you have done in 2003.

Section B

Place a cross in the box that corresponds to your choice.

The following statements relate to how scientific investigations take place in your class

		NEVER	SELDOM	SOME-TIMES	OFTEN	ALWAYS
	In choosing the question...					
9	The teacher gives us the investigation questions.					
10	The learners decide on what variables to investigate.					
11	We formulate the question but the teacher identifies which variables we shall investigate.					
12	The teacher helps us to clarify the investigation question.					
	In planning how to investigate the question...					
13	The learners decide what method to follow.					
14	The learners decide what data to collect.					
15	The learners decide what apparatus to use.					
16	We do not plan the investigation as the teacher tells us what method to use.					
	In carrying out the investigation and collecting data...					
17	We conduct the investigation on our own without being told by the teacher what to do.					
18	The teacher helps us if we don't know what to do.					
19	We follow the step-by-step instructions of the teacher.					
20	The teacher does the investigation and we observe.					
21	The learners make measurements and observations to collect the data.					

APPENDIX C INTERVIEW SCHEDULE

1. Provide some background information on yourself and describe the school in which you teach.
2. The introduction of OBE has signalled a paradigm shift from a teacher-centred to a learner-centred in the classroom. Are you in favour of this change?
3. Scientific investigations is the first learning outcome in the Revised National Curriculum document (2002). What is your view of scientific investigations as a learning strategy? How would learners doing investigations contribute to the learning of science?
4. How many investigations were conducted last year and how many have been done this year?
5. Do learners enjoy doing their own investigations? What aspects do they enjoy?
6. Do you feel more investigations should have been done? What prevented this?
7. What was your role in the investigation? Would this role be the same for all investigations or would it change?
8. Use an example of an investigation which was conducted last year to explain what you had done and what learners did?
9. Do you believe grade 9 learners are competent enough to conduct their own investigations through all 4 stages? Are they cognitively developed to carry out their own investigations?
10. If one were to place all 4 stages on a continuum from closed to open where would you locate most investigations conducted in your class?
11. Do you give learners worksheets with instructions to follow?
12. In planning the investigation, what support have you given the learners?
13. Have learners grasped the concepts of dependent and independent variables?
14. What do you do while learners are conducting the investigation? To what extent do you intervene should learners need assistance?
15. Do learners make their own conclusions/findings?
16. In your class, do you feel learners should be given the opportunity to assume more responsibility in the investigation?
17. What are some of the factors at your school preventing learners from doing their own investigations?
18. How well resourced is your school?
Do you believe scientific investigations can be conducted in a poorly resourced school? If so, how can this be done?
19. Do you believe certain investigations can be conducted by learners collecting
And using resources from their environment?
20. Do you give learners project work in the form of an investigation to do at home?
21. If so, do they enjoy doing this and how would you describe the quality of work?

APPENDIX D SCIENCE EXPO QUESTIONNAIRE

Learner Questionnaire: Science Expo

Please could you assist me with my research on investigations by answering the following questionnaire. Where applicable place a cross in the block of your choice.

1. What is the title of your project ?

2. Describe your project in terms of the following ?

construction	comparison	explanation	exploration	other
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3. Describe briefly the objective of your project ?

4. In doing this expo project, how did you work in relation to other learners ?

I worked on my own	I worked with another learner	I worked with two other learners	I worked with more than two learners
--------------------	-------------------------------	----------------------------------	--------------------------------------

5. How long did it take to do the project ?

Date started: _____

Date completed: _____

6. Has your science teacher assessed this project at school or was this project done only for the expo ?

7. Why did you decide to participate in the expo ?

8. What help did you receive in choosing your topic/question to investigate ?

9. What assistance did you receive while planning and collecting data ?

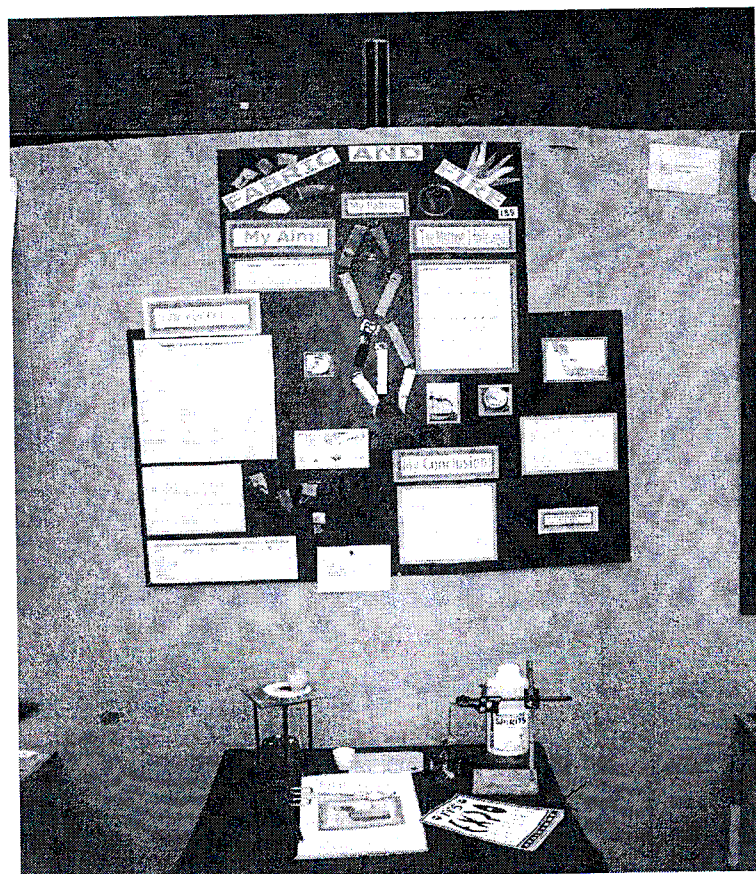
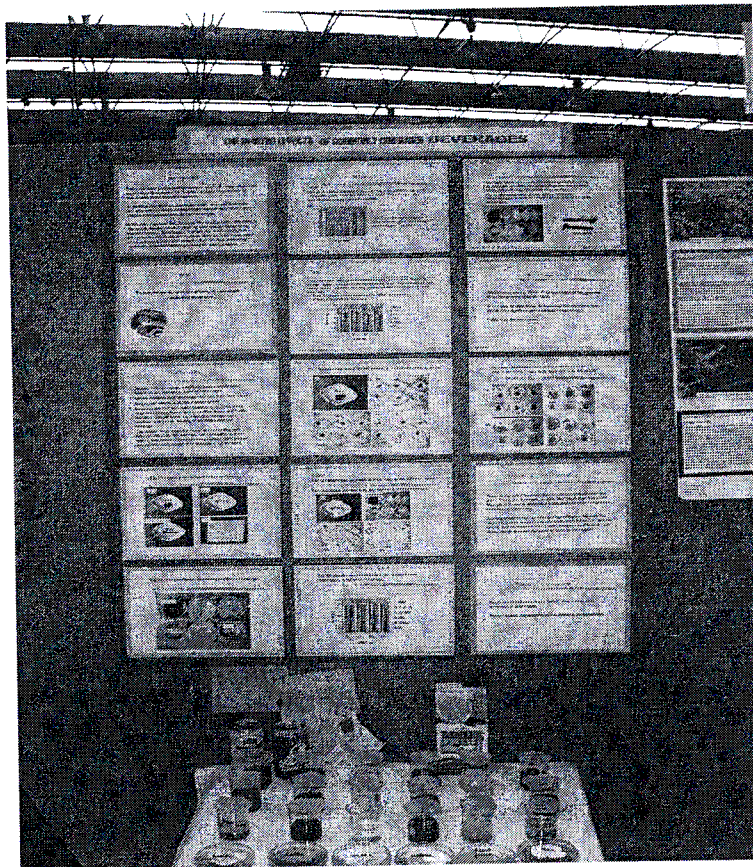
10. What resources did you use and where did you obtain them from ?

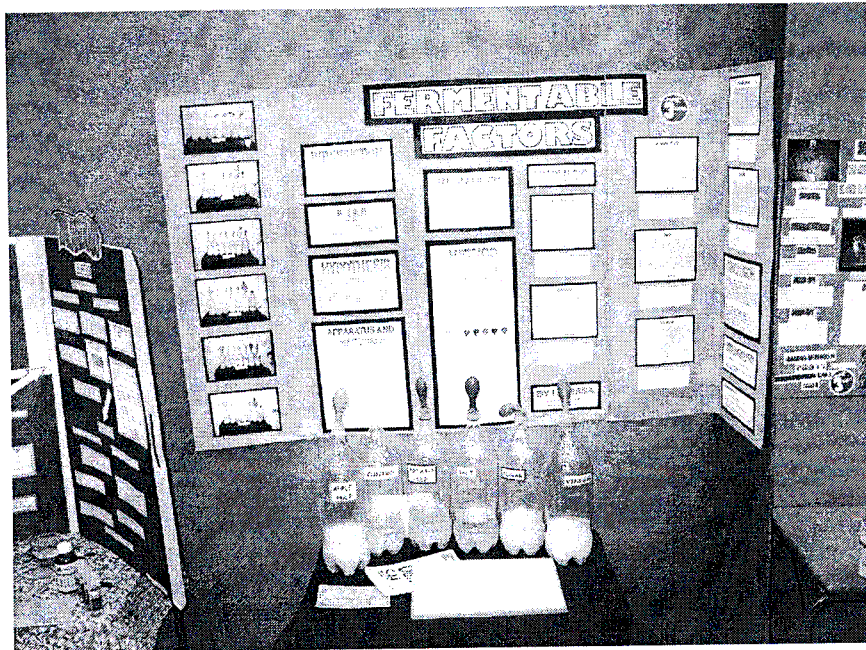
11. Where did you do most of the work on your project ? e.g. at home, at school, in the library etc..

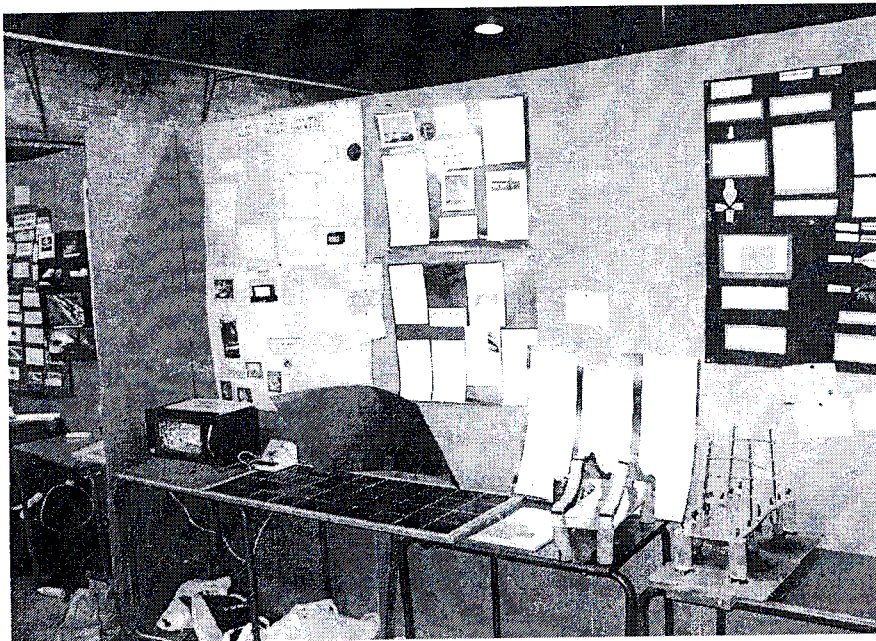
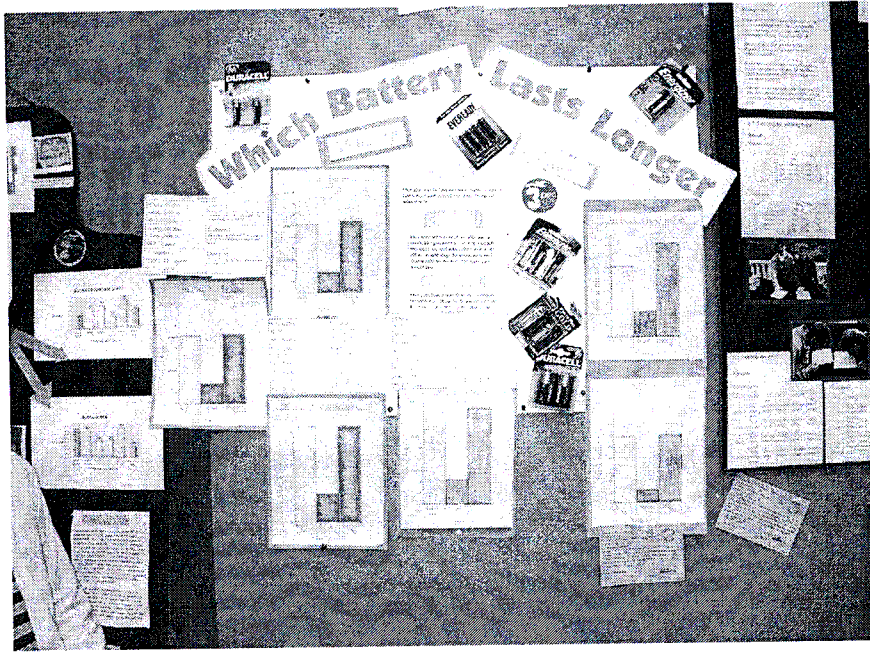
12. Compared to your normal school science lesson, what have you learned by doing this project ?

APPENDIX E

SCIENCE EXPO PHOTOGRAPHS







APPENDIX F WORKSHEET OF THE SCIENTIFIC METHOD GIVEN TO MISS ESSOP'S CLASS

The scientific method is a step-wise process that is used by a scientist in an investigation.

STEP 1: Stating the hypothesis

A hypothesis is a statement that a person believes is true about something.
For example, doing exercise increases the heartbeat.

STEP 2: Designing the experiment

The scientist presents a procedure/plan to test the hypothesis.

STEP 3: Experimentation

The scientist carries out an experiment according to his design.

STEP 4: Analysis of results

The results of the experiment are analyzed. The hypothesis is addressed by stating it is false, inconclusive or true.

STEP 5: Preparing a report

The scientist presents the details of his investigation in a report.

STEP 6: Replication

The scientist repeats the experiment in order to establish its reliability

APPENDIX G

WORKSHEET GIVEN TO MR BOTHA'S CLASS

Task: To identify factors which affect the resistance

Group members:

- 1.
- 2.
- 3.
- 4.

Factor

I think this will affect the resistance:

How will I investigate it ?

How does it affect resistance ?

APPENDIX H WORKSHEET GIVEN TO MR PILLAY'S CLASS

INVESTIGATION: To investigate the relationship between current strength and potential difference across a resistor.

Hypothesis

Can you predict what this relationship will be ?

Planning

Plan your investigation by discussing in your group what you will do. Then draw a circuit diagram.

Plan

Circuit

Conducting the investigation

Collect the apparatus you will need. Carry out the investigation by connecting the circuit and taking your readings.

Record your results in the following table :

NUMBER OF CELLS	VOLTMETER READING (V)	AMMETER READING (I)	V/I
1			
2			
3			

Conclusion

What can you conclude from the above table of readings

APPENDIX I

WORKSHEET GIVEN TO MRS NAIDOO'S CLASS

Density of objects

Aim: To investigate the floating and sinking of objects

Apparatus: Triple beam balance, measuring cylinder and a beaker.

Materials: Pieces of wood, glass, metal, a stone, water

Procedure:

1. Use the triple beam balance to find the mass of each object.
2. Fill the measuring cylinder with a 100ml of water. Add the object to it. Take the reading on the measuring cylinder. Subtract 100ml from this reading to get the volume of the object.
3. Add the object to the beaker of water and see whether it floats or sinks.
4. Tabulate all you results in the table below:

Objects	Mass(g)	Volume(cm^3)	Density(g/cm^3)	Float/sink

Water has a density of $1\text{g}/\text{cm}^3$. From the density values, what do think determines whether an objects floats or sinks ?
