# Exploring Zimbabwean Students' Approaches to Investigations in Advanced Level Chemistry

by

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# Preface

The work described in this thesis was carried out in the School of Education, University of KwaZulu-Natal from January, 2014 to December, 2016 under the supervision of Professor Paul Hobden and Dr Sally 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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# ABSTRACT

This thesis is an exploration of Advanced Level chemistry students' approaches to investigations in the Zimbabwean educational context. In this study, students' approaches are viewed from two theoretical perspectives, learning and designing. The participants' responses were used to categorise students by approach and to understand why specific approaches were predominant.

A pragmatic approach was adopted for this study based on the belief that multiple sources of data would lead to a deeper understanding of the research problem. A quasi-parallel convergent mixed-methods design was used. Data was collected from 50 students through survey and semi-structured questionnaires before purposively selecting 32 of them to participate in eight focus group discussions. Classroom observations were used to augment the qualitative data from the semi-structured questionnaires and focus group discussions. Part of the qualitative data from the semi-structured questionnaires and focus group discussions was transformed to compliment the quantitative data from the survey questionnaire. The quantitative data was subjected to descriptive statistical analysis while the textual qualitative data was analysed through coding, categorisation, identifying patterns and drawing assertions.

Four main assertions were drawn from the data to provide answers to the research questions. The predominant approaches were strategic from a learning perspective and iterative from a designing perspective. There was no common understanding of an investigation with some students defining it in terms of scientific inquiry and others focusing on process skills. Students' approaches were found to be influenced by various contextual factors with success in examinations dominating. By matching students' approaches to investigations from the two perspectives of learning and designing, new categories called hybrid approaches emerged. These hybrid approaches were then characterised and it is envisaged that this will act as a springboard for further research by science educators to enhance our understanding of students' approaches to investigations in similar contexts. The findings of this study are significant to high school chemistry teachers, teacher educators, resource persons and curriculum developers who endeavour to enhance the teaching and learning of Chemistry through investigations.

# ACKNOWLEDGEMENTS

The completion of this thesis was made possible by the astute guidance of my supervisors Professor Paul Hobden and Dr Sally Hobden. I am indebted to them for their countless reviews of my drafts, technical and moral support. To Professor Paul Hobden, now I have the answer to your question. Yes, I worked hard! To Dr Michele Stears and Professor Rogan who acted as the critical readers for my proposal, I cannot thank you enough but I wish you enough!

To my wife, Lorraine, who endured many days and nights of limited attention, I am sincerely grateful for her love, care and invaluable support. I have always wanted to be an exemplary father and I hope my son Dion Panashe has seen this in my practice. Now that I have set the academic bar height for you to aim for, go for it.

Amazing school Headmasters, Chemistry teachers and students opened their doors and hearts to facilitate the collection of data for this study and I would like to thank them for their support. Please continue doing the good work I witnessed during the data collection period.

I would probably be still thinking about doing doctoral studies where it not for a good old friend, Colin, who encouraged me join the University of KwaZulu-Natal back in 2012. For that, I am eternally grateful. I was the Master of Ceremony at my friend's graduation party and I hope we will swop roles one day.

# DEDICATION

This PhD thesis is dedicated to my father who sacrificed his tertiary education by channelling all his financial resources to educating his siblings, nephews and nieces.

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# CHAPTER 1
# INTRODUCTION

The purpose of this study is to explore the approaches used by Advanced Level Chemistry students when doing investigations. This covers the approaches in terms of learning as well as the process of designing, planning and carrying out investigations in Chemistry. This introductory chapter gives a brief outline of the study. In this chapter, I present an outline of the rationale and purpose of the study. In addition, the research approach gives a synopsis of how the study addresses the research questions.

## 1.1 Rationale of the Study

Doing investigations is one of the most challenging parts of practical work for Advanced Level chemistry students (Wellington, 2000). This is confirmed by the Zimbabwe School Examinations Council [ZIMSEC] (ZIMSEC, 2010, 2011, 2012a) in their examination reports where they indicate that Advanced Level (A-Level) chemistry students do badly in investigations. The literature reviewed also assert that a large proportion of teachers confess that the most challenging part of a science curriculum is managing investigations (So, 2003). This is worrying because the ability to design and carry out investigations is a critical part of chemistry education. One of the major aims of contemporary chemistry education is to develop and produce people who have the capacity to research, investigate and draw connections between everyday life and scientific concepts, employ scientific methods in solving real life problems and see the world through the lenses of scientists (Ozgelen, 2012). One way of achieving this is for science educators to place greater emphasis on practical work that aims to develop higher order skills in science students. To this end, investigations should be at the core of the practical work done in schools (Woolnough & Allsop, 1985).

The investigative approach to teaching and learning science is very different from what the researcher experienced during his high school days. Although investigations were part of the broader science curriculum, the practical examination assessment tasks were of the recipe type. The researcher’s graduation as a science teacher in 1996 coincided with major curriculum changes in all the science subjects at Advanced Level. The ability to design and execute investigations became an object of assessment. Through these assessment tasks, students demonstrate their competence in various process skills. This component of practical work is weighted at between 20 and 30% of the practical examination.

Investigations, in the Zimbabwean curriculum context, are practical activities where students design and carry out an experiment on their own. The chemistry teachers usually decide the investigation tasks to be done by the students. Since 1996, every examiner's report has noted a poor performance by students in this component of practical work as exemplified by the three reports cited earlier (ZIMSEC, 2010, 2011, 2012a). In addition, during my ten years of practice as an Advanced Level chemistry teacher and science resource person at provincial level, I had first-hand experience of the performance of students in investigations.

Designing and carrying out investigations accords students an opportunity to appreciate how experimental data underpinning much of our existing and accepted body of scientific knowledge was acquired as well as strengthen their understanding of it (Kanari & Millar, 2004; Millar, 2004, 2010). It is important for students to learn to design appropriate investigations to gather data which satisfies specific questions. This can be accomplished by doing collections of observations and measurements which are planned taking into account key aspects like accuracy, validity, reliability, data analysis and interpretation to arrive at conclusions based on the available data (Millar, 1997). If students leave high school without acquiring these skills, it implies that they are missing a part of science and are ill prepared for higher education and possibly professional work. In essence, it would mean a failure to satisfy the demands of one of the broad aims of chemistry education, resulting in a shortage of skilled personnel in science and engineering. A report by the Organisation for Economic Co-operation and Development (OECD) highlights that the global demand for scientists and engineers is increasing exponentially while there is a decrease in students pursuing science degrees (OECD, 2006). More recent studies in have also reported a decline in student enrolments in science in the UK (E. Smith, 2011) and Australia (Kennedy, Lyons, & Quinn, 2014). Meanwhile, Africa (and the world at large) needs scientists who can solve its problems and improve the lives of its people. A case in point would be inventing tractors that can run on water-based fuel cells, which would be ideal for poor farmers in rural parts of Africa.

The intended learning outcomes in high school science curricula are increasingly responding to marketplace expectations. High levels of mechanisation in today's industrial world have seen automated machines and robots drastically reducing the need for human labour in menial occupations. The increased use of artificial intelligence compels modern professionals to have better problem-solving skills to be employable as less routine jobs are on offer (Gijbels, van de Watering, Dochy, & van de Bossche, 2005). Such problem-solving skills can be developed by doing investigations.

The educational significance of determining students' approaches to investigations from a learning perspective is in its use in promoting an effective teaching approach, helping teachers to monitor and increase their effectiveness in the classroom, singling out those students who are underperforming as a result of unproductive learning strategies and determining the quality learning experienced by students (Angus, 2004). An understanding of students' approaches to investigations can therefore help teachers to devise appropriate teaching strategies, monitor their effectiveness as well as implement the necessary remedial interventions to assist underperforming students and improve how they learn (Mogre & Amalba, 2015). Approaches to investigations, in this study, refer to the nature of the relationship between the student, context and task in learning science (Biggs, Kember, & Leung, 2001) as well as the underlying processes and strategies used in designing and carrying out investigations.

## 1.2 The Aim of the Study

The aim of this study was to explore how Advanced Level Chemistry students approach (design, plan and carryout) investigations. The approaches used by students are tied to the type of learning (from investigations), their motives or intentions and their attitudes towards this component of practical work (Cano, 2007). An understanding of the approaches used by the students can be used to inform the teaching of Advanced Level Chemistry.

The study pursued the following objectives: to explore how students' approach investigations from a learning perspective; to explore how students' approach investigations from a designing perspective; to investigate students' understandings of what investigations are and to understand why students approach investigations the way they do. The key research questions derived from these objectives are as follows:

1. How do students approach investigations from learning perspectives?
2. How do students approach investigations from designing perspectives?
3. What are the students' understandings of investigations?
4. Why do students approach investigations the way they do?

The findings of this study are of significance to practising chemistry teachers who are tasked with developing skills required to successfully design and carryout investigations in their Advanced Level students, Education officers and Science Resource Persons who have the responsibility of organizing in-service education programmes, curriculum material developers who produce resources for chemistry teachers and students as well as informing science teacher training programmes at tertiary level.

## 1.3 The Methodology

In this study a pragmatic approach to research was adopted in order to take advantage of all methods deemed appropriate to collect data to satisfy the guiding research questions (Creswell, 2013; Descombe, 2008; Mertens, 2010). A *quasi parallel convergent* mixed method design was used to answer my research questions. In the absence of a design that would provide relevant data to answer the research questions, the parallel convergent design (Creswell & Clark, 2011) was modified to incorporate aspects of a quasi- mixed design (Cohen, Manion, & Morrison, 2011) in line with how the data was collected, analysed and interpreted. The partial mixing of data done during this study (explained in detail in chapter three) resulted in describing the design 'quasi parallel convergent'. Data for this study were collected through a survey questionnaire, a semi-structured interview, focus group interviews, document analysis and classroom observations. The participants were a convenience sample of 50 sixth form Advanced Level Chemistry students at two schools in their final high school year. While all 50 students responded to the survey questionnaire, only 32 were selected for the focus group interviews.

## 1.4 Outline of the Thesis

This thesis is composed of seven chapters. Chapter two describes the context in which the study is carried out, the Zimbabwean science curriculum context, with a special focus on the Advanced Level Chemistry practical component. The next chapter gives a brief account of the historical context of science practical work and the significant connections with the United Kingdom chemistry education curriculum. A review of the relevant literature on investigations as well as the theoretical framework on approaches to investigations is presented in subsequent sections of the same chapter.

In chapter three, the research design employed in this study, which is derived from a mixed method approach, is described and justified. In the same chapter, the researcher outlines how data was collected through a survey questionnaire, focus group interviews, and document analysis as well as classroom observations in a bid to understand the approaches to investigations used by the students.

The findings of this study are contained in three chapters. In chapter four, the findings related to the first research question on how students approach investigations from a learning designing perspectives are outlined and discussed. In chapter five, I present and discuss the findings that respond to the second research question on students' approaches to investigations from a designing perspective. Advanced Level students' understanding of investigations is dealt with in the first section of chapter six followed by a response to the last research question on why students approach investigations the way they do in the second section. A summary of the findings and answers to the research questions as well as some recommendations for further studies are put forward in the chapter seven. In the last chapter, I also highlight the limitations of this study, how they arose and the implications of the findings.

# CHAPTER 2
# A REVIEW OF RELATED LITERATURE

A review of related literature was done under three sections. The first section deals with the conceptual referents related to investigations in order to create an understanding of their meaning within the context of the participants and this study. The second segment explores global and Zimbabwean literature on investigations with a view to identifying the gap that will serve as the focal point of the study. In the third segment, I then use literature to develop an interpretive framework which will serve as the basis for making sense of the research data.

## 2.1 Teaching of Chemistry in Zimbabwe

Zimbabwe gained independence from British colonial rule in April 1980. Political independence did not necessarily result in immediate curriculum changes in education although there was increased accessed to education. Primary and secondary education continued to use a system which sees learners go through seven years of primary school education, two years of junior secondary school and two years of Ordinary Level (O-Level) studies. The junior secondary certificate national examinations have since been scrapped. Students who pass O-Level and want to go to university then proceed to Advanced Level (A-Level) which takes another two years.

Chemistry education starts in primary school where it is studied under an all-inclusive subject called Content. In junior secondary school, there is General Science. At O-Level science is studied under a range of subjects namely Chemistry, Physics, Physical Sciences, Biology, Human and Social Biology and Integrated Science, a home-grown version of Combined Science. At A-Level students take at least three subjects. The most common subject combinations for those who choose to do the sciences are: Chemistry; Physics and Mathematics or Chemistry; Biology and Mathematics. It can therefore be generalised that the majority of A-Level science students do Chemistry.

The University of Cambridge Local Examinations Syndicate (UCLES) did the assessment of students in Zimbabwe until a localisation process, which started in 1985, was completed in 2002. Consequently, the science curriculum used in Zimbabwe was the same as that of the United Kingdom and the scripts were marked abroad until the localisation process began. In the same token, all the curriculum changes introduced in chemistry education in the United Kingdom were also implemented in the Zimbabwean education system. Consequently, in order to understand the place of investigation in the curriculum, it is necessary to give an outline of the historical developments in chemistry education, and practical work in particular, in the United Kingdom.

The historical developments of practical work in science in the United Kingdom are well documented in the works of Gott and Duggan (1995), Wellington (1998), Woolnough and Allsop (1985). According to these authors nineteenth century chemistry education was characterised by lecture demonstrations as the mode of instruction of choice. The demonstrations were useful to illustrate or verify known theories. The early years of the twentieth century saw the emergence of the heuristic approach advanced by Armstrong (Woolnough & Allsop, 1985). This approach sought to "place pupils in the place of the original investigators" (p.15). While the approach placed huge emphasis on individual practical work to equip learners with relevant practical skills, the theoretical aspects of science were largely neglected. Around the 1920s the examination system had clear outlines on how practical skills were to be tested.

In the 1950s there were loud voices calling for a learner-centred approach to practical work in which learners would do open-ended investigations (Gott & Duggan, 1995). Learners were expected to do investigations with an emphasis on method rather than content. The 1960s saw the birth of the Nuffield Science initiative which proposed the discovery approach to practical work. It brought with it more emphasis on integrating scientific theory with practice. Science educators were given a collection of experiments to do with their learners. While this approach was deemed successful and achieving the desired outcomes, its major limitation was that of being too prescriptive. Practical work was all recipe type (Gott & Duggan, 1995).

According to the above-mentioned authors, a revision of the discovery approach gave birth to the process approach in the 1980s. The process approach was aimed at developing transferrable skills in learners, that is, process skills (Gott & Duggan, 1995; Woolnough &

Allsop, 1985). The work of the Assessment of Performance Unit led to the holistic approach to practical work in early 1990s (Gott & Duggan, 1995). Investigative work was incorporated into the science curriculum. Investigations were intended to give learners opportunities to apply concepts and cognitive processes while sharpening their practical skills.

As a result of the curriculum changes with a shift towards investigative practical work in science, the University of Cambridge Examinations Syndicate introduced the assessment of planning skills in their international A-Level Chemistry syllabus in 1996. In the practical examination, learners were assessed on their ability to design, plan and carry out investigations. Notably, the investigations were short term, something that can be accomplished in less than an hour.

The complete localisation of the A-Level examinations in Zimbabwe in 2002 did not bring with it wholesale curriculum changes. In fact, the Zimbabwe Examinations Syndicate (ZIMSEC) adopted the UCLES syllabi and repackaged them in their own name. The nature of the assessment therefore remained the same with investigations an integral part of the chemistry assessment.

There are six broad aims outlined in the syllabus booklet. The syllabus aims are to:

1. provide, through well designed studies of experimental and practical chemistry, a worthwhile educational experience for all students, whether or not they go to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific import; recognise the usefulness and limitations, of the scientific method and to appreciate its applicability in other disciplines and in everyday life; be suitably prepared for employment and/or further studies beyond A-Level;

2. develop abilities and skills that are relevant to the study and practice of science; useful in everyday life; encourage efficient and safe practice; encourage the presentation of information and ideas appropriate for different audiences and purposes and develop self-motivation and the ability to work in a sustained fashion as well as accuracy and precision;

3. develop attitudes relevant to science such as objectivity; integrity; enquiry; initiativeness and insight;

4. stimulate interest in, and care for, the environment;

5. promote awareness that the study and practice of science are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations; the applications of science may be both beneficial and detrimental to the individual, the community and the environment and the use of information technology is

important for communication, as an aid to experiments and as a tool for interpretation of experimental and theoretical results;

6. stimulate students, create and sustain their interest in Chemistry, and understand its relevance to society. (ZIMSEC, 2012b, pp. 4-5).

Going through these aims, it is apparent that the curriculum designers intended to see practical work playing a pivotal role in the teaching and learning of A-Level Chemistry. The aims place huge emphasis on the development of cross-curricula critical skills, including process skills, which are required by students to become useful citizens.

The assessment objectives are presented in three categories (ZIMSEC, 2012, p. 6-7). These are: (a) knowing with understanding; (b) handling, applying and evaluating information; (c) experimental skills and investigations. While investigations are explicit in the third of these assessment objectives, both the first and second ones cover aspects of practical work too. For example, under the first assessment objective, students are expected “to demonstrate knowledge with understanding in relation to scientific instruments and apparatus, including techniques of operation and aspects of safety” (p. 6). The second assessment objective emphasises on students’ abilities in collecting, processing and analysing data. The third assessment objective, focusing on experimental skills and investigations, is central to this study. It is envisaged that by studying the A-Level Chemistry curriculum and doing the relevant practical work, students will be able to “plan, design and carryout out investigations; use techniques, apparatus and materials; make and record observations, measurements and estimates; interpret and evaluate observations and experimental results; select techniques and materials as well as evaluate and suggest possible improvements” (p. 7).

When students design, plan and carry out experiments they use their knowledge of related topics and concepts and process skills, which are also used by seasoned scientists when doing research. By doing this type of practical work, students develop higher order thinking skills which help them “to learn how to recognize, define and to an extent, solve individual and social problems” (Aydin, 2013, p. 52). It can also be argued that students who show competence in investigations are better equipped to identify and solve problems in their own everyday lives. The implication is that both instructional strategies and learning approaches should help students to link theory to the practical work as well as navigate from basic to integrated process skills.

The intellectual demands become more rigorous and challenging moving from assessment objective (a) to (c).

The assessment scheme for A-Level Chemistry has five examination papers, one of which is dedicated to the assessment of practical skills. Papers 1 to 4 are theoretical in nature while Paper 5 is the practical examination. The weighting of the papers is as follows: Paper 1- 72 marks; Paper 2 – 48 marks; Paper 3 – 40 marks; Paper 4 – 40 marks and Paper 5 – 50 marks. In reality Paper 5 is marked out of 75 and then scaled down to a mark of 50 for grading purposes (ZIMSEC, 2012b, p. 8). This distribution of marks shows that the practical examination (Paper 5) ranks second in terms of weighting in the final analysis. If the raw marks only were used, the practical examination would rank first in weighting. This highlights the central role of practical work in the teaching and learning of Chemistry at A-Level.

In the practical examination students are assessed on their designing and planning skills among other process skills. The weighting of this investigative component, on planning and designing, ranges between 20% and 30% depending on the context in which it is set (p. 9). The investigations may be of a quantitative or qualitative nature. Students will be asked to determine specific quantities (quantitative analysis) or solve observational problems by executing specific experiments (qualitative analysis). Notably the investigative problems may involve contexts that are not directly specified in the syllabus but requiring students to apply their knowledge of A-Level chemistry concepts and practical procedures. Strict examination conditions are applied where students are not allowed access to textbooks, note books or any other sources of information during the practical examinations.

There is stiff competition for places in schools offering A-Level science subjects when students make the transition from O-Level to A-Level for a number of reasons. Firstly, only those who pass five O-Level subjects, including English Language and Mathematics, with grade C or better can proceed to do A-Level. Secondly, to study Chemistry at A-Level, one should have a pass in O-Level Chemistry or Physical Sciences. Thirdly, not all A-Level schools offer science subjects because they lack the prescribed laboratory facilities for practical work. Consequently, there is stiff competition for the limited spaces to study science subjects like Chemistry in those schools which offer them. In many established schools, which offer science subjects at A-Level, it not uncommon to find that all the students achieved 5 A’s or better in their

O-Level examinations and have a grade A in Chemistry or Physical Sciences. The average number of students per A-Level Chemistry class across the country is 25. This number is determined and limited by the size and design of the laboratory found at each school. Specialisation starts at this level as students study subjects which are listed as the entry requirements for their intended degree programmes at various universities across the country.

The Zimbabwean curriculum is largely centralised and public examinations are a crucial determinant of the teaching and learning activities in the classrooms. The context is similar to the one obtaining in Hong Kong as described by Biggs (1991) in his study of the approaches to learning in secondary and tertiary students. Chalk and talk is generally believed to be an effective way of meeting curriculum expectations. The expository teaching method is often punctuated with references to examination techniques and examiners' expectations. As Biggs (1991) puts it, the teaching and learning context apparently promotes surface learning.

The teaching and learning culture in Zimbabwe places a lot of responsibility on the students. Schools, especially boarding schools, are characterised by study hours, which are monitored and strictly adhered to, during the evenings and weekends. In my experience as a student and teacher in Zimbabwe, there is a strong belief that effort and endurance are the pillars of academic success. This again resembles the Chinese culture which underscores that success is derived from effort and skill which is in sharp contrast to the westerners (from where the curriculum is borrowed) who believe that success is a product of skill (Biggs, 1991). The school system tends to reward only the best students in each subject or grade during prize giving ceremonies. The motivation to work hard for most of the students therefore comes from the need and desire to achieve excellent grades in public examinations, which would allow them to study medicine or engineering at university. This is exacerbated by the fact that only two universities in the country offer medicine and engineering resulting in a fierce competition for places. For boys to secure a place to study medicine or engineering at one of these two universities they have to achieve A's in three of Chemistry, Physics, Biology, Mathematics and Geometrical and Mechanical or Building Drawing. The girls have to achieve at least 2 A's. As a result, the system places a lot of pressure on students to work hard until their last high school day. There is a general belief that praising students frequently does more harm than good as it may induce them to put less effort while criticism is favoured as it is considered a necessary evil to keep students on their toes (Salili, Hwang, & Choi, 1989) as informed by Xunzi's theory of salvation through pain (Biggs, 1991). There is a visible concentrated focus on the academic behaviour (at the expense of the social behaviour) of students from both teachers and parents given that the teaching and learning activities are assessment driven (Biggs, 1991; Donnison & Penn-Edwards, 2012). On their part students idolise teachers who show content mastery, knowledge of examiners' expectations and regularly give them assessment tasks that simulate public examinations.

#### Summary

The Zimbabwean chemistry curriculum was adopted from UCLES who were tasked with assessing students at both O-Level and A-Level, the two major high school exit points. Consequently, the evolution of chemistry education in Zimbabwe was influenced by changes in the British curriculum. An increasing emphasis on inquiry learning in science education lead to the introduction of the assessment of planning skills as part of the A-Level chemistry practical examination in 2002. This curriculum innovation brought with it new challenges in teaching and learning Chemistry, especially the practical component. A highly competitive education context characterised by a few high schools teaching A-Level science subjects and only two universities offering degrees in the engineering and medical fields means passing Chemistry with good grades is crucial to both students and teachers.

## 2.4 Conceptual referents

Practical work is an integral part of high school Chemistry hence it is important to understand its meaning and purpose in chemistry education. There are different types of practical work done in science, one of which is investigations, which in turn are done in different ways depending on the context and objectives of the curriculum. In this section, I discuss different perspectives of practical work, scientific inquiry and investigations, the working definitions for the current study based on the Zimbabwean A-Level chemistry curriculum context.

### 2.4.1 Practical work in chemistry education

Practical work has been defined in many different ways by various science educators. This shows a lack of consensus in the meaning of practical work although it is considered by all to be a core component of science teaching and learning. Two of the more recent definitions of practical work found in literature were provided by Lunetta, Hofstein, and Clough (2007) and Millar (2010). Lunetta et al. (2007) define practical work as:

> learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world (for example aerial photographs to examine lunar and earth geographic features; spectra to examine the nature of stars and atmospheres; sonar images to examine living systems (p. 394).

On his part Millar (2010) defines practical work as "any science teaching and learning activity in which students, working individually or in small groups, observe and/or manipulate objects or material they are studying" (p. 109). In proposing this definition, Millar argues that the classic definition put forward by Lunetta et al. (2007) encompasses even activities in which students work with secondary data such as analysing and interpreting data in tabular or graphical form, activities which most science educators do not consider to be practical work. Another difference in the definition is that Millar points to the ways in which educators can organise their classes to do practical work (individually or collaboratively in small groups) something which is omitted by Lunetta et al. For the purposes of this research project, the definition by Millar is adopted since the practical work done by the A-Level chemistry students is limited to the chemistry laboratory context where they manipulate different chemicals and apparatus.

Many science educators (Hodson, 1990; Hofstein & Lunetta, 2004; Millar, 2010; Toplis & Allen, 2012; Woolnough & Allsop, 1985) have described the reasons for (or aims of) doing practical work and these can be summarized as: to motivate learners by stimulating interest and enjoyment; to enhance practical skills, problem solving abilities and argumentation from data; to enhance the learning of scientific knowledge; to give insight into scientific methods and develop expertise in using it; to enhance scientific habits and to challenge learners' misconceptions. In addition Millar (2010) highlights the central importance of practical work as "to link the domain of objects (tangibles) and observables (what can be seen) and the domain of ideas (not directly observable)" (p. 119). Based on these two domains, he states five learning objectives of practical work in chemistry education. The objectives encompass identifying and familiarising with objects and phenomena; learning facts; learning concepts; learning relationships and learning theories or models. The first two relate to the domain of objects and observables while the last three fall under the domain of ideas. According to Millar these two domains will be part of all types of practical work in chemistry education.

Woolnough and Allsop (1985) classified practical work done by students as three activities, namely; exercises, experiments and investigations. Exercises would be designed to enhance students' practical skills and techniques and experiments would be aimed at according students a feel for phenomena. Investigations are meant to give students opportunities to practice problem solving just like real scientists. Millar (2004) added a fourth category of activities which are intended to support the learning of scientific ideas, concepts and theories. This research will focus on the third class of practical activities proposed by Woolnough and Allsop, investigations, which embodies the concept of scientific inquiry.

### 2.4.2 Scientific inquiry, scientific methods and process skills

*Scientific inquiry*: There seems to be no consensus on the definition of inquiry but most of its characterisation is similar (Anderson, 2002; Gott & Duggan, 2007; Khan, 2007; Martin-Hansen, 2002). One way of defining inquiry is offered by Hammer, Russ, Mikeska, and Scherr (2008), who say "inquiry in science is the pursuit of coherent, mechanistic accounts of natural phenomena" (p. 13). The breadth of this definition includes a diversity of epistemic classroom activities such as seeking assistance or guidance from the teacher, designing and conducting an experiment and predicting the outcomes. Perhaps this definition is linked to the notion that inquiry always requires scientific reasoning coupled with a meticulous use of the language of science and yet Warren, Ballenger, Ogonowski, Rosebery, and Hudicourt-Barnes (2001) argue that students can practice inquiry by using everyday language to make sense of their everyday experiences. To add weight to this idea, Tang, Coffey, Elby, and Levin (2010) argue for a change in the enactment of scientific inquiry by science teachers "in order to emancipate the students from mandatory futile learning of scientific methods, so they could truly engage in productive thinking and practice through inquiry" (p. 47).

A different definition of inquiry, which is adopted for the current study, comes from Martin-Hansen (2002) who understands scientific inquiry to be the work scientists do when they study the natural world, proposing explanations that include evidence gathered from the world around them. This definition differs from that put forward by Hammer et al. (2008) since it directly points out what scientists do which can be emulated by high school students(Martin-Hansen, 2002). At high school level, scientific inquiry will include student activities such as posing questions, planning investigations, and reviewing what is already known in light of the experimental evidence that mirrors what scientists do. Martin-Hansen identifies and describes four different types of inquiry. The first one is o*pen or full inquiry*. It is a student-centred approach that starts with a student's question, before designing and conducting an investigation and reporting the results. This approach most closely resembles what scientists do. The second one, *guided inquiry,* is characterised by the teacher assisting students develop inquiry investigations in the classroom (laboratory). The teacher chooses the topic and question for investigation and students decide how to proceed with the investigation. In the context of this study, and based on my personal experiences, guided inquiry seems to be the dominant form of inquiry in Zimbabwean A-level chemistry classrooms with the teachers providing the questions and students designing and conducting the investigations.

The third one, c*oupled inquiry,* combines a guided-inquiry investigation with an open-inquiry investigation. The teacher provides the questions to investigate at the beginning then gradually shifts to a more-student centred approach where students have total autonomy in all the stages of the investigation. The fourth one is s*tructured inquiry* which is also referred to as direct inquiry. The teacher-centredness of this type of inquiry implies that student task engagement is restricted to following the teacher's instructions. This recipe type of inquiry is bereft of most of the characteristics of true scientific inquiry.

An alternative classification of inquiry is offered by Eick, Meadows, and Balkcom (2005) who preferred to use levels 1 to 4 to identify the different types. While this type of classification gives an idea of the increasing cognitive demand from level 1 to 4, such a nomenclature does not describe what each type entails. The classification by Martin-Hansen (2002) is therefore preferred for the current study.

The abilities pertinent to inquiry appear in various studies and science curricula documents worldwide (Espinosa-Bueno, Labastida-Pina, Padilla-Martínez, & Garritz, 2011; Khan, 2007; Martin-Hansen, 2002). Khan's list of abilities or processes reflects all the stages in the iterative approach (Roberts, Gott, & Glaesser, 2010), which derived from the Problem Solving Chain (PSC) (Woolnough & Allsop, 1985) and is discussed further in greater detail in another section of the current study covering the theoretical (Figure 2.5). These are:

> identifying a problem and gathering information; making predictions; making sense of observations and finding patterns in information; using analogies and physical intuition to conceptualize phenomena; analysing and representing data; postulating potential causal factors; working with evidence to develop and revise explanations and generating hypothetical relationships between variables. (p. 878)

Scientific inquiry is often considered synonymous to scientific methods. The practice and conceptualisation of scientific inquiry is viewed as tied to the knowledge of various scientific methods (Tang et al., 2010). Literature suggests that the majority of scientists subscribe to the idea that there are several versions of the scientific method (Mahootian & Eastman, 2008; Millar, 2010). While using the term 'the scientific method', McPherson (2001) concedes to the argument that there is no solitary collection of investigation steps that can represent how all the scientists under the universe work. McPherson goes on to identify formulating and testing hypothesis as key components of scientific methods. This contrasts with the views of De Boer (1991) who asserts that science inquiry, and by implication, scientific methods do not necessarily involve all of the following: asking questions; formulating and testing hypotheses; conducting investigations; observations and data interpretation; reflecting and modifying the hypotheses and reporting the findings. Earlier, Millar (1989) described doing science as a craft and argued against 'the scientific method' by saying that:

> Scientific inquiry cannot be portrayed as rule following but involves the exercise of skill in deciding what to observe in selecting which observations to pay attention to in interpreting and drawing inference, in drawing conclusions from experimental data, even in replicating experiments. (p. 168)

As McLelland (undated) puts it, "creative flexibility is essential to scientific thinking, so there is no single method that all scientists use, but each must ultimately have a conclusion that is testable and falsifiable; otherwise, it is not science" (p.2).

*Scientific methods:* The nature of the question under investigation often dictates the type of method to be employed (Tytler, 2007). All the scientific methods are associated with many of the following steps: observation, questioning, hypothesising, experimentation (testing the hypothesis), analysis and evaluation, and reporting (Hodson, 2009). In general, when the investigation is of a quantitative nature, students are required to come up with a hypothesis by making use of their pre-existing knowledge of concepts and experimental procedures. However, a hypothesis is not necessarily required when the investigation is of a qualitative nature. For example; students can be provided with six unlabelled colourless solutions of metal ions, aqueous sodium hydroxide, hydrochloric acid, aqueous ammonia and sulphuric acid and are supposed to design an experiment to identify all of them positively by name. A hypothesis is not required in this case but the rest of the components and steps in the investigative processes are similar. Reflection is a key part of both investigative processes as students are expected to intermittently evaluate their actions and make any necessary alterations to the original plan. Thus, investigations are different from other practical tasks in that students are expected to engage in decision making, evaluation and modification of their plans throughout the investigative process which is not always the case in other types of practical work such as a demonstration or verification (Roberts, 2009). My experience in teaching high school Chemistry has helped me take note of the fact that most textbooks for both O-Level and A-Level give emphasis on the use of the scientific method in which a hypothesis has to be formulated and tested. This has also led to an overuse of this fixed method by teachers who often rely on these textbooks for planning practical activities (Lunetta et al., 2007).

*Process skills***:** The practice of inquiry through investigations requires the use of various process skills. Process skills (SPS) are a collection of thinking skills employed by scientists to construct knowledge, provide solutions to problems and formulate results (Ozgelen, 2012). Abruscato (2000) says that process skills are used to carryout investigations with the aim of discovering scientific knowledge. These skills have been categorised hierarchically into basic and integrated skills (Ozgelen, 2012; Padilla, 1990; Sheeba, 2013). Basic process skills include observing, measuring, inferring, classifying, predicting and communicating. On the other hand, integrated process skills involve formulating hypothesis, identifying variables, defining variables operationally, describing relationships between variables, designing investigations, experimenting, acquiring data, organising data in tables and graphs, analysing investigations and their data, understanding cause and effect relationships and formulating models. The latter group of skills demands a more advanced knowledge foundation (Carin, Bass, & Contant, 2005). According to Millar (1989), these process skills are not performed in a rigid sequential manner as if there is a defined and universally agreed scientific method with a set of rules and procedures that can be used by scientists to solve new problems or provide the same interpretations to the same experimental results.

Padilla's (1990) use of the term 'process skills' suggests that these skills are exclusive to science and yet Millar (1989) asserts that process skills are not a preserve of chemistry education and no individual or group of individuals should claim to be teaching them. For example, observing is an innate skill that everyone uses to make sense of the world across all disciplines and in everyday life. In her view, by teaching science "we are helping students to internalise the procedures and standards of the scientific community. We are assisting students to construct for themselves a mental representation of the scientific ways of working and judging" (p. 176). Investigations are one way of doing this.

### 2.4.3 Science investigations

Woolnough and Allsop (1985) see investigations as open-ended problem-solving practical activities in which students assume the role of scientists. Open-ended refers to the existence of more than one possible design and solution to the problem situation. Open-endedness can also be taken to be an indicator of a defined or undefined investigation problem. Woolnough (1991) argued that practical work done in the form of investigations provides students with a holistic approach to learning scientific concepts. Gott and Duggan (1995) seem to borrow from Woolnough and Allsop when they defined an investigation as a form of problem-solving where there is no single method for achieving the solution. According to Gott and Duggan the broad aim of scientific investigations is to give students a chance to use concepts and develop cognitive abilities and skills in problem solving. Millar (2010) defined investigations as "practical activities in which students are not given a complete set of instructions to follow (a recipe), but have some freedom to choose the procedures to use, and to decide how to record, analyse and report the data collected" (p. 2). This conceptualisation of an investigation unpacks the idea of open-endedness and recognises that the doing part is a process encompassing many stages. Miller's definition is adopted for this study.

Investigations do not have an obvious solution and students do them with relative autonomy as defined by their open-endedness (Gott & Duggan, 1995; Lock, 1990) and the teachers' planning. Wellington (2000) suggested three dimensions of investigations which are represented as three separate continua reflecting the open or closed nature of these practical activities, whether they are student or teacher-led and the level of assistance given to students. This is shown in Figure 2.1.

| *Less autonomous* | *More autonomous* |
|---|---|
| **Closed**<br>- one possible design<br>- one correct solution | **Open**<br>- several possible designs<br>- many possible solutions |
| **Student-led**<br>- students choose the investigations to do<br>- no restrictions | **Teacher-led**<br>- teacher chooses the investigations to be done |
| **Directed, Structured**<br>- students are assisted at all stages of the investigation | **Undirected, Unstructured**<br>- no assistance<br>- no constraints |

Figure 2.1 Dimensions of investigations (Wellington, 2000, p. 159)

According to Lock (1990), the extent to which an investigation is open-ended depends on the relative autonomy the students are allowed by their teachers. Based on the characteristics of the three continua, it can be argued that the way investigations are done in each classroom largely depends on the respective teachers' epistemological and pedagogical beliefs leading to either student-led or teacher-led, structured or unstructured approaches. Those who view teaching as knowledge transmission will most likely be located near the teacher-led and directed-structured end of the corresponding continua.

Ramnarain and Hobden (2015) produced a classification framework for the different autonomy levels observed when students do investigations. The five levels of their framework are based on the level of teacher control during each of the key stages of the investigation process: choosing the topic; formulating the question; planning; collecting data; analysing data and drawing conclusions. The framework reflects a decrease in teacher control with an increase in autonomy level from one to five. Notably, students have autonomy in analysing data and drawing conclusions in all the five levels. A possible explanation is that teachers generally believe their students have the relevant skills to successfully perform this investigation stage. My personal experience with A-level chemistry investigations is that the third level, where the teachers retain control of choice of topic and question to investigate, is the predominant one. Students are given autonomy to plan (design) the investigation, collect, analyse and draw conclusions from their own data even in the public examinations.

Teachers do not normally create space for students to do investigations of their choice although this is known to generate greater enthusiasm in students (Chin & Kayalvizhi, 2002). Based on my knowledge of the investigations found in most of the high school textbooks, the problem is that the majority of them are of the recipe type. This naturally curtails the development of the students' capacity to generate science problems worthy of investigating. If students were encouraged to do their own investigations, this would arguably lead to positive approaches to learning.

Five different categories of investigations were identified by Watson, Goldsworthy, and Wood-Robinson (1998). These categories are shown in Table 1 together with relevant examples as they apply to the A-Level practical component.

Table 2.1 Categories of investigations and examples

| **Category** | **Example** |
|---|---|
| Fair testing and comparing | Which pain-killer is the strongest, cafemol, disprin or paracetamol? |
| Classifying and identifying | Classification and identification of metal ions in unknown samples |
| Pattern seeking | Investigating the effect of temperature on the rate of a chemical reaction. |
| Exploring | Exploring what happens to the rate of a chemical reaction when the concentration of one reagent is increased. |
| Making things or developing systems | Making an effective mosquito repellent from traditional herbs |

The assessment of investigation skills under the A-Level Chemistry curriculum covers the first four categories only (ZIMSEC, 2012b). This arises because the practical examination lasts for one and half hours hence only short-term investigations are entertained. Making things or developing systems would fall under long-term investigations and these would be suitable if the assessment was school based and done as projects lasting several days, weeks or months.

## 2.5 The value of investigations in learning science

According to So (2003), the acquisition of scientific knowledge should be viewed as eternally married to the practice of science. Consequently, science curricula worldwide place emphasis on the development of knowledge and understanding coupled with the acquisition of process and procedural skills. Investigations provide a vehicle for achieving this objective. The reasons for engaging in investigations are derived from the purposes of practical work highlighted earlier on. Many authors have identified different purposes of investigations, one of whom is Cumming (2002) who came up with three major purposes . Firstly, investigations help students to ‘discover’ scientific ideas. Discovering in this context simply means finding out things for themselves rather than contributing something previously unknown to the scientific world. Secondly, investigations promote active construction of knowledge. By performing investigations students are expected to rectify their incorrect conceptual understandings as an adaptation cognitive conflict induced by the empirical data collected. Thirdly, investigations help to develop scientific literacy in students as they acquire an improved appreciation of how scientific knowledge is created and participate in debate on issues of scientific importance. It can however, be argued that doing investigations in high school is not a guarantee for producing citizens who are socially responsible and are capable of taking part in scientific discourse. The practice of investigations has other benefits. These include enhancing social skills, promoting creativity and critical thinking, developing competency in experimental techniques, honing problem solving skills and enhancing the understanding of scientific concepts (Moeed, 2013). It is believed that investigations ensure that chemistry education covers content as well as develop invaluable practical skills (So, 2003).

The purpose of the investigation generally determines its nature and the investigative approach to be employed. This implies that teachers always have to give a clear outline of the aims and objectives of the investigative tasks they assign to their students in order to achieve the intended learning outcomes (Millar, 2004). The idea is to make investigations effective at both levels 1 and 2 (Millar, 2009) as illustrated in Figure 2.2. An important focal point on the same figure is what students actually do in the classroom during investigations. If level 1 is not satisfactorily achieved, that is, if what students actually do is divorced from what was intended then, level 2 is very difficult to achieve. Given that investigations lay the foundation for a solid appreciation of scientific concepts, investigation tasks should be carefully selected in order to satisfy this broad aim (Moeed, 2013). Moeed argues that investigations are the experiential component of science in which students exercise the application of learned concepts and processes in problem solving.

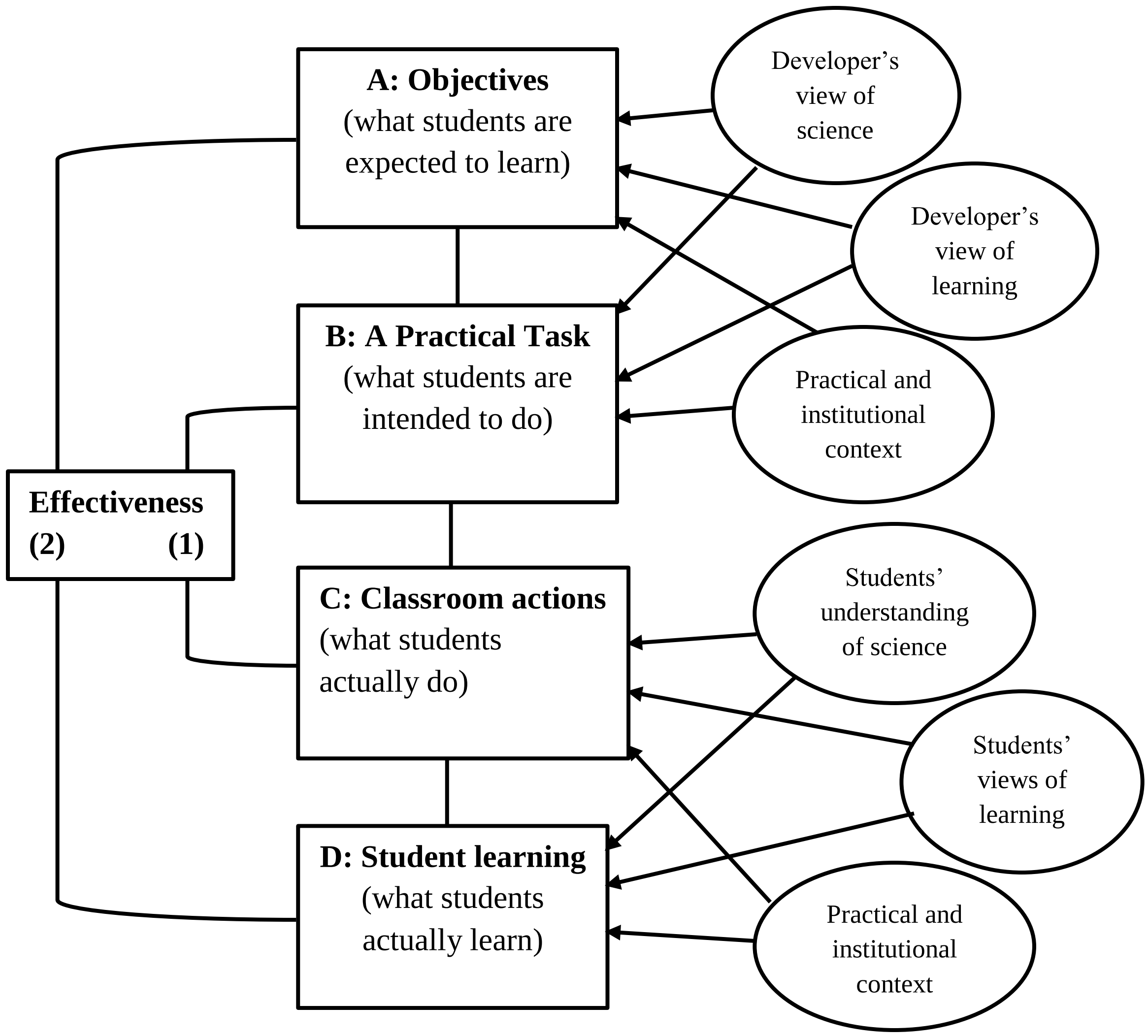



Figure 2.2 The process of developing and implementing a practical task (Millar, 2009, p. 2)

Figure 2.2 shows that there are various factors that can influence the effectiveness of practical work and investigations in particular. Among these factors are those related to curriculum designers, teachers and students' epistemological beliefs about science and learning, students' understanding of science (investigations) and the context in which the practical work is done.

Meaningful learning from investigations is often limited due to poorly developed investigative skills (Hodson, 1990; Roberts & Gott, 2004). Doing investigative activities by itself alone is not sufficient for high school students to acquire a solid understanding of scientific investigations as a process of knowledge construction (Trumbull, Bonney, & Grudens-Schuck, 2005). Students’ understanding of investigations and their value in learning science concepts is directly related to their teachers’ own understanding and ability to use an investigative instructional approach (Lotter, Singer, & Godley, 2009). If teachers do not understand what an investigation entails, it influences how they teach it and consequently the value that their students will attach to it (Moeed, 2013).

Moeed (2013) says that high school students develop a strong belief that investigations are carried out through a scientific method in which the procedure is outlined in steps. In their minds this is how real scientists work to generate knowledge. The misplaced focus on student activities due to limitations in teaching methodologies leads to a superficial understanding of scientific reasoning and practice according to Windschitl, Thompson, and Braaten (2007). They go on to highlight a sad but common scenario whereby students who come through the hands of such teachers go on to train as teachers themselves. This naturally leads to a perpetuation of the situation and the worsening of high school students’ understanding and practice of investigations. To put an end to this cycle we need to understand what is going on when students do investigations and that is one of the primary aims of this current research.

## 2.6 The Interpretive Framework: Approaches to investigations

The nature of the relationship existing between the student, an investigation task and the associated context determines the approach used (Biggs et al., 2001). Approaches to investigations in this study describe what students do when they go about designing, planning and carrying out investigations and why they do it the way they do. This definition is influenced by the approaches to learning theory advanced by Marton and Saljo (1976) and expounded later by Biggs (1987b), Ramsden (1992), Entwistle (1981) and Entwistle, McCune, and Tait (2013). The study by Marton and Saljo (1976) was primarily in the languages. They gave their participants some readings and then asked them questions based on those readings in a bid to understand their approaches to learning. The categories of deep and surface approaches to learning were coined as a result of their study. The major finding from this study and subsequent studies by different researchers with different participants was that the approach used by each student was not permanent but could vary from time-to-time depending on the task. Furthermore, the intentions of the students as they do a given task, had a significant bearing on the approaches they adopted in accomplishing it. While Martin and Saljo's pioneering work was significant in helping educationists understand how students approach learning, it did not recognise the influence of assessment on the students' choices of approach (Biggs, 1987b). A third category was therefore introduced, namely the strategic approach.

While the approaches to learning theory came into existence through studies in the languages, educationists agree that it can be applied to other disciplines as well. Consequently at least three generic instruments under the name of Approaches and Study Skills Inventory (ASSIST) have been used in various studies all over the world by educationists (Entwistle et al., 2013). This study focuses on the approaches to investigations used by A-Level Chemistry students and the theory has been adapted to this end. While there will be a lot of similarities in learning the theoretical aspects of any subject, a science subject like Chemistry involves a practical component which requires process skills not emphasised in other disciplines. The term approaches to investigations (instead of the general approaches to learning) was therefore used in this study, in line with its focus.

The approaches students adopt when doing investigations can be viewed from two different angles. Taking into account the type of learning experienced (Cuthbert, 2005; Houghton, 2004; Laurillard, 2005) students can employ a deep, surface or strategic approach. By considering how students go about designing and carrying out investigations, Roberts et al. (2010) identified three different approaches: iterative, linear and divergent. These approaches are represented in Figure 2.3.

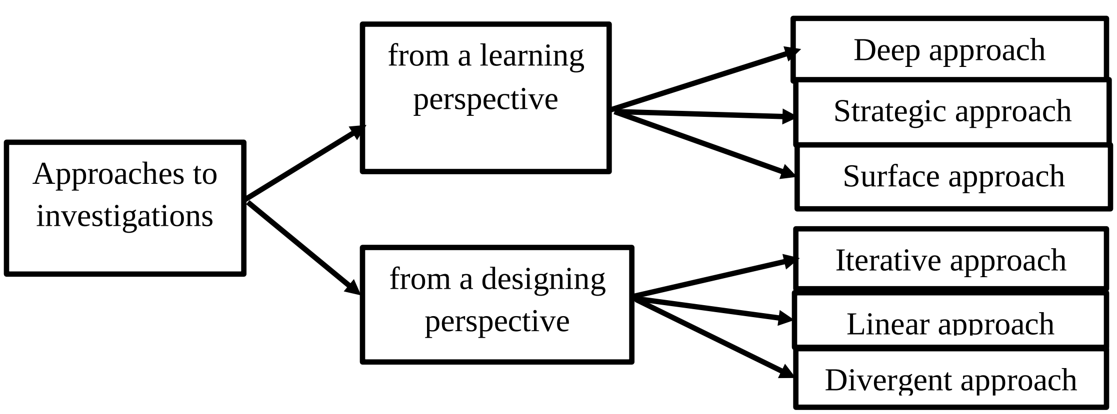



Figure 2.3 Approaches to Investigations

### 2.6.1 Approaches to investigations in terms of learning

Approaches to investigations is a broad term used in this study to describe what students bring to learning situations involving investigations encompassing how they handle information and their personal learning intentions (Houghton, 2004). As Mogre and Amalba (2015) say, students' approaches to learning are influenced by their motives and strategies. This can also be applied to how students approach specific learning situations such as those involving investigations. The motives often influence the strategies adopted by the students as they do investigations. Students can adopt a deep, surface or strategic approach to investigations (Houghton, 2004; Laurillard, 2005).

The deep approach involves critical thinking and connecting new ideas to prior knowledge thereby developing a solid understanding and boosting long-term memory of concepts which can be applied to problem solving, even in novel situations in real life contexts (Cuthbert, 2005). Entwistle and Peterson (2004) highlight the defining features of the deep approach, which support Cuthbert's thinking. They say that students' intention (motive) would be to understand scientific ideas for personal development. Their performance of investigations would be characterised by a holistic process where they relate ideas to prior knowledge and experiences of doing similar practical work. Additionally, students with a deep approach are meticulous in their execution of an investigation as evidenced by thorough checking of experimental data, cautious and critical evaluation of solutions, monitoring understanding, engaging with scientific ideas and enjoying the intellectual challenge that comes with doing this type of practical work.

The strategic approach, identified by Entwistle (2004) is characterised by the desire to achieve excellent grades in summative assessment tasks such as tests and examinations in which the ability to design, plan and carry out an investigation is assessed. Students who use a strategic approach organise their work thoughtfully, manage their time and effort effectively and are aware of the examiners' expectations through their teacher, examiners' reports and marking schemes. In addition, such students tend to monitor their own effectiveness when they do investigations and feel personally accountable to themselves for their own performance. Consequently, these students will create ideal conditions, optimise resource utilisation and spend time going over past examination papers with the aim of forecasting questions and use marking schemes in order to master what examiners want with respect to investigations (Donnison & Penn-Edwards, 2012). While some characteristics of the strategic approach point towards deep learning, the difference is that the manifestation of such traits is extrinsically driven. Under the deep approach active construction of meaning from investigations is the intention, which develops intrinsically.

The third approach, the surface approach, is generally about recalling facts. Students give emphasis to what they think will be assessed in both internal (school level) and external (public) examinations (Cuthbert, 2005). According to Entwistle and Peterson (2004), students will do the minimum required to cope with the practical component which deals with investigations, treat the investigations as unrelated to the science learned elsewhere. This induces to routine memorisation of facts and experimental procedures. Students do investigations without reflecting on their purpose as they see little or no value in such practical work. Furthermore, students associated with the surface approach often feel undue pressure and anxiety about investigations.

Moving through the continuum of approaches, from deep to surface, it is generally believed that the use of a deep approach is linked to higher quality learning while the surface approach is related to lower learning outcomes. Given that investigations are an integral part of the A-Level chemistry curriculum, the expectation is that the corresponding students will adopt a deep approach in doing them (Felder & Brent, 2005). It can also be argued that the way the chemistry teachers develop investigation skills (process skills) should be inclined towards enabling the development of a deep approach.

There is ample evidence from research that students are not bound to an individual approach throughout their schooling life and that the adoption of one approach or another is contextually dependent (Cuthbert, 2005; Houghton, 2004; Laurillard, 2005). This is also valid within a subject as students navigate through various sections of the syllabus or as they shift from one subject to another. For example, students may be associated with a deep approach when they deal with the theory component of the A-Level chemistry curriculum and then switch to a strategic or surface approach when they do with investigations.

The characteristics of the three approaches are captured in Table 2.2. Houghton's (2004) characterisation was based on the approaches to learning in general.   It was therefore, necessary to modify the wording to focus on investigations and include the strategic approach which was not considered by Houghton. For example, in Houghton's characterisation, the deep approach is encouraged by students:

- having an intrinsic curiosity in the subject.
- being determined to do well and mentally engaging when doing academic work.
- having the appropriate background knowledge for a sound foundation.
- having time to pursue interests
- positive experience of education leading to confidence in ability to understand and succeed. (p.11)

This was modified to encouraged by students having a:

- desire to do investigations driven by intrinsic curiosity.
- sound and appropriate conceptual understanding which is required to design and execute investigations.
- positive view of investigations leading to high confidence in ability to design and execute them.

These characteristics were used to categorise the participants using the data from the semi-structured questionnaire (DUQ) and focus group interviews.

Table 2.2 Characteristics of the deep, strategic and surface approaches to investigations (adapted from Houghton, 2004)

| | **Deep Approach** | **Strategic approach** | **Surface Approach** |
|---|---|---|---|
| ***Characteristics*** | Students construct knowledge through designing and carrying out investigations. | Students create a balance between meaningful construction of knowledge and rote learning. | Students rely on rote learning. |
| | Students focus on the concepts and materials needed to successfully design and execute an investigation. | Students focus on gaining sufficient conceptual understanding and knowledge of the required materials in order to successfully design and carryout an investigation. | Students focus on procedures used before to design and execute the investigation. |
| | Students relate new and previous knowledge gained through investigations. | Students are mainly worried about getting good marks for their investigations. | Students do not recognise new material as building on previous work. |
| | Students can link investigations to real life and the everyday work of real scientists. | Effort is channelled towards achieving good marks for the investigations done. | Students see investigations only as practical work done to prepare for and pass examinations |
| ***Encouraged by (students)*** | A desire to do investigations driven by intrinsic curiosity. | Execution of investigations without necessarily being driven by intrinsic motivation. The desire to pass examinations is greater. | Doing of investigations as a necessary evil to pass examinations. |
| | Sound and appropriate conceptual understanding which is required to design and execute investigations. | Students who do enough to master the relevant concepts required to do investigations. | Lack of background knowledge required to successfully design and execute investigations. |
| | Positive view of investigations leading to high confidence in ability to design and execute them. | Negative view of investigations and low confidence in their ability to design and carry out investigations. | Cynical view of investigations believing that recall of facts and procedures is what is required. |
| ***Encouraged by (teachers)*** | Demonstration of personal interest in investigations. | Teachers may not necessarily demonstrate a personal interest in investigations. | Conveying of disinterest or negative attitude to investigations. |
| | Bringing out the structure of the subject. | Teachers help students to see the relationship between facts and ideas while doing investigations to maximize their chances of passing practical examinations. | Presenting of material so that it is perceived as a series of unrelated facts and ideas. |
| | Adoption of active teaching and learning approaches and confronting students' misconceptions. | Teachers drill students on experimental procedures. | Allowing students to be passive. |
| | Use of investigative problems that are thought provoking and incorporate concepts from different topics of the subject. | Teachers use past examination questions and give marking guidelines to students. | Use of investigative problems that lack in depth and breadth. |
| | Relating new material to what students already know and understand as well as linking theory to investigations. | Teachers emphasise on the importance of linking theory to investigations. | Failure to show students how to link theory to investigations. |

### 2.6.2 Factors that influence students' approaches to investigations from a learning perspective

Biggs (1991) proposed a 3P-Model in which he recognises the strong influence of the context in which learning occurs. He argues that there are several reasons why students learn and the learning process is influenced by various contextual factors, which in turn determine the quality of the school product. Each of the P's in the model represents a phase. The first of these, the *presage phase*, is characterised by factors, which exist even before learning begins. One arm of the presage phase is the student context, which is defined by a traditional understanding of teaching and learning, proficiency in the language of teaching and learning, expected academic results and inclinations towards specific learning approaches influenced by prior experiences. Gender and age are the other factors identified by Mogre and Amalba (2015). The other arm is the teaching context, which covers institutional and classroom factors such as the subject content and its structure, assessment criteria, school rules and how the learning process is managed. Time induced pressure and examinations related stress derived from the teaching and learning context often lead to the adoption of a surface approach. The second phase is the *process phase*. Students' conceptions of teaching contexts, their motivational levels and the nature of the learning tasks significantly determine the process through which learning is accomplished. Students can be located on a continuum ranging from rote learning to high cognitive processing. This is synonymous to the continuum of surface to deep learning which forms part of the theoretical framework of this study. The third phase, *the product of learning,* is a quantitative and qualitative measure of students' learning as well as students' perceptions of their own learning. In the context of this study, students' approaches ultimately determine how much and how well they learn the Chemistry concepts related to the investigations they do.

### 2.6.3 Approaches from a designing perspective

Arguably the most detailed approach to investigations is derived from the PSC developed by Assessment of Performance Unit in the United Kingdom (Woolnough & Allsop, 1985). Roberts et al. (2010) chose to call it the iterative approach to investigations as shown in Figure 2.4. Four major phases are distinguishable in the investigative process based on the PSC which are: a designing and planning phase, a performance phase, a reflection phase and a recording and reporting phase (Hodson, 2009). I argue here that the PSC can be consolidated into five phases: designing and planning; performance and data recording; data processing and interpretation; reflection and reporting. Data processing and interpretation ideally takes place after the completion of the experimentation when the students believe they have collected sufficient data. Students can do it in a more convenient place away from the workstations where they carry out the experiments. Based on my experiences of doing investigations with A-Level chemistry students, this is a better reflection of the logical sequence of phases in the application of process skills when students do an investigation.

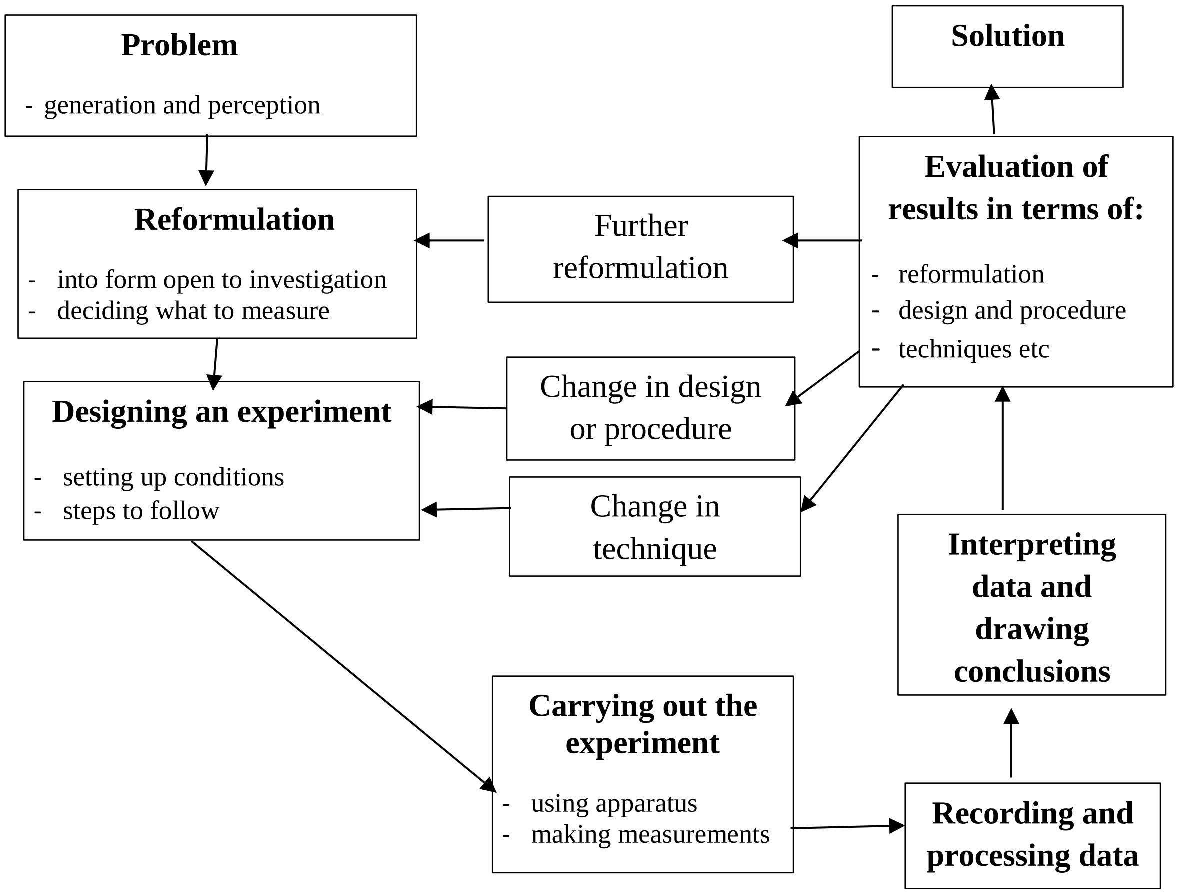



Figure 2.4 The iterative approach (Roberts et al., 2010, p. 382)

The first phase of designing and planning starts once the students are presented with a problem. The students start with problem perception and reformulation. According to Woolnough and Allsop (1985), “the students analyse the factors relevant to the question, assemble the appropriate information; create or consider various ways of attacking the problem, select the best option and then plan the investigation” (p. 51). The methodological implication of highlighting problem perception and reformulation is that there is emphasis on problem sense-making which discourages students from diving headlong into writing the experimental steps without a good understanding of what is required of them. Problem perception and reformulation is therefore the beginning of the planning part of this phase.

Planning may also involve formulating a hypothesis especially when the investigation falls under quantitative analysis. Once the students identify a feasible way of doing the investigation they then proceed to outline a series of steps that consist of the experimental procedure to be used. The designing part of this phase involves a description and often a diagrammatic representation of the set-up of the apparatus to be used.

The second phase of performance and data recording phase involves executing the proposed experimental procedure. The students will set the apparatus and corresponding experimental conditions to collect the relevant data. During this stage, they will make the necessary measurements and/or observations and capture this data in an appropriate manner such as tables. Coupling performance with data recording ensures that students are reminded of the need to write down the relevant data from measurements and/or observations as they occur. Such data were often captured in tables with appropriate headings.

During the third phase of data processing and interpretation, students often transform the collected data to determine derived values in quantitative analysis. For example, in an investigation to determine the effect rate of a chemical reaction, concentration and time measurements will be transformed to give the rate of reaction at various stages of the reaction. Numerical data can also be used to construct graphs from which extrapolations or interpolations can be done. This is followed by data sense making and providing an answer to the initial problem. In qualitative analysis students use their observations to make deductions based on known characteristics of the various inorganic ions and organic functional groups.

The fourth phase of reflection is when students do an evaluation of their results. The students auto-assess and make judgements on whether their results make sense or not in relation to the original problem. If the results deviate from their expectations, then they (students) can go back to reformulate, redesign or improve their techniques and collect new data with the aim of obtaining better results. In practice, reflection is not solely done at the end of data processing and interpretation. It is expected that students engage in reflective practice at every stage to ensure that the desired learning outcomes are achieved. This mirrors what happens in the real world. Doing an investigation, as done by real scientists, is an iterative process (Moeed, 2013). The phases are not done one after the other in a linear unidirectional process but rather concurrently with continuous modification of the proposed plan (Hodson, 2009). If the way students do investigations approximates how real scientists work, then they are more likely to be successful in their own way.

The fifth and final phase of reporting is done, in most cases, when the students feel they have the desired results and correct interpretation. In typical open-ended investigations, apart from the results, reporting includes the experimental design that worked best if the students were successful or details of why the experimental design did not work if they were unsuccessful. Reporting should ideally reflect that doing an investigation is a messy process which does not always lead to success although valuable lessons are always learned. In the context in which A-Level students do investigations, the messiness of these practical activities is not always evident on students' scripts due to the structured nature of the examination papers and the time restrictions.

When students use a linear approach in an investigation, the stages are done sequentially as illustrated in Figure 2.5.

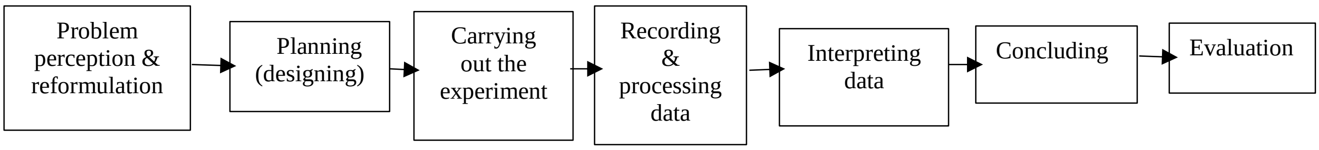



Figure 2.5 Linear approach to investigations (adapted from Roberts et al., 2010)

The first stage is the same as in the iterative approach, which is problem perception and reformulation. Differences with the iterative approach are noticeable from the planning stage onwards. Students will come up with one plan and then religiously execute it without minding about its appropriateness (Roberts et al., 2010). This might be because of using a procedure used before in a similar investigation or as a direct consequence of limited autonomy. The Chemistry teachers might suggest the best experimental procedure to use and out of trust, the students do not see it necessary to consider alternative ways of doing the investigation. The students don't always appreciate the need to constantly review their plan, experimental design or techniques in order to do any necessary changes leading to better results. The same can be said of the data processing and interpretation stages. Students tend to use predetermined ways of transforming the data and do not always give the interpretations that match the results.

Generally, there is limited reflective practice and learning from the data generated. Consequently, the success rate of students associated with a linear approach is lower than that of their counterparts using the iterative approach. An emphasis on neatness by the teachers can also lead to this approach. Students will prioritise pleasing their teachers at the expense of reflecting the messiness of doing investigations.

A divergent approach is witnessed when students find it extremely challenging to come up with a plausible plan when confronted with an investigation initiated by the teacher or during an examination (Roberts et al., 2010). This normally occurs when students get stuck right from the beginning, in problem perception and reformulation. A limited conceptual understanding and failure to link theory with practical work might be the reasons. The students then fail to come up with a workable experimental procedure compounded by wrong choices of materials to use during the investigation. This normally occurs when students are clueless about the basis of data collection. If students manage to collect some data, the processing is often flawed, leading to incorrect conclusions. Students with a divergent approach are never associated with reflective practice and therefore never revisit their plans with a view to improving them. Consequently, students who adopt a divergent approach are always unsuccessful in investigations.

### 2.6.4 Challenges in designing and carrying out investigations

Challenges to successful designing and carrying out of investigations come in the form of students' knowledge base. According to Mayer and Wittrock (2006) there are five different types of knowledge that students need to successfully design and carry out investigations. The first one is *facts*, that is, knowledge about characteristics of elements and scientific phenomena like the colour of the precipitate formed when aqueous sodium hydroxide is added to a solution of copper (II) sulphate. The second one is *concepts*, which refers to knowledge of categories, models or principles such as le Chatelier's principle. The third one is *strategies*, that is, knowledge of general methods, like how to break the investigation into manageable parts. An example would be how to separate and identify components of a mixture of metal cations in a solution. The forth one is *procedures*, that is, unique procedural knowledge, for example determining the percentage of water of crystallization of a given sample of hydrated salt. The fifth one is *beliefs*, a mental awareness of one's abilities with respect to investigations (for example, I am not good at planning) or about the nature of investigations (for example, if the student can't design the investigation instantly then they will never be able to achieve it).

Watts (1994) preferred to talk about various hurdles which need to be overcome by the student in order to accomplish an investigation. He identifies the different ‘hindrances’ that may need to be overcome by students as psychological, challenges to knowledge and understanding and the need for specific skills as represented in Figure 2.6.

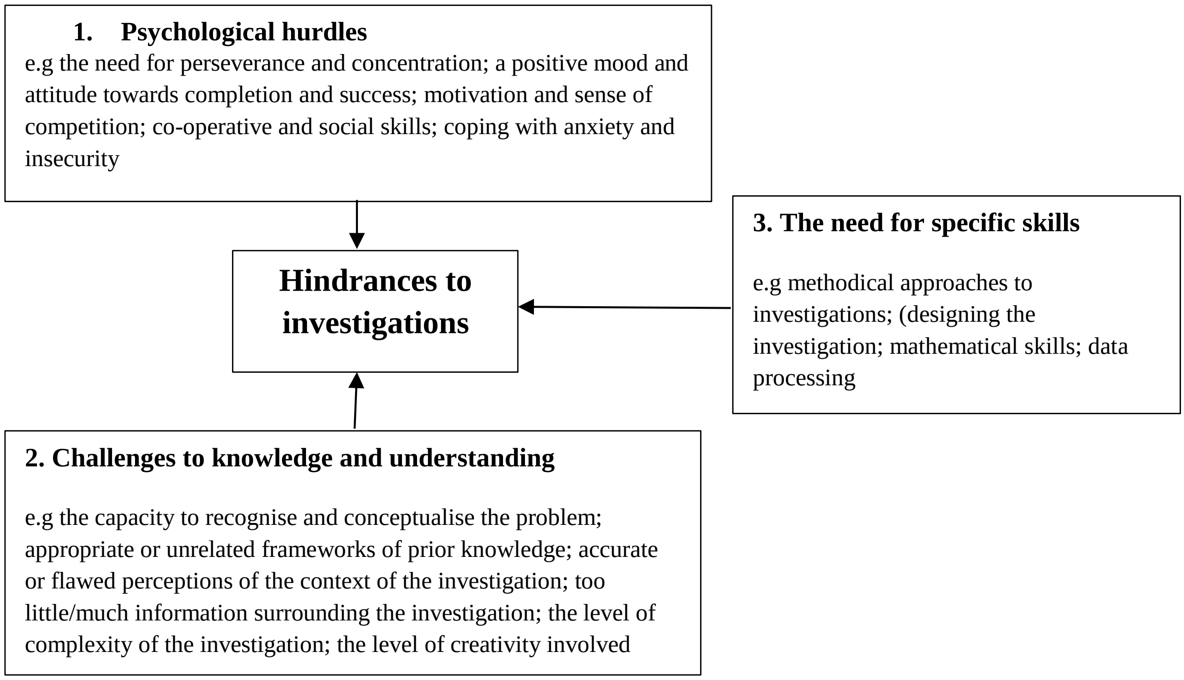



Figure 2.6 Hindrances to Investigations (adapted from Watts, 1994)

It can be argued that if a student lacks one or more of the first four kinds of knowledge highlighted by Mayer and Wittrock (2006) then they are unlikely to succeed in solving the investigative problem. Therefore, both the hindrances and the types of knowledge generally point to the same thing. Factual and conceptual knowledge can be seen as related to the second hindrance identified by Watts (challenges to knowledge and understanding) while strategic and procedural knowledge are connected to the third one (the need for specific skills). The beliefs can be viewed as related to the psychological hurdles.

Beliefs can also be viewed from an epistemological perspective. In the current study, epistemological beliefs refer to students’ beliefs about the nature of knowledge and how knowing is achieved (Labbas, 2013). These beliefs impact on students’ thinking processes, conceptualisation of learning and learning approach preferences and ultimately their performances in investigations (Sadi & Dagyar, 2015). The instruction experienced by students shapes their epistemological perceptions of investigations ((Tsai, 1998). In addition

Buehl and Alexander (2001) assert that students' academic settings and cultural diversity play a role in their epistemological beliefs. Such contexts may be defined by human and physical resources as well as instructional strategies. School and individual learning orientations form part for the cultural differences that lead to the reinforcement of particular beliefs, the nature of knowledge and knowing.

Perry (1970) cited in Tanriverdi (2012) proposed four phases associated with the development of epistemological beliefs which are dualism, multiplism, relativism and commitment. Building on Perry's work, Schommer (1994) identified four type of epistemological beliefs with naive to sophisticated as the opposite extremes. Naive students view the contemporary body of scientific knowledge as absolute. They therefore see science processes and concepts as refined and believe that their responsibility as students is to learn them by heart and then regurgitate them when required. As such, their favoured approach to investigations is inclined towards surface learning where memorisation of experimental procedures is prevalent. Literature gives credence to the fact that naive beliefs are promoted by objectivist teaching strategies where knowledge transmission is regularly (Chai, 2010; Hogan, 1999). In the case of investigations, the activities would be organised in a way that is structured with limited student autonomy. Sophisticated students acknowledge the dynamic and evolving nature of scientific knowledge and seek to improve their personal conceptual and procedural understanding at every opportunity (Schommer, 1994; Tanriverdi, 2012). They use investigations to forge new knowledge or gain a deeper understanding of concepts learned theoretically. This is encouraged by constructivist learning spaces (Chai, 2010) where the students have relatively more autonomy in choosing, designing and performing investigations. It can be argued that such students show enhanced capabilities in problematising, hypothesising, designing and carrying out investigations. They are naturally predisposed to high intrinsic motivational levels, characteristic of deep learning and positive self-efficacy.

Self-efficacy has its roots in Bandura's social learning theory, now known as the social cognitive theory. It influences students' affective dispositions and ideas about themselves as learners and elevates their motivation to learn while transforming their behaviours (Bandura, 2001). Based on the social cognitive theory, Bandura (2001) understands self-efficacy as a student's belief about their academic, organisational and behavioural capabilities in order to accomplish their targets in learning situations. Mastery experiences, observation, social persuasion and physiological states are the tenets which singularly or collectively induce self-efficacy (Bandura, 1997). For example, student's personal or colleagues' performances in investigations, exogenous encouragement that they can successfully design and carry out investigations and affective states can impact on self-efficacy and performance. Naturally, good academic performances will raise students' beliefs about their own self-efficacy.

Students' self-efficacy can be linked to prior learning experiences. Li, Liang, and Tsai (2013) suggest that students' conceptions of learning science can have a positive impact on their self-efficacy in investigations. Such conceptions of learning science are built over many years as direct consequence of the students' learning contexts and experiences. As has already been alluded to, learning contexts and experiences produce students' with approaches ranging from surface to deep learning which are associated with low and high efficacy in investigations respectively (Sadi & Dagyar, 2015). The same argument can be extended to how students' approaches to designing and carrying out investigations. Those with a low efficacy tend to be unsystematic while those with high efficacy will be methodical and more successful.

It has been highlighted in chapter on that A-Level chemistry examiners for the practical examinations report poor performances by students in investigations every year. Chin (2003) identified a number of weaknesses shown by students when doing this type of practical work. First, the activation of prior knowledge is not always successful. Students often fail to retrieve the required theoretical and practical knowledge. In addition, prior knowledge and experiences can lead to incorrect predictions, inaccurate data and hence erroneous interpretations. Second, planning and designing is compromised by students' failure to identify, control, manipulate and measure any variables involved. The planning often lacks procedural details including how data should be collected, recorded and processed. Third, performing the proposed plan is usually characterised by a flawed use of equipment resulting in errors in measurements resulting in inaccurate interpretations and deductions. Fourth, students do not show competence in data processing and presentation. They fail to draw tables, different types of graphs and leave out the units of measurements. Tables and graphs are left without the necessary headings and labels. The fifth common weakness is related to data interpretation and drawing conclusions. Data sense making is often incorrect and in some cases students falsify results in line with preconceived ideas. Students' write-ups also show evidence of limited or absence of reflexive practice. These weaknesses clearly indicate that the concerned students may not be using effective approaches when they do investigations.

**Summary of interpretive framework**

Based on the literature above the interpretive framework was developed. It has a number of components with the approaches to investigations at the core. These are linked together in Figure 2.7. The interpretive framework was used to categorise students by approach, first from a learning perspective and second from a designing perspective. The details of how it was used are presented in chapters four and five respectively. The various factors which influence the use of one approach or the other were important in understanding why the students approached investigations the way they did.

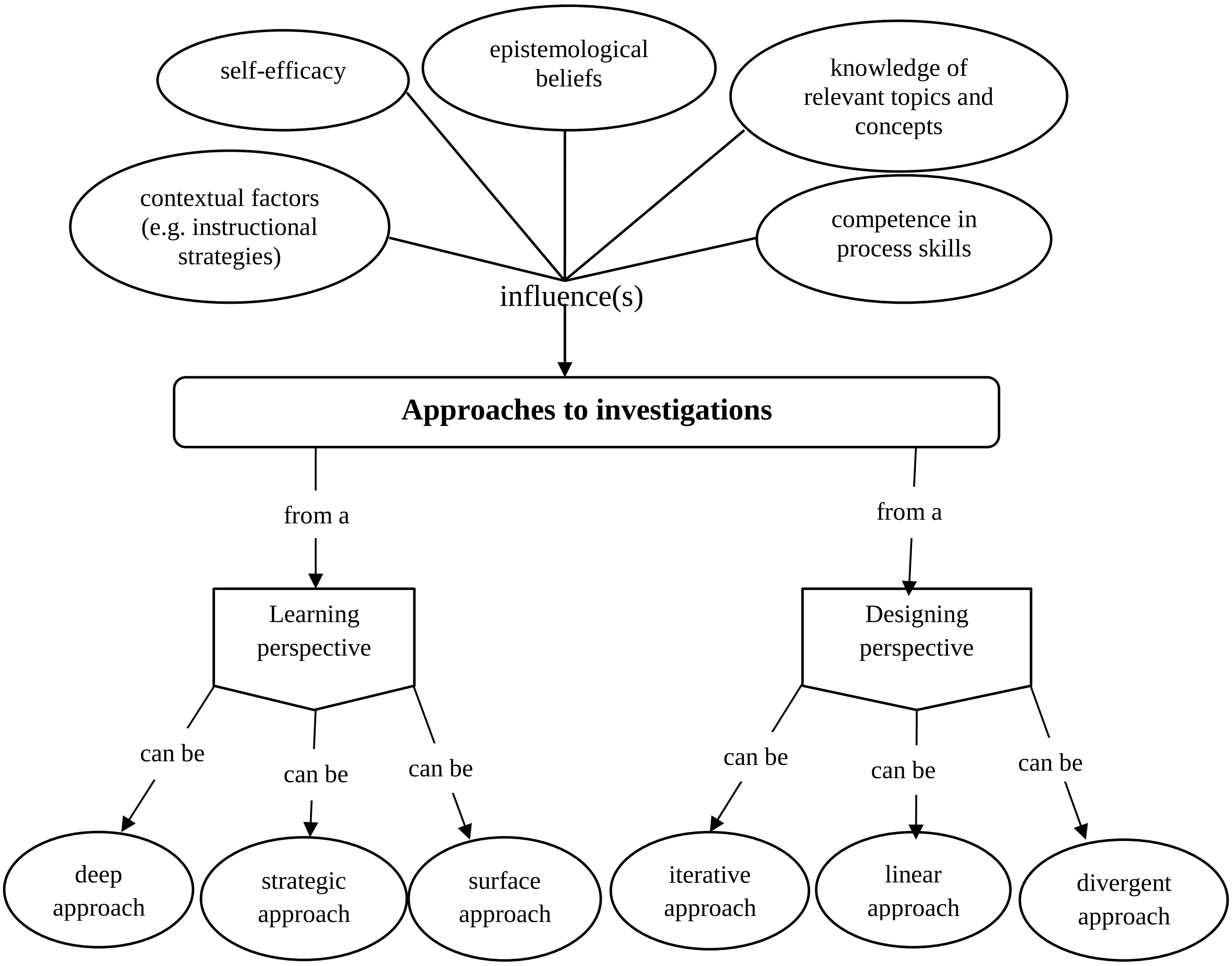



Figure 2.7 Components of the interpretive framework

## 2.7 A review of literature on approaches to investigations

In the preceding section, an outline of the interpretive framework which guided the study, and was used in the interpretation of the data, was presented. In this section, I deal with relevant literature on approaches to investigations. Guided by the interpretive framework, the review of the research literature is presented in two parts, one covering the approaches to investigations from a learning perspective and the other from a designing perspective.

### 2.7.1 A review of literature on approaches to investigations from a learning perspective

There is abundant literature on practical work in science at global level with the leading scholars focusing on its role and effectiveness (Abrahams & Millar, 2008; Abrahams & Reiss, 2012; Dillon, 2008; Hodson, 1993; Millar, 2004, 2010; Toplis & Allen, 2012), assessment (Abrahams, Reiss, & Sharpe, 2013; Moeed, 2015; Roberts & Gott, 2004), the teaching and learning of the scientific methods (McPherson, 2001; Millar, 1989; Osborne, 2014), students' understanding of scientific inquiry (Millar, 1997) and process skills (Ozgelen, 2012; Padilla, 1990). Millar's work in particular has extended science educators' conceptualisation of practical work and scientific inquiry as well as contributing to the debate on its effectiveness in achieving the intended aims and objectives in various science education curricula. The focus on the assessment of practical work, especially in the form of investigations, by scholars as such Abrahams, Moeed, Reiss and Sharpe has raised questions on the learning derived from the related activities.

Abrahams and Reiss (2012) carried out a project aimed at improving the effectiveness of practical work in schools in England. They studied 30 wide ranging practical lessons delivered by teachers who had undergone a professional development programme to improve their instructional strategies with respect to practical work. It was a multi-site case study in which data were analysed based on what students do and think in relation to intended outcomes set by their teachers. They found out that recipe type practical work helped students develop better conceptual understanding. There were no deliberate instructional strategies to help students to link observations to substantive knowledge during open-ended investigations. Consequently, these practical activities were ineffective in enabling students to link scientific ideas, make sense of what they were doing and engage in reflective practice. This implies that what the students were expected to learn from investigations was not achieved.

In South Africa, Ramnarain and Hobden (2015) explored how teachers supported grade nine students doing science investigations. Data were collected by administering a questionnaire to 55 teachers and observing students doing science investigations on five occasions followed by teacher interviews. They found out that students did not have autonomy in doing investigations with teachers using a range of strategies to support students at different stages of the investigation. As opposed to the earlier study by Abrahams and Reiss (2012), where students lacked the necessary support in order to learn what was intended, Ramnarain and Hobden suggest that excessive assistance rendered to students during investigations takes away the autonomy that is necessary for students to learn to work like real scientists apart from developing process skills. If students are assisted at every stage of an investigation, they might discover what is intended but deep learning might be curtailed. In addition any iterative practice will not be due to the students' self-reflective practice but induced by teachers questioning their planning, data collection, processing and interpretation of results.

A study on the views of high school students, teachers, subject advisors and inspectors on school science from year 9 to year 12 in England was carried by (Nott & Wellington, 1999). Their focus was on practical work, Sc1 investigations and how the nature of scientific ideas was taught. Sc1 investigations are similar to what A-level students do in that they are short term in nature, investigations which can be completed in short periods, usually between 30 minutes to an hour. They collected data, through questionnaires and interviews, from teachers and their 11 to 16-year-old students. Part of the findings was that most of the participants felt that Sc1 investigations were predominantly about achieving good marks and less about learning and understanding science concepts. Nott and Wellington commented that:

> Sc1 investigations are generally routines that teachers know will provide access to all the levels and can be organised and completed quickly in small 'windows' of time. They are frequently done holistically to 'get them out of the way' – not because teachers want to provide a comprehensive view of investigations or problem-solving. The skills and processes of investigations are not taught but experienced, and the conduct of investigations is about summative marks for GCSEs rather than formative assessment to become a competent scientist. In that both students and teachers see them as more about getting marks than learning some science, the assessment tail is definitely wagging the science dog. (p. 17)

The influence of assessment on how investigations are done at high school level was candidly expressed by one teacher in a later study by (Abrahams, 2005):

> When we do investigations I'm perfectly honest with the kids. I'll say to them that, as a piece of science, I think this is garbage, in terms of getting coursework marks it's superb. So we'll just play the game, we'll spend two or three weeks playing the game, getting some good marks, and then we can move on and do some science again. That's intellectual honesty. (p.136)

More recent research in New Zealand (Moeed, 2010) explored how an investigation assessment initiative influenced teaching and students' motivation to learn. Data were collected from Year 11 students and teachers in selected schools through document analysis, surveys, classroom observations and interviews. Moeed's findings included that the narrow scope of the investigations covered by the formal assessment promoted a surface approach instead of the more desirable deep approach to learning. Students set personal academic targets and showed high levels of motivation to achieve good grades. A more recent study by Moeed (2011) focusing on teachers' perspectives in science investigations following changes in the New Zealand high school assessment policy "teachers responded to the assessment requirement of science investigation by taking a pragmatic approach and tailoring their teaching and assessment process to their specific needs" (p. 93). The collection of findings and comments from studies focusing on assessment of investigations suggest that the nature of the prescribed assessment tasks and the need for good grades influenced both instructional strategies and students' approaches. Therefore, the driving force, when doing investigations, appears to be meeting examiners' expectations rather than meaningful learning.

While there seems to be concern about the assessment of investigations and the learning related to these practical activities, the studies reviewed are silent on the approaches by the students. Given the scarcity of studies focusing on approaches to investigations, useful insights can be drawn from literature on students' approaches to learning in general.

A study whose participants were 243 students from an English university was done by C. F. Smith and Mathias (2010) to determine students' approaches to learning a course in anatomy. They collected data using the Approaches to Study Skills Inventory for Students (ASSIST) developed by Tait and Entwistle (1996). The participants were found to be deep learners especially at the beginning of their studies. A shift towards a strategic approach occurred as they progressed from first to final year. Students associated with a strategic approach were also found to produce better academic performances. The two researchers assert that both the design of the curriculum and the mode of assessment are major factors in the furtherance of effective learning. This study was of interest in relation to the current study in the sense that an anatomy course for medical students is characterised by a lot of practical work and investigations in particular. The gap between first year medical students and final year A-Level high school students is small, thus the approaches to learning are relatively comparable. University students in their first year, in all probability retain the approaches to learning that are characteristic of their pre-university years until they are well adapted to their new teaching and learning environment.

In Australia, Trigwell, Prosser, and Waterhouse (1997) carried out a study to establish the relationship between university students' approaches to learning and the teaching approaches used by their teachers in chemistry and physics modules. They collected data from 46 teachers using the Approaches to Teaching instrument developed by Trigwell and Prosser (1996) and from 3956 students by using the Study Process Questionnaire (Biggs, 1987b). They established that teacher-centred teaching approaches were often associated with surface learners while students whose teachers used learner-centred approaches were classified as deep learners. While this study contributed significant insight with respect to the thinking behind the teachers' preferred teaching approaches and the resultant student learning, the lack of qualitative data from students means the reason for their adoption of surface or deep learning remained unclear.

Chin and Brown (2000) investigated the differences in six eighth-grade American students' approaches to learning by observing them doing practical work co-operatively before interviewing them. They established that those who employed a deep approach were eloquent in describing their procedures while those with a surface approach demonstrated shortcomings in procedural and factual knowledge. Chin and Brown asserted that scaffolding coupled with classroom discussions before and after the practical activities, could be effective in transforming surface learners to deep learners. This study was an explanatory case study in which the qualitative data gathered was meant to get a deeper understanding of the differences in the students' factual and procedural knowledge. This study fell short of establishing why the students planned and performed their practical activities the way they did, which could have given insight into the contextual factors influencing their actions.

### 2.7.2 A review of literature on approaches to investigations from a design perspective

Some of the leading scholars in practical work in science like Hodson (1990), Woolnough and Allsop (1985), and Wellington (2000) have focused on developing, analysing and extending various models for designing and carrying out investigations. The models, such as the PSC, provide useful instructional tools for designing and executing investigations (Gott & Duggan, 1995). Some researchers have focused on process skills over the years (Germann, Aram, & Burke, 1996) with the aim of establishing students' competence levels when they do investigations. A few scholars have dedicated time to investigating how students approach investigations from a design perspective.

Watson (1994) did a study on 11 and 12 year old students' engagement in investigations. He collected data by observing 13 students doing the investigations and found out that those who performed badly in the investigations were not methodical in their planning and arrived at solutions that were not consistent with their experimental data. Their approach was unsystematic and characterised by unproductive use of time. Watson (1994) concluded that the absence of co-operative learning during the investigations meant students were unable to assist each other in constructing appropriate experimental designs. His recommendation was that teachers should help students apply the steps outlined in the PSC thereby inculcating reflective practice. In a another study, Hackling and Garnett (1995) established that problem perception, reformulation and planning were major limitations when students do investigations. Students' experimental designs (sequence of steps) did not clearly indicate how they intended to collect, record and process data before they started doing the proposed experiments. Insufficient control of variables led to erroneous data interpretation. Furthermore, there was evidence pointing to the fact that students were often not cognisant of the methodological limitations of their experimental designs. Based on these findings it can be said that the participants in Watson's (1994) and Hackling and Garnett's (1995) studies were inclined towards a divergent approach to planning, designing and carrying out investigations. Divergent in this context refers to an approach which is all over the place. Omissions of some steps in the PSC and a failure to identify weaknesses in their own sequence of experimental steps are an indication of an absence of iteration in the execution of the science investigation. Both sets of researchers' recommendations apparently suggest that limitations in the instructional strategies of the teachers could have precipitated a divergent approach to investigations.

A study by Toh, Boo, and Yeo (1997) added weight to the argument that good instructional strategies can help students perform well in investigations. According to their findings, students with a sound understanding of both substantive and procedural knowledge outshined their counterparts who had substantive but lacked procedural knowledge. Another important finding from their study was that the possession of procedural knowledge led to better planning and communication skills but execution and data interpretation remained problematic. In light of these findings, it would appear that if teachers want to improve the performance of their students in investigations, they should equip them with procedural knowledge. They should also train them based on the iterative approach, which emphasises reflective practice.

Kanari and Millar (2004) carried out a study in which they sought to understand how students collect and interpret data in investigations. One of their aims was “to identify common approaches and patterns in students’ reasoning as they collect data in a practical science inquiry task and draw conclusions from it” (p. 751). They conducted an experiment in which the participants had to perform two investigations on fair testing. Ten students from each of the age groups 10, 12 and 14 years participated in each investigation. Video recording and interviews were the main data collection methods. The performances of the students in each of the two tasks were similar. Students performed differently depending on the existence of covariation or non-covariation of variables. They showed limited understanding of measurement of error leading to deficiencies in dealing with non-covariation. Kanari and Millar worked with Physics students and one of the assumptions they made was that students are competent in designing and carrying out investigations but fail to collect sufficient data or draw credible conclusions from their own data. This is in sharp contrast with the situation observed with A-Level Chemistry students in Zimbabwe where the reported problem is that of students’ failure to design or plan the investigations (ZIMSEC, 2010, 2011, 2012a).

Hammann, Ehmer, Grimm, and Phan (2008) carried out a quantitative study on the designing skills of 11 year old high school biology students in which they highlighted the scarcity of studies that focus on designing and carrying out of investigations. They did a comparative study on the performance of students in a laboratory seed-germination experiment and students’ experimental planning and data analysis skills in a written test. In the laboratory experiment, “planning was assessed in action” (p. 69) which meant students collected and analysed data from their own experiments, which were not always correctly designed and executed. Only two of the 24 participants methodically planned their experiments while the majority were unmethodical and incorrect. A notable finding of this study was that those who had flawed experimental designs consequently made invalid conclusions save for those who were able to identify weaknesses in their own planning. While there is a notable age difference between the participants in this comparative study and my research, useful insights can be drawn from this finding. It can be argued that success in designing investigations and carryout investigations hinges on the students' competence in procedural knowledge.

In a survey study, Ercan and Tasdere (2011) investigated the skills level of 206 second year Turkish pre-service teachers in experimental design by administering a multiple choice questions based Scientific Operation Skill Test followed by a Test of Scientific Processing Skills For Teachers with open-ended questions. The participants found the multiple choice items more manageable compared to the open-ended questions but in both cases, the majority of them were not as competent in designing experiments. They conceded that designing experiments is an integrated process skill that is difficult to master especially for students who are taught science in a traditional way. This survey study did not go as far as understanding why the participants chose to design the experiments the way they did which could have helped in coming up with the necessary remedial action. Since these were second year undergraduate students, it can be inferred that they did not master the art of designing experiments during their high school days and the problem persisted at tertiary level.

Roberts et al. (2010) did research on the role of substantive and procedural understanding in relation to students' ability to carry out open-ended investigations. It was a transformative case study whose 91 participants were second year undergraduate pre-service teachers. The participants were asked to perform an investigation (pre-test) before being equipped with basic procedural understanding of doing investigations, as an intervention strategy, after which they were asked to do the science investigation again (post-test). In both cases, they were given a question and all the material required but they had to come up with the experimental design themselves. The findings were that the participants showed an improved appreciation of data sets and tended to employ an iterative approach as a direct response to the data they collected during the investigation. The participants were found to engage in reflective practice, something that was missing before the intervention strategy was undertaken. This leads to the conclusion that deliberately planned teaching methods that give students a good foundation in procedural and substantive knowledge can bring about increased capacity to design and carryout investigations. This study by Roberts et al. (2010)

also points to the skills gap with respect to investigations that undergraduate students bring with them from high school.

Keiler and Woolnough (2002) carried out a study in one school which highlighted students' concerns with investigations. Limited time, lack of familiarity with apparatus and the almost exclusive association of investigations with assessment were the concerns raised by the students. In the same study students viewed their teacher's role as a trainer and provider of ideal strategies that would help them to maximise their performances in investigations.

### 2.7.3 Minding the gap in literature

A review of Zimbabwean literature revealed a dearth of research on investigations and approaches to learning in general. The same can be said of Sub-Saharan literature (Mogre & Amalba, 2015). Much of the research on high school chemistry education in Zimbabwe has focused on the teaching process (Mandina, 2012) and students' performance (Kazembe & Musarandega, 2012) in A-Level Chemistry. Globally, there is abundant literature on students' approaches to learning (C. F. Smith & Mathias, 2010), the relationship between teaching and learning approaches (Trigwell et al., 1997) and the effect of teaching and assessment on students' approaches (Moeed, 2010) but does not make direct links to the specific area of science investigations. As far as students' approaches from a designing perspective, a lot of work has been done on identifying students' approaches from experimental data (Hackling & Garnett, 1995; Hammann et al., 2008; Kanari & Millar, 2004; Toh et al., 1997; Watson, 1994). Notably, none of these studies were done with A-Level students as participants. The researchers either collected data from students at a lower or higher level compared to A-Level. Perhaps this is not surprising because researchers often collect data from participants that are accessible to them. Consequently, university lecturers, the major contributors to science education research, often collect data from undergraduate students. The scarcity of relevant literature, with respect to approaches to investigations at A-Level, can also be attributed to the fact that very few countries outside the UK follow the British education system, apart from the former British colonies such as Zimbabwe. In this study a relatively unexploited group of participants is used as a data source, not just to identify their approaches to investigations from two perspectives, but also to understand why they use specific approaches.

## 2.8 Conclusion

Practical work is a core element of chemistry education and takes various forms, one of which is investigations. When doing investigations, students varying degrees of autonomy in using the scientific methods to develop and use a range of basic and integrated process skills. By doing investigations, students are equipped with knowledge and process skills that will be useful in their future studies as well as professional and everyday lives.

In the process of doing investigations students show weaknesses in both substantive and procedural knowledge (Roberts et al., 2010). These weaknesses are compounded by psychological hurdles, which have their origins in the students' epistemological beliefs about teaching and learning, teaching and learning context, and self-efficacy (Watts, 1994).

Given the documented poor performances in investigations by A-Level chemistry students, the focus of this study is on their (students) approaches from two different perspectives, which comprise the theoretical framework. Firstly, from a learning perspective, deep, surface and strategic approaches can be singled out. Secondly, the design perspective is also associated with three different approaches which are iterative, linear and divergent. Literature suggests that the summative assessment of investigations prescribed in curriculum documents influences instructional strategies and by extension the approaches adopted by the students. There seems to be a consensus in literature that students' approaches are dynamic, hence change depending on the task, module and context.

Most of the literature reviewed gave insight into the approaches to learning adopted by students in various university modules and high school subjects in general. Studies on the approaches from a design perspective are also scarce and largely limited to tertiary level students as the participants. Consequently, exploring students' approaches in a specific problem area of A-Level Chemistry emerged as an enticing study. Identifying the approaches and how they emerge may provide answers to why students perform badly in investigations, which may in turn act as a springboard for planning and implementing remedial actions.

# CHAPTER 3
# THE RESEARCH DESIGN

This study explored A-Level chemistry students' approaches to investigations. The main focus question was: What are A-Level students' understandings and approaches to investigations? The research questions derived from it were:

1. How do students approach investigations from learning perspectives?

2. How do students approach investigations from designing perspectives?

3. What are the students' understandings of investigations?

4. Why do students approach investigations the way they do?

A synopsis of the methodology used to accomplish this study was outlined in Chapter One. In this chapter details of the methodology are provided, including the fieldwork undertaken to gather data which was used to provide answers to the research questions.

The philosophical foundation of this study is pragmatism and the stated research questions informed my choice of the mixed methods research approach. The link between the paradigm, research questions, approach, design and tools is illustrated in Figure 3.1.

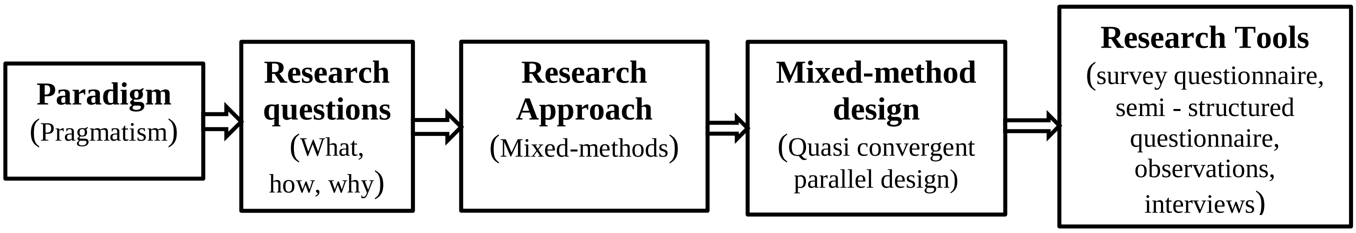



Figure 3.1 The research design map

## 3.1 The research approach

The research methodology and design adopted for this study is based on a pragmatic paradigm. It was deemed appropriate to explore the students' approaches to investigations by exploiting all the means available. According to Mertens (2010), a paradigm defines how one sees the world and is shaped by various philosophical assumptions. For any paradigm, four philosophical assumptions (belief systems) can be identified which are ontology, epistemology, axiology and methodology (Creswell, 2009; Mertens, 2010).

The ontological dimension focuses on the nature of reality. Pragmatists make use of both the positivist and the constructivist appreciations of reality. While positivists believe that there is one objective reality, a singular truth, constructivists accept there are several realities and that different social actors have unique ways of interpreting reality (Morgan, 2007). Instead of aligning with one world view or the other, pragmatist stance meant embracing both ontological perspectives in this study (Mertens, 2010). In the view of Descombe (2008), pragmatism is a “practice-driven” (p. 280) paradigm hence it allowed me to adopt whatever was effective (Maxcy, 2003) with respect to investigating the practical problem which prompted the undertaking of this study. Cohen et al. (2011) emphasise that pragmatists consider “fitness for purpose and applicability” (p. 23) when carrying out a research study. This study is double edged. The quantitative section of the study brings with it the idea of an objective reality while the qualitative one recognises the existence of multiple realities. The quantitative data was an ideal vehicle to categorise the participants as belonging to one category or the other. The qualitative data went a step further. Apart from categorising the participants, qualitative data helped me to understand why the participants adopted one approach or the other as influenced by their context.

Positivists and constructivists differ in what they believe to be credible knowledge. According to Wahyuni (2012), the epistemological stance of positivists is that only “observable phenomena can provide credible data and facts” (p. 70) while constructivists give value to “subjective meanings and social phenomena” (p. 70) as forms of data. Cohen et al. (2011) assert that epistemology deals with the “ways of researching and enquiring into the nature of reality and nature of things” (p. 3). In this study, credible knowledge was derived from both observable phenomena (the approaches to investigations) and subjective meanings (the understandings of investigations and why students approach them the way they do). Thus, different perspectives were engaged in order to achieve the intended outcome (Maxcy, 2003; Wahyuni, 2012), that is, providing answers to the proposed research questions. To find answers to the question on how students approached investigations from a learning perspective, a survey questionnaire was administered to the participants. The rest of the research questions were answered using textual data from documents, semi-structured questionnaires, interviews and lesson observations in which multiple realities were represented.

The third belief system, axiology, which is taken into consideration in framing this study is about the role of values. I adopted both etic and emic approaches in gathering data (Wahyuni, 2012). Using an etic approach in gathering quantitative data meant that I had no influence on the data generated while in the emic approach I was immersed in the data collection process thereby introducing relative subjectivity in its interpretation (Guba & Lincoln, 2005; Morgan, 2007; Wahyuni, 2012). The use of a survey questionnaire to gather quantitative data for this study was convenient as it was the best and easiest way to collect a lot of data to answer the first research question. My relationship with the participants changed when I collected the necessary qualitative data. It meant greater interaction with them, lots of conversations and spending many hours in their laboratories observing them doing their practical work.

The methodology forms the fourth philosophical assumption and constitutes the bridge between the research focus and methods (Mertens, 2010). Johnson and Onwuegbuzie (2004) argue that pragmatism gives researchers the opportunity to employ a cocktail of research methods as dictated by their research questions. Onwuegbuzie and Leech (2005) in their attempt to promote the use of pragmatism argued that methodological pragmatism should replace dogmatic methodological approaches as may be demanded by the research questions. As Greene, Caracelli, and Graham (1989) put it, the research questions play a pivotal role when designing a mixed methods study. The specific questions that guided this study could best be answered by using a combination of quantitative and qualitative approaches to gathering data. Consequently, I used a mixed method methodology.

Descombe (2008) says that the mixed methods methodology has the advantage of: (a) enhancing the accuracy of data; (b) producing a more complete picture (of the phenomenon) by merging complementary types of data; (c) side-stepping biases inherent in quantitative or qualitative on its own and (d) building on the initial findings by employing different data types. Using a mixed method methodology enabled me to combine the strengths of both qualitative and quantitative methodologies in a single study. This, in other words, helped to overshadow the weaknesses of either methodology on its own. This study explored the approaches to investigations from a learning as well as a designing perspective. The learning perspective lends itself largely to a qualitative approach while the designing perspective is aligned with the quantitative one.

The credibility of a mixed methods study hinges on a good and carefully crafted set of research questions (Tashakkori & Creswell, 2007). The study should be driven by *what and how* or *how and why* questions (Cohen et al., 2011; Mertens, 2010; Tashakkori & Creswell, 2007). Cohen et al. (2011) go on to suggest that the research questions do not necessarily have to be a 'hybrid' (p. 24), that is, *what* and *how* or *how* and *why* combined in one question. Separate questions can also be asked, each falling under one of quantitative and qualitative. The focus questions of this study were separate what, how and why questions. I used the quantitative data to answer the *what* question, one *how* question required quantitative data while the other was answered using qualitative data. The *why* question was responded to by interpreting data from all the sources.

There are various types of mixed method designs identified in literature. In a convergent parallel design, quantitative and qualitative data is collected simultaneously and then merged for interpretation purposes (Cohen et al., 2011; Creswell, 2009). The researcher would then be able to explain points of convergence or divergence. Another mixed methods design identified by Cohen et al. (2011) is *quasi-mixed*. In a typical quasi-mixed design, both quantitative and qualitative data are gathered but not merged in order to answer any of the research questions. Each data set is kept separate and is used to answer a different question in the same study. While this is largely so in this study, there is partial mixing of data in order to comprehensively answer the second research question on how students approach investigations from a learning perspective and the fourth question on why students approach investigations the way they do. I therefore call the design I used in this study *quasi convergent parallel design*. This design is illustrated in the flow diagram in Figure 3.2.

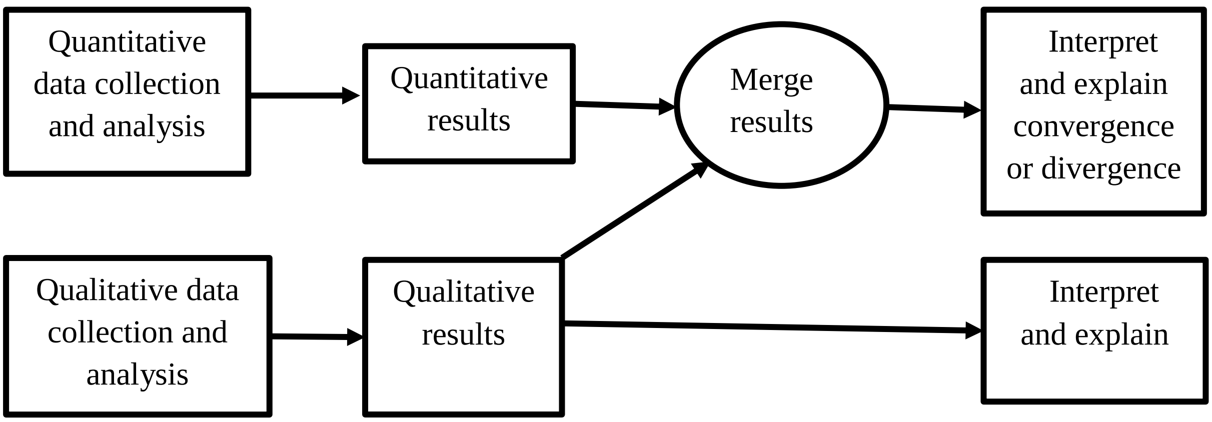



Figure 3.2 The quasi-convergent parallel design

Data from the semi-structured questionnaire was coded during analysis to categorise each student as falling under deep, strategic or surface approach. The results of this data analysis were then compared with the results from the survey questionnaire data. The rest of the qualitative data was analysed and interpreted separately to answer research questions one, three and four. The research methods and data collection process are described and explained in greater detail elsewhere in this study.

## 3.2 The participants

The population of students who enrol for A-Level Chemistry in Zimbabwe averages 3500 each year. The average number of students in an A-Level Chemistry classroom across the country is 25. The average age of A-Level students is 18 years across all schools, hence it's safe to say they have the same level of maturity. Although these students do their A-Level studies in different schools scattered throughout the country, their contexts share similar characteristics.

Firstly, to enrol for A-Level studies one should have passed five O-Level subjects at Grade C or better, including Mathematics and English at home (first) language level. Owing to the limited number of schools offering A-Level sciences, the competition for places is high. Consequently, those who study A-Level Chemistry, in all probability, would have achieved at least five A's at O-Level, including an A in Chemistry or Physical Sciences.

Secondly, all the schools that offer Chemistry at A-Level have a standard laboratory approved by the Ministry of Primary and Secondary Education. The A-Level Chemistry syllabus outlines the minimum laboratory equipment for each student and schools are obliged to meet these requirements. Consequently, such schools are few and far between. It can therefore be concluded that all A-Level Chemistry students in the country have comparable resources irrespective of the schools they attend.

Thirdly, all the schools follow the same curriculum and write the same examination administered by ZIMSEC. Each A-Level Chemistry class has a designated laboratory session where they cover the practical component of the syllabus. This is in addition to the practical activities that they do in the form of demonstrations or otherwise to reinforce relevant concepts during their regular Chemistry lessons which cover the theoretical components of the syllabus.

Fourthly, for one to teach A-Level they must be a holder of at least a bachelor's degree. It can therefore be concluded with reasonable confidence that A-Level Chemistry students throughout the country are taught by teachers with comparable qualifications.

A total of 50 students from two classes in two similar schools were purposively sampled for this study (Cohen et al., 2011). The two schools were within a 60 kilometre radius from where I stayed during the data collection period. This allowed me to travel between the schools and attend all their designated practical sessions thus enabling me to collect all the necessary data. I chose to use non-probability purposive sampling in order to provide significant depth to my study although the breadth could have been compromised (Cohen et al., 2011). According to the same authors, 30 is the minimum acceptable sample size. However, they caution that small samples undermine statistical generalisation. I found the sample of 50 students to be a fairly representative given that their characteristics matched those of the population of A-Level chemistry students in Zimbabwe as described above.

Of the 50 students, 42 were boys and eight were girls. The average age for the whole group was 18.16 years. The majority of the participants were 18 years old with only eight aged 19. This was significant in two ways. First, this meant that all the participants had reached the age of consent in the Zimbabwean context hence it was not necessary to seek parental consent to collect data from them. Second, the age range of 18-19 years has largely been left out by researchers focusing on approaches to learning as has been pointed out under the literature review section in chapter two of the current study.

An impressive 100% of the participants achieved a grade A in the Chemistry O-Level public examinations making them above average performers in the subject. It is therefore not surprising that they chose to study the subject at A-Level. All the students who took A-Level Chemistry were compelled to take Mathematics in both schools. According to both chemistry teachers, this was meant to ensure that all the students taking science at this level had the mathematical skills required to do practical work of a quantitative nature and study Chemistry topics such as Stoichiometry, Reaction Kinetics, Molecular and Ionic Equilibria and Chemical Energetics. Chemistry and Mathematics were therefore, by design, common subjects for all those who chose do science subjects at A-Level. The students then chose either Physics or Biology depending on their career aspirations. 30 of the students were doing Physics and the others Biology.

## 3.3 Ethical issues

When doing a research study that involves gathering data from other people, it is mandatory to get permission from the relevant authorities and individuals involved. Permission was obtained from the Ministry of Primary and Secondary Education, Zimbabwe, before applying for and getting ethical clearance from the Research Ethics Office of the University of KwaZulu-Natal. All the teachers and students who participated in this study filled in consent forms, in which all of them agreed to be photographed and video recorded, without applying any coercive force. Time was taken to explain to the participants how their anonymity would be protected. In all the questionnaires, worksheets and transcripts the actual names of the participants were replaced with codes or pseudonyms in order to protect their identity (Blaxter, Highes, & Tight, 2006; Cohen et al., 2011). The transcripts of the focus group discussions and interviews with the chemistry teachers were made available to the corresponding participants for member checking to ascertain the veracity of the data before embarking on data analysis. I asked them if they wanted any part of the transcripts to be changed through deletions or additions. All the participants were satisfied that the transcripts were a correct record of what they had said during the focus group discussions and interviews. Interacting with the participants at this stage also gave me an opportunity to thank them for their individual and collective contributions.

## 3.4 Data collection methods

The quantitative data for this study were obtained through a survey questionnaire (Appendix E) administered to all 50 students. Qualitative data were gathered through a semi-structured questionnaire, observations, focus group discussions, interviews and document analysis. The data consists of exhaustive "descriptions of participants' activities, behaviours and actions recorded in observations of practical sessions, direct quotations of their (participants) experiences, opinions, feelings and knowledge gathered from focus group interviews as well as excerpts, quotations or entire passages from various documents" (Merriam, 2009, p. 85).

### 3.4.1 The Approaches to Investigations Inventory for Students (ASIIS)

A survey questionnaire was designed and administered in order to determine and describe the students' approaches to investigations from a learning perspective. Cohen et al.

(2011) identified several characteristics of survey questionnaires. According to them, a survey questionnaire generates accurate data through piloted and revised instruments, gathers standardised information (using the same instrument for all participants), captures data from Likert type items, generates data that can be processed statistically and provide descriptive, inferential and explanatory information. These characteristics point to some of the advantages of using a survey questionnaire. It is efficient and economical as data is gathered from many, if not all, participants simultaneous (Guthrie, 2010). The unobtrusive nature of this data collection method is another significant advantage. Apart from explaining the aim of the questionnaire and assuring the participants that their identity would not be revealed in the study, there was no influence on their responses. Cohen et al. (2011) add that the anonymity and confidentiality of the participants is significantly improved by aggregating the data in the analysis stage. The data from the fifty students was analysed together to identify group patterns, without trivialising atypical cases.

Surveys generally depend on huge amounts of data when the aim is statistical generalisation (Cohen et al., 2011; Creswell, 2009). As explained in an earlier section, a relatively small convenient sample was preferred for this study in order to do an in-depth study of their approaches to investigations. I was however, cognisant of the limitations of the study in terms of statistical generalisation from the onset.

The instrument was designed to gather data in order to categorise students based on the constructs of deep, strategic and surface learning. Since this was an exploratory study no hypotheses were formed, the intention was to gather descriptive data in the form of factual information based on the preferences, behaviours and experiences of the participants (Cohen et al., 2011; Guthrie, 2010).

A number of instruments, referred to as inventories, have been designed over the years with the aim of assessing students' approaches to learning in general. These include, among others, the Approaches to Study Inventory (ASI) by Entwistle, Hanley, and Hounsell (1979) which evolved into the Revised Approaches to Study Inventory (Entwistle & Tait, 1994) and then to the Approaches to Study Skills Inventory for Students (ASSIST) by Tait and Entwistle (1996) and a more recent version by Entwistle et al. (2013). These instruments were largely aimed at understanding students' learning at tertiary level. Entwistle, Tait, and McCune (2000) administered the ASSIST to South African and Scottish university students in a comparative study. Although the South African context is closer to the Zimbabwean one, the educational level of participants is different since I collected data from A-Level chemistry students. Biggs (1987c) on his part developed the Study Process Questionnaire (SPQ) together with a secondary school version called the Learning Process Questionnaire (LPQ) (Biggs, 1987a). While it might have seemed logical to adopt Biggs' LPQ, the items on this instrument were found to be less suitable as many of them were too general and could not be satisfactorily modified to suit this study. For example, the first item on the question read: "I chose my present subjects mainly because of career prospects when I leave school, not because I'm particularly interested in them" (Biggs, 1987a, p. 42). I found the ASSIST to be more comprehensive as it includes a section on preferences for teaching. As has been alluded to earlier, the teaching methodologies employed by teachers often shape students' approaches to learning (investigations).

The ASSIST (Entwistle et al., 2013) was modified to produce a survey questionnaire entitled Approaches to Investigations Inventory for Students (ASIIS) (Appendix E). Just like in the original ASSIST, the items in the ASIIS address deep, strategic and surface approaches to learning. The ASIIS excludes Section A from the ASSIST but adopts the structure of Sections B and C. The ideas in Section A of the ASSIST were included in a separate semi-structured questionnaire which was administered to all the participants. I modified all 52 questions in Sections B and C of the ASSIST to suit this study. Examples of the differences between the ASSIST and the ASIIS are shown in Table 3.1.

Table 3.1 Differences between the ASSIST and ASIIS

| ASSIST | ASIIS |
|---|---|
| 1. I manage to find conditions for studying which allow me to get on with my work easily. | 1. I manage to find conditions for doing investigations that allow me to get on with my work easily. |
| 2. When working on an assignment, I'm keeping in mind how best to impress the marker. | 2. When doing an investigation, I keep in mind how best to impress the marker. |
| 3. Often I find myself wondering whether the work I am doing here is really worthwhile. | 3. Often I wonder if the investigations I am doing are worthwhile. |

Another deviation from the ASSIST is that the Likert scale in my questionnaire runs from 1 (disagree) to 5 (agree) as opposed to 5 (agree) to 1 (disagree). This decision to invert the scale was informed by the results of the pilot study which is discussed below.

*Piloting and administration of the survey questionnaire*

The designing of the questionnaire was done in a recursive manner. This is illustrated in Figure 3.3. After drafting the questionnaire, I administered it to a group of 11 A-Level Chemistry students. This was done three months prior to the commencement of the main data collection process. As a result of the feedback received from the pilot participants, the Likert scale was changed to run from 1 to 5. The pilot participants suggested that a scale running from 1 to 5 gave the impression of 'low to high' (disagree to agree) which was easier to remember and use in answering the questions. The changes of responses (crossed out their original choices and selected a different option) on 5 (n=11) of the questionnaires provided proof that some participants could have been confused by the scale.  In addition to this, the scale was inserted on the top of each page for easy reference.

To guarantee a high return rate of the survey questionnaires, the participants completed them in my presence. This also ensured that the participants would not consult each other when responding to the items thus enhancing the validity of the data collected. Figure 3.3 illustrates the development and administration of the survey questionnaire.

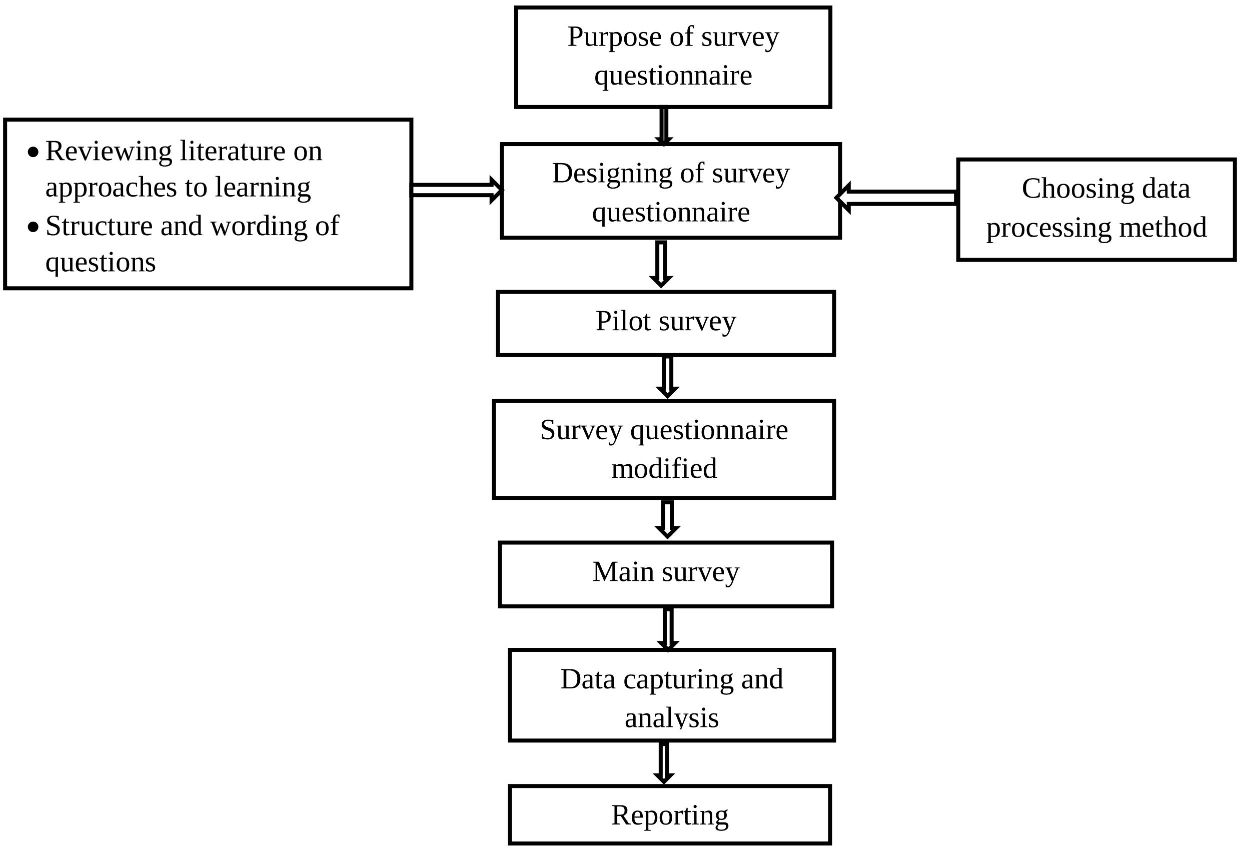



Figure 3.3 The design and administration of survey questionnaire

### 3.4.2 The designing and understanding questionnaire (DUQ)

A more open-ended qualitative semi structured questionnaire was administered to the participants in order to gather data with respect to their understanding of and approaches to investigations. It was also used as a precursor to focus group sessions with students and one-on-one interviews with their teachers. To enhance the validity of the data collected, the DUQ contained open-ended questions thus allowing respondents to frame the answers in their own words (Cohen et al., 2011; Guthrie, 2010; Jackson, 2008). The only restriction was the space provided on paper for them to write their responses. The multiplicity of responses expected when people express their understanding of a scientific phenomenon meant that open-ended questions were an appropriate choice (Cohen et al., 2011). The relatively small number of participants, conveniently and purposively chosen, meant that the textual data would be manageable.

Cohen et al. (2011) point out that semi-structured questionnaires often have the disadvantage of gathering 'irrelevant and redundant information' (p. 382). Another shortcoming of this method cited in literature is related to the challenges of analysing the textual data given the significant variations in the responses (Bell, 2010; Cohen et al., 2011). To reduce the impact of these weaknesses, the DUQ was piloted three months prior to the commencement of the data collection process.

*Piloting the DUQ*

The DUQ was piloted with 11 A-Level students to ascertain its validity. This was done with the same group of students used in piloting the survey questionnaire. The participants were asked to make comments if they didn't understand any of the questions. While no comments were made by the students, the completed questionnaires revealed blanks or very short phrases especially in the first question. I suspected that there may have been problems with understanding terms such as science investigation and sources of investigations. I therefore included accompanying explanations or examples to ensure that I would collect relevant data.

Two experienced lecturers, one of them an associate professor and the other an experienced chemistry educator, were requested to review the same DUQ. The feedback received led to significant modifications to the original questionnaire. The associate professor's feedback read, "There is need to rearrange the questions to start from less to more complex. For example, I consider the conceptualisation of an investigation to be a challenging question, especially to high school students”. The experienced chemistry educator said, “While I acknowledge that the questions seek to gather relevant data for your study, I suggest that you expand on them to make sure that the respondents will understand what you are looking for”.

Consequently, the questionnaire was restructured to bring more clarity to the questions and reflect a gradual increase in complexity. In addition, a fourteenth question was added to allow respondents to express any other views related to the way they do investigations. Table 3.2 shows the first four questions of the both the pilot and the final draft questionnaires illustrating the changes made as a result of the feedback received from the students and my colleagues. The complete versions of the questions are found in Appendix M.

Table 3.2 Versions of the DUQ

| Pilot Questionnaire | Final draft |
|---|---|
| 1. In many of your practical sessions you are asked to design, plan and carry out an investigation. What is an investigation to you? | 1. One of the assessment areas in the A-Level Chemistry syllabus is ‘Experimental Skills and Investigations’. Consequently, in the practical sessions and examinations, you are asked to design, plan and carry out an investigation. I am also aware that you did an investigation in your last practical session. What was it about? |
| 2. What in your opinion is the role of investigations in your study of Chemistry? | 2. Describe to me how you went about designing, planning and carrying out this investigation. Did you use any specific strategy/steps/method/procedure? |
| 3. You did an investigation in your last practical session, what was it about? | 3. Did you find yourself stuck at any moment during the investigation? If so, how did you solve the challenge, if at all? |
| 4. Have you done a similar investigation before? If so briefly describe what the investigation was about. | 4. How successful were you in planning and performing the investigation? Did you manage to produce the desired plan and results? |

### 3.4.3 Direct observation of practical work sessions

Observation involves systematically looking, noting and recording events, behaviours, artefacts and routines within the context in which the study is done (Cohen et al., 2011; Marshall & Rossman, 2011). Observation as a method of data collection is based on the assumption that “behaviour is purposeful and expressive of deeper values and beliefs” (Marshall & Rossman, 2006, p. 98). The coverage of the A-Level Chemistry curriculum was done in two parts. There were four 70 minutes sessions in which they covered the theory component of the syllabus and one two-hour session dedicated for practical work each week. The practical sessions fell on Thursdays for both classes, one in the morning and the other in the afternoon with a two and half hour gap in-between them. I made a decision not to observe the theory lessons for logistical reasons. It was difficult to schedule the visits in two locations and also see the theory lessons because the timetables in the two schools overlapped.

Four practical sessions were observed per class and in each case two of them were video recorded. During the observations, data was also captured through field notes. The practical sessions were very similar in style and after consultation with teachers, I came to the decision that further observations would result in very similar data as this was their routine way of doing investigations.

The observation of students doing investigations was often punctuated with informal interviews and document perusal if clarifications of observed behaviour was needed (Marshall & Rossman, 2011; Merriam, 2009). This allowed me to collect authentic data from the natural environment where they do their practical work, the chemistry laboratory (Cohen et al., 2011). By doing observations, I was able to gain significant first-hand knowledge of the context and give accounts of specific incidents and behaviours which could not have been obtained otherwise. Some of the observations were then used as referents in interviews and later on during data analysis and interpretation (Marshall & Rossman, 2011).

The data from the observations was essentially used to answer the research questions on how students approach investigations from a designing perspective as well why they approached them the way they do.

### 3.4.4 Documents analysis

According to (Merriam, 2009), *document* is an umbrella term referring to “a wide range of written, visual, digital and physical material relevant to the study at hand” (p. 139). To begin with, documents of interest were students’ worksheets and their teachers’ plan books. Gathering data from these documents had the advantage of being unobtrusive and it offered me a deeper understanding of the phenomenon through accessing students’ practical worksheets covering investigations done even before the data collection process began (Marshall & Rossman, 2011; Merriam, 2009). By going through the practical worksheets it was possible to determine each student’s approach from a designing perspective. Part of the outcomes of the focus group discussions with the student participants, led to the inclusion of O-Level Chemistry syllabus and textbooks as relevant data sources. The types of practical work prescribed for O-Level and the nature of the practical activities in the textbooks were of special interest.

The data from documents was used to complement what I got from the completed DUQ, observations, focus group discussions and interviews with teachers (Marshall & Rossman, 2011).This data was useful in answering the questions on how students approach investigations from a designing perspective as well as why they approached investigations the way they did.

### 3.4.5 Focus group interviews

An interview is a purposeful conversation between the researcher and the participant aimed at collecting data that will help answer the research questions (Marshall & Rossman, 2011; Merriam, 2009). In choosing to interview students, I was influenced by Patton (2002) who says:

> We interview people to find out from them those things we cannot directly observe….. We cannot observe feelings, thoughts and intentions. We cannot observe behaviours that took place at some previous point in time. We cannot observe how people have organized the world and the meanings they attached to what goes on in the world. We have to ask people questions about those things. The purpose of interviewing, then, is to allow us to enter into the other person's perspective. (p. 340-341)

Focus group interviews were, in my opinion, an ideal way of collecting data given that the total number of students involved was 50. Instead of choosing a few students for one-on-one interviews, I felt focus groups would involve more students and hence help me capture large volumes of more credible data quickly. In addition, the attitudes and beliefs that people possess are not formed in isolation but constructed in social settings (Marshall & Rossman, 2011). People often use other people's opinions to develop their own. Marshall continues to say that focus groups are done in a more comfortable social environment compared to one-on-one interviews.

Open-ended questions were used during the focus group interviews (Merriam, 2009). This allowed the participants to express themselves uninhibited while according me a deeper appreciation of the meanings attached to regular activities associated with investigations. The high level of personal interaction with the participants during a focus group session is sometimes viewed as a weakness since they (participants) may find it difficult to talk about some issues deemed sensitive (Merriam, 2009). I had anticipated that the students would be unwilling to share with me everything I wanted to explore, for example, the instructional approaches used by their teachers (Marshall & Rossman, 2011). However, surprisingly, there were no topics that were considered untouchable by any of the focus group participants.

The focus group sessions allowed me to probe the students on some of their responses recorded in the DUQs. The questionnaire served as a precursor to the focus group discussions. The data from the questionnaires was captured and used to formulate questions that guided the discussions. Thus having a panoramic idea of how students conceptualise and approach investigations assisted me in probing specific areas of interest. The focus group data gave me valuable insight into the students' understanding of investigations, how they approach them from learning and designing perspectives and why they approach them the way they do. This alternative data source provided an opportunity for triangulation during analysis.

In each school, I had a maximum of two hours to complete the discussions due to other school activities. The second term is traditionally a very busy time of the school year due to various sport competitions. Each focus group discussion lasted an average of 25 minutes. It meant that there was only time to do four groups in each school. The participants for each focus group session were organised in a systematic way. Each of the two Chemistry groups was divided into quartiles based on their term one examination performances. Each focus group was composed of four students, one from each of the quartiles. This ensured that each group had students with differing abilities which increased the probability of having a diversity of views and ensuring robust discussions during each session. The purpose was not to obtain group consensus. It was possible to probe students on their responses since all the participants' names were available to me. While I was busy with one group, the rest of the students were kept occupied by their teacher, which eliminated the risk of interviewed students sharing the discussion proceedings with colleagues who had not yet been interviewed.

All the interviews were done on the same day. There was a one and half hour time difference between the end of the last focus group discussion in one school and the commencement of the first one in the second school. This was meant to ensure consistency in the way I asked the questions. Although it was exhausting to do all ten interviews in one day, the vibrancy and robustness of the discussions kept me going. The first two focus group sessions in each school were relatively longer than the last two. This can be explained in two ways. Firstly, experience helped me to ask the questions in a clearer way and coordinate the discussions better each time. Secondly, the answers were similar which eliminated the need to probe extensively during the last two sessions.

## 3.5 Data transformation and analysis

*Quantitative data*

The survey questionnaire data was first captured on an excel spreadsheet before loading it onto Statistical Package for Social Scientists (SPSS) 23. The SPSS is a software used to by researcher and statisticians to analysis and present numeral data (Cohen et al., 2011). This enabled the researcher to determine descriptive statistics values such as mean and standard deviation as well as Cronbach alpha coefficients to test the reliability of the data. Descriptive statistics are useful in describing a sample without necessarily generalising the findings to include the parent population (Bell, 2010). The group and individual mean agreement scores generated from the ASIIS were used to categorise the students according to the approaches of deep, strategic and surface. The standard deviations gave an indication of the spread of views with respect to the constructs and items under each approach.

*Qualitative data*

Data analysis in this study involved “organising, accounting for and explaining the data, making sense of data in terms of the participants’ definitions of the situation noting patterns, themes, categories and regularities” (Cohen et al., 2011, p. 535). The same authors’ idea of ‘fitness for purpose’ was also embraced during the analysis and presentation of qualitative data. Consequently, some of the qualitative data was transformed through coding, using NVivo 11. NVivo is a type of computer software which facilitates the collection, processing and analysis of qualitative data in the form of texts, photographs, video and sound recordings (Cohen et al., 2011). Appropriate mother nodes and child nodes were created as was found necessary to enable counts to be made and themes to emerge (Bazely & Richards, 2000).

An excel spreadsheet was used to capture and organise the responses generated from the DUQ. The spreadsheet, which shows the participants and their responses to each of the questions was then loaded into NVivo11 for thematic analysis. The constructs of iterative, linear and divergent approach, reflected in the theoretical framework for this study, were used as the basis for coding process. Codes were also generated based on the emerging themes on students' understanding of investigations, and why they approached them the way they did. Appendix N shows a sample NVivo 11 output illustrating themes and counts.

Data from documents and observations of practical sessions were captured through field notes as indicated in section 3.6.2. Video recordings and photographs were taken to improve the accuracy of the data collected from these sources. I personally produced summaries of the video recordings which enabled me to do the initial isolation of themes as well as acquiring a detailed understanding of the data. I also did the transcription of all the focus group and teacher interviews. I then reported the emerging themes from the qualitative data as assertions (Gallagher & Tobin, 1991) to reflect both the abductive nature of the study and " the situational nature of the findings" (Nolen & Talbert, 2011, p. 270).

The confidentiality of the data and anonymity of the participants was guaranteed by using pseudonyms while keeping a record of their actual names for tracking purposes and linking with data from other sources. All these forms of qualitative data were loaded into NVivo 11 for systematic analysis (Cohen et al., 2011). The analysis of the qualitative data, to come up with themes, was done in an iterative manner to ensure it was exhaustive. The process is illustrated in Figure 3.4.

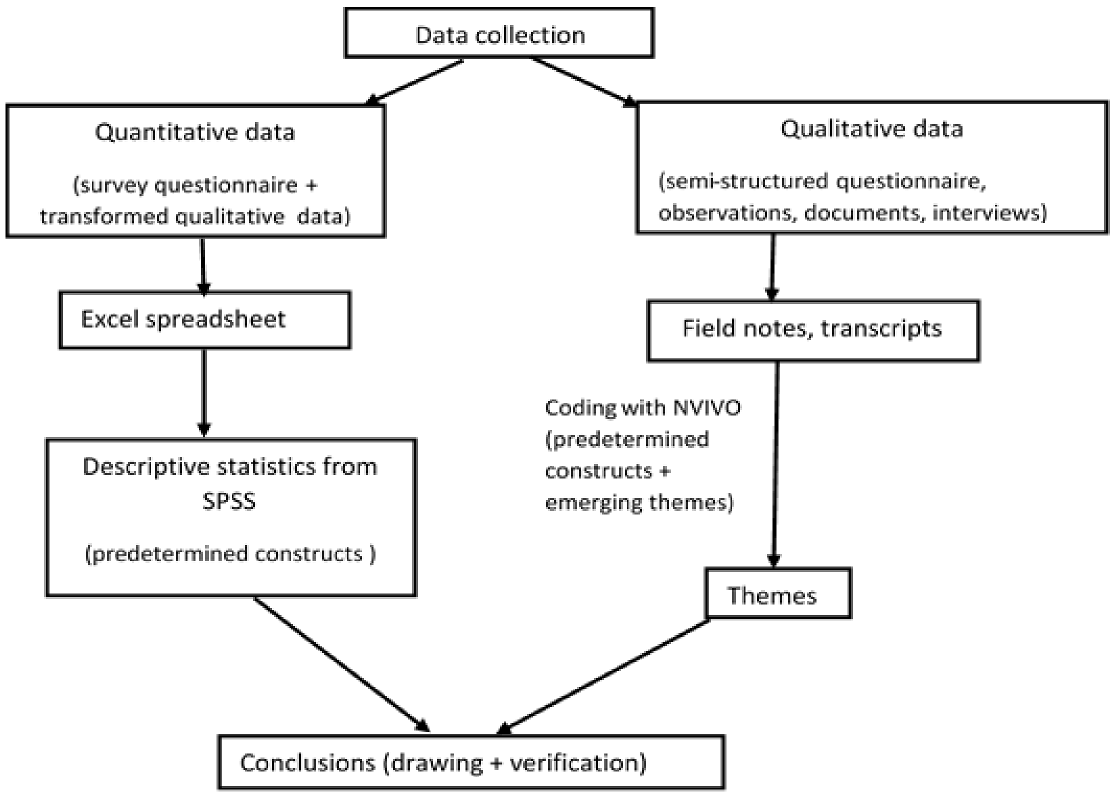



Figure 3.4 Systematic data analysis (adapted from Miles and Huberman (1994))

## 3.6 Validity and reliability

When doing research, it is essential to ensure that the data gathered is authentic and will help answer the proposed research questions (Cohen et al., 2011; Yin, 2009). Appropriate choices of research methods and strategies should be followed by thorough data analysis and assertions born from the evidence at hand. At the same time the researcher should be able to discard any alternative explanations that can be inferred from the same data collected (Cohen et al., 2011; Yin, 2009).

The use of multiple data sources and triangulation enhanced the credibility of the study (Cohen et al., 2011; Patton, 2002; Yin, 2009). Data triangulation was used in this study by taking advantage of the data collected using various methods namely semi-structured questionnaire, documents and focus group discussions. For example, in the DUQ and focus group discussions, the participants were asked to describe how they went about designing, planning and carrying out investigations. Their descriptions were used to categorise them under iterative, linear or divergent approaches. This was then followed by an analysis of their scripts to see if their descriptions matched what they did in practice leading to categorisation based on a third source of data. A more detailed analysis of the data related to this example is presented in chapter five.

Throughout the study, a research database was kept in the form of detailed descriptions of methods; choices of participants and the data collection process in order to enhance the reliability of my study (Cohen et al., 2011; Geertz, 1983; Yin, 2009). All the transcripts of the focus group discussions and teacher interviews were subjected to member checking to ascertain their accuracy.

## 3.7 Conclusion

This study was grounded within a pragmatic paradigm and a mixed methods approach adopted. A quasi convergent parallel mixed methods design guided the data collection and analysis process. To achieve an in-depth study of the A-Level students' approaches to investigations, data was collected from two purposively chosen classes containing a total of 50 students who I consider to be representative of the population of all A-Level students doing Chemistry. Quantitative data was gathered through a survey questionnaire while qualitative data was obtained from direct observation of practical sessions, document analysis, a semi-structured questionnaire and student focus group and teacher interviews. The quantitative data was processed using SPSS 23 to obtain descriptive statistical values which were then used to draw conclusions on the approaches used by the students from a learning perspective (Cohen et al., 2011). The qualitative data was analysed using NVivo to determine the students' approaches to investigations from a designing perspectives as well as drawing assertions on their understanding of investigations and why they approach investigations the way they do.

The findings of this study are presented in three chapters. Chapter four deals with students' approaches to investigations from a learning perspective while chapter five covers the approaches from a designing perspective. In chapter six, the findings on students' understanding of investigations, and why they approach them the way they do are presented.

# CHAPTER 4
# THE LEARNING PERSPECTIVE

In the preceding chapter, the paradigm, research approach, design and data collection methods for this study were described together with the reasons for their selection. Four research questions were put forward to guide this study and form the basis for designing the data collection instruments. The questions were framed to explore how students approach investigations from both learning and designing perspectives, their understandings of investigations and why they approach investigations the way they do. In this chapter, the data presented was used to provide answers to the first research question on how students approach investigations from a learning perspective. The approaches to investigations from a learning perspective framework discussed in greater detail in chapter two was used to make sense of the findings. The framework identifies three distinct approaches, namely deep, strategic and surface, which were used to profile the participants based on the data they provided.

Quantitative data was obtained from more than one instrument as can be inferred from the quasi concurrent-parallel mixed methods design explained in chapter three. These instruments were a survey questionnaire (ASIIS), a semi-structured questionnaire (DUQ) and focus group interviews. The data from the DUQ and focus group discussions were transformed through a coding process to produce numerical data. The details of the data transformation process are described in the corresponding sections where the data were also presented.

The first set of data was obtained through the administration of a survey questionnaire to 50 A-Level Chemistry students. The first part of the survey questionnaire was meant to collect demographic data from the student participants which was deemed relevant to give context to the understanding of their approaches to investigations. The demographic data was presented in chapter 3. The second part was about students' approaches to investigations. The data were captured and analysed using SPSS 23.

## 4.1 Approaches to investigations from a learning perspective: group analysis of ASIIS data

The main part of the Approaches to Investigations Inventory for Students (ASIIS) survey questionnaire used in this study had 61 items and the data collected was used to categorise the students as having a deep, strategic or surface approach to investigations. Each of these categories had sub-constructs that were linked to four questions on the ASIIS. Table 4.1 shows the constructs falling under each of the approaches.

Table 4.1 Constructs under deep, strategic and surface approaches

| Approach | Constructs and associated questions on the ASIIS |
|---|---|
| **Deep** | Seeking meaning (SM) [4; 17; 30; 43] |
| | Relating ideas (RI) [11; 21; 33; 46] |
| | Use of evidence (UE) [9; 23; 36; 49] |
| | Interest in investigations (ISI) [13; 26; 39; 52] |
| **Strategic** | Organised (O) [1; 14; 27; 40] |
| | Time management (TM) [5; 18; 31; 44] |
| | Alertness to assessment demands (AA) [2; 15; 28; 41] |
| | Achieving (A) [10; 24; 37; 50] |
| | Monitoring effectiveness (ME) [7; 20; 34; 47] |
| **Surface** | Lack of purpose (LP) [3; 16; 29; 42] |
| | Unrelated memorisation (UM) [ 6; 19; 32; 45] |
| | Syllabus-boundness (SB) [12; 25; 28; 51] |
| | Fear of failure (FF) [8; 22; 35; 48] |

The questionnaire was validated by administering it to 11 A-Level Chemistry students and reviews from an associate professor and a senior lecture in the chemistry education department as outlined in Chapter three.

## Testing the reliability of the ASIIS

The ASIIS data was captured on an excel spreadsheet and then loaded onto SPSS 23 to ascertain the reliability of the instrument and determine the relevant descriptive statistical values. The reliability of the ASIIS was tested based on internal consistency and to check "that the items combined to produce scores which have high enough positive inter-item correlations to produce meaningful scores" (Speth, Namuth, & Lee, 2007, p. 108). Cronbach's alpha was used to determine the internal constancy of the items. The coefficients for the deep ($\alpha = .62$), strategic ($\alpha = .75$) and surface ($\alpha = .64$) approaches were all greater than ($\alpha = .60$), which is considered to be reliable internal consistency by Cohen et al. (2011). Descriptive statistical parameters such as the mean were used to categorise the students individually and collectively in terms of deep, strategic and surface approaches.

***Assertion 1:*** **A-Level chemistry students are predominantly strategic in their approach to investigations**

The ASIIS data was processed by grouping the questions falling under one construct and calculating the average scores. Subsequently, the mean agreement scores of the constructs under each approach were calculated and compared with the scale to determine whether the group or the student fell under deep, strategic or surface approach. Table 4.2 shows the group means and standard deviations for each of the constructs under each approach.

*Group data:* The mean agreement scores show that the students are strategic (*M* = 4.44) in engagement with investigations. All the constructs under the strategic approach have high means above (*M* > 4.00). For example, the construct *alertness to assessment demands* (*M* = 4.66, SD = .39) has a high mean agreement score. The items corresponding to this construct were: 2. When doing an investigation, I keep in mind how best to impress the marker (*M* = 4.58); 15. I look carefully at the teacher's comments on my investigations to see how to get higher marks next time (*M* = 4.80); 28. I keep in mind how my Chemistry teacher marks our investigations and what he is likely to be looking for (*M* = 4.48) and 41. I keep an eye open for what my teacher thinks is important when doing investigations and concentrate on that (M = 4.78).

The constructs *monitoring effectiveness* (*M* = 4.69) and *alertness to assessment demands* (*M* = 4.66) show significantly higher means than the others in this category which could be an indication of the students' desire to do the investigations correctly and score high marks by satisfying the teacher's (examiner's) expectations.

Under the deep approach, *seeking meaning* (*M* = 3.9, *SD* = .78) was the only construct with a group mean below 4.00. This construct had the largest standard deviation indicating a more pronounced spread in the responses. This was caused by moderate mean agreement scores for two of the items: 17. When I read about a concept in a Chemistry textbook, I think of an investigation that I could do to understand it better (*M* = 3.46) and 30. When I am doing an investigation I stop from time to time to reflect on what I am trying to learn from it (*M* = 3.32).

Table 4.2 Group means of the constructs under the approaches to investigations from a learning perspective

| Approaches and constructs | N | Mean | Std. Deviation |
|---|---|---|---|
| **Deep approach** | **50** | **4.07** | |
| Seeking meaning | 50 | 3.79 | .78 |
| Relating ideas | 50 | 4.28 | .57 |
| Use of evidence | 50 | 4.19 | .56 |
| Interest in investigations | 50 | 4.03 | .71 |
| | | | |
| **Strategic approach** | **50** | **4.44** | |
| Organised | 50 | 4.15 | .69 |
| Time management | 50 | 4.32 | .60 |
| Alertness to assessment demands | 50 | 4.66 | .39 |
| Achieving | 50 | 4.40 | .65 |
| Monitoring effectiveness | 50 | 4.69 | .35 |
| | | | |
| **Surface approach** | **50** | **2.78** | |
| Lack of purpose | 50 | 1.92 | .86 |
| Unrelated memorisation | 50 | 3.09 | .74 |
| Syllabus-boundness | 50 | 3.43 | .97 |
| Fear of failure | 50 | 2.70 | .91 |

**Agreement scale: 1 – 1.99 = very low; 2.00 – 2.99 = low; 3.00 – 3.99 = moderate; 4.00 – 5.00 = high**

The mean agreement for the surface approach construct (*M* = 2.78) is low but two of the sub-constructs under this approach show interesting means. A moderate agreement score for syllabus-boundness (*M* = 3.43, *SD* = .97) possibly means that the students rely on syllabus specifications to prepare for investigations. The A-Level chemistry syllabus outlines the practical work syllabus and the nature of the investigations to be done and how they will be assessed. *Unrelated memorisation* (*M* = 3.09, *SD* = .74) also scored moderately. This might indicate that students acknowledge that they learn by rote because they don't understand the chemistry at times. Of note is the fact that the construct *lack of purpose* (*M* = 1.92, *SD* = .86) had a very low mean, the lowest mean agreement score of all the constructs. The item with the lowest mean agreement score for this construct, and for all constructs, was: 16. There is nothing on investigations in Chemistry that I find interesting (*M* =1.32) [Table 4.3]. Based on this very low mean agreement score, it can be said that the investigations done by the students are probably achieving the objective of generating interest in the subject to some extent.

Table 4.3 Descriptive Statistics for linked to the construct *Lack of purpose*

| | N | Mean | Std. Deviation |
|---|---|---|---|
| 3. Often I wonder if the science investigation I am doing is worthwhile. | 50 | 3.14 | 1.63 |
| 16. There is nothing on science investigations in Chemistry that I find interesting. | 50 | 1.32 | .91 |
| 29. When doing science investigations I sometimes wonder why I chose to do Advanced Level Chemistry. | 50 | 1.72 | 1.29 |
| 42. I am not really interested in Chemistry but I have to take it for other reasons. | 50 | 1.50 | 1.07 |

Part B of the ASIIS asked the student participants about their preference for teaching, resources, and practical examinations. This section had items linked to the deep and surface approaches but not the strategic approach just like in the original ASSIST. The assumption was that the type of teaching students receive has a strong influence on their approaches to investigations. Table 4.4 summarises the students' preferences in rank order based on the mean agreement score for all the students.

The data for students' preferences for teaching, resources, and examinations with respect to investigations showed inconsistencies. A high mean for item (b) indicated that most of the students preferred chemistry teachers who encouraged them to think for ourselves and showed them how they themselves think. Only 3 of the 50 students did not agree. Most of the students (44 of 50) also preferred practical examinations that allowed them to demonstrate their thinking capacity and apply chemistry concepts. The students were divided over 'a chemistry practical syllabus that encourages us to read around a lot for ourselves' with 29 students agreeing and 21 of them disagreeing. A moderate mean agreement score was the result. A low mean agreement score for item (g) was due to more than half of the students (29 of 50) not preferring investigations that were challenging and requiring them to go beyond the material learnt in class with the teacher. With three of the items under *supporting understanding* having high or moderate means, the group can be viewed as having elements of a deep approach.

Computing the mean agreement scores for transmitting information produced only one item with a high mean. 40 of the 50 students (*M* = 4.24) preferred textbooks that have descriptions of investigations that can be easily learned. This is associated with a surface approach. Equal numbers of students (24 of 50) agreed or disagreed with the idea of teachers telling them exactly what to do during investigations and examinations that are restricted to what is specified in the syllabus. The means of the mean agreement scores for both sets of items were moderate hence the group cannot be viewed as exclusively having a deep or surface approach.

Table 4.4 Preferences for different types of teaching, resources, and examinations with respect to investigations in Chemistry

| **Item** | **Preferences for different types of teaching, resources, and examinations with respect to investigations in Chemistry** | **1** **Disagree** | **2** **Disagree somewhat** | **3** **Unsure** | **4** **Agree somewhat** | **5** **agree** | **Mean** |
|---|---|---|---|---|---|---|---|
| ***Supporting understanding (related to a deep approach)*** | | | | | | | |
| b | Chemistry teachers who encourage us to think for ourselves and show us how they themselves think. | 1 | 2 | 1 | 11 | 35 | **4.54** |
| c | Practical examinations that allow me to demonstrate my thinking capacity and apply chemistry concepts. | 0 | 6 | 0 | 8 | 36 | **4.48** |
| f | A chemistry practical syllabus that encourages us to read around a lot for ourselves. | 7 | 12 | 2 | 12 | 17 | **3.40** |
| g | Investigations that are challenging and require us to go beyond the material learnt in class with the teacher. | 22 | 7 | 5 | 8 | 8 | **2.46** |
| **Mean of mean agreement scores** | | | | | | | **3.72** |
| ***Transmitting information (related to a surface approach)*** | | | | | | | |
| a | Chemistry teachers who tell us exactly what to do during investigations. | 8 | 16 | 2 | 10 | 14 | **3.12** |
| d | Practical examinations that need only assess us on investigations described in our chemistry textbooks and in past examination papers. | 10 | 14 | 2 | 15 | 9 | **2.98** |
| e | A chemistry practical syllabus that clearly states the investigations that we will be examined on. | 3 | 5 | 4 | 17 | 21 | **3.96** |
| h | Chemistry textbooks that have descriptions of investigations that can be easily learned. | 1 | 4 | 5 | 12 | 28 | **4.24** |
| **Mean of mean agreement scores** | | | | | | | **3.58** |

**Agreement scale: 1 – 1.99 = very low; 2.00 – 2.99 = low; 3.00 – 3.99 = moderate; 4.00 – 5.00 = high**

*Individual students' data*: The scores for the constructs falling under each approach were collated and used to determine mean agreement scores which were then used to categorise each student according to the approaches of deep, strategic and surface. The mean agreement scores of all the constructs in each category were calculated and compared, as reflected in Table 4.5, in order to assign the corresponding approach for each student. The highest mean agreement score was used to assign the approach in each case.

Table 4.5 Individual students' means per approach based (ASIIS data)

| Participant | Deep | Strategic | Surface |
|---|---|---|---|
| STD1 | 4.56 | **4.70*** | 2.81 |
| STD2 | 4.13 | **4.90*** | 2.63 |
| STD3 | 4.56 | **5.00*** | 3.00 |
| STD4 | 4.00 | **4.55*** | 2.75 |
| STD5 | 3.63 | **4.80*** | 2.06 |
| STD6 | **4.63*** | 4.55 | 3.25 |
| STD7 | 4.44 | **4.95*** | 2.31 |
| STD8 | 4.13 | **4.90*** | 2.63 |
| STD9 | 3.94 | **4.458** | 2.75 |
| STD10 | 3.31 | **4.55*** | 2.25 |
| STD11 | 3.69 | **4.55*** | 3.00 |
| STD12 | **4.63*** | 4.30 | 1.81 |
| STD13 | 3.88 | **4.55*** | 3.50 |
| STD14 | **4.63*** | 4.55 | 2.38 |
| STD15 | 4.19 | **4.85*** | 2.13 |
| STD16 | 4.50 | **4.90*** | 3.00 |
| STD17 | 3.94 | **4.50*** | 3.19 |
| STD18 | **4.31*** | 3.95 | 2.38 |
| STD19 | 4.56 | **4.85*** | 2.69 |
| STD20 | 4.31 | **4.45*** | 3.44 |
| STD21 | **4.63*** | 4.55 | 2.38 |
| STD22 | **4.69*** | 4.60 | 2.06 |
| STD23 | 3.69 | **4.10*** | 3.63 |
| STD24 | **4.44*** | 4.25 | 3.06 |
| STD25 | 3.69 | **4.60*** | 2.94 |

| Participant | Deep | Strategic | Surface |
|---|---|---|---|
| STD26 | 3.31 | **4.25*** | 2.31 |
| STD27 | 3.56 | **4.10*** | **3.88** |
| STD28 | 3.13 | **3.35*** | 2.88 |
| STD29 | 4.06 | **4.30*** | 2.00 |
| STD30 | 3.88 | **4.15*** | 2.81 |
| STD31 | 3.06 | **3.75*** | 2.38 |
| STD32 | 3.94 | **4.35*** | 3.19 |
| STD33 | **4.00*** | 3.80 | 3.50 |
| STD34 | 4.13 | **4.15*** | 3.88 |
| STD35 | 4.19 | **4.65*** | 3.25 |
| STD36 | 3.88 | **4.75*** | 2.38 |
| STD37 | **4.63*** | 4.25 | 3.31 |
| STD38 | **3.44*** | 3.10 | 3.19 |
| STD39 | 3.56 | **4.40*** | 2.56 |
| STD40 | 4.13 | **4.70*** | 2.69 |
| STD41 | 4.38 | **4.90*** | 2.06 |
| STD42 | 4.31 | **4.40*** | 2.94 |
| STD43 | 3.88 | **4.65*** | **4.44** |
| STD44 | 3.75 | **3.95*** | 2.31 |
| STD45 | 4.31 | **4.55*** | 2.19 |
| STD46 | 4.75 | **4.90*** | 3.06 |
| STD47 | 3.44 | **4.25*** | 2.19 |
| STD48 | 4.00 | **4.60*** | 2.69 |
| STD49 | 4.31 | **4.45*** | 2.56 |
| STD50 | 4.38 | **4.60*** | 2.56 |
| **Totals** | **10** | **40** | **0** |

***Highest mean agreement score**

Table 4.5 shows that 10 of the students were associated with a deep approach while 40 of 50 fell under the strategic approach. None of them could be placed under the surface approach. One participant, however had a high mean score for surface approach ($M$ = 4.44) although they fell under the strategic approach ($M$ = 4.65). A second student also recorded their second highest score under the surface approach ($M$ = 3.88) while falling under the strategic approach (*M* = 4.10). Seven other students had moderate mean scores for the surface approach. These results indicate that although they report being strategic learners, they do have elements of surface learning perhaps because they don't understand some ideas and so just learn anyway as important for high marks.

## 4.2 Approaches to investigations from a learning perspective: DUQ data

The data from the DUQ were also used to categorise the students based on the approaches of deep, strategic and surface. Four questions (Question 5 to 8) were aimed at gathering data to help understand how students approached investigations through a narration of how they went about planning, designing and carrying out this type of practical work, the strategies they used, the challenges they faced and how they overcame them and what they learned. The statements made by the students in the DUQ were analysed, coded and recoded to ascertain that the categorisation of each student participant was thorough and consistent with the data available. Abductive reasoning was used to determine the approach for each student. Abductive reasoning entails "inferring a case from a rule and a result" (Svennevig, 2001, p. 2). The defining characteristics of the three approaches (Table 2.3) were used to determine the approach associated with each one of the students based on what they said. The statements in Table 4.6, taken from the DUQ data, illustrate how the categorisation of the students according to approach was done. 12 of the participants were classified under the deep approach, 38 as strategic and none could be classified under the surface approach.

Table 4.6 Exemplar statements and corresponding approaches from a learning perspective (DUQ, May 21, 2015)

| Participant | Statement | Approach |
|---|---|---|
| STD8 | … I knew that $Pb^{2+}$ forms a white ppt upon adding NaOH(aq) and $Mn^{2+}$ forms (an) off-white ppt insoluble in excess but both being in the same solution, I filtered the mixture and obtained a filtrate containing $Pb^{2+}$ and a residue containing $Mn^{2+}$. For the filtrate I added dilute HCl drop by drop then formed a white ppt upon addition which was insoluble in excess. For the residue I placed the funnel in another test tube with the filter paper containing the residue and then added dilute HCl to the residue to form $MnCl_2$ which I knew to be insoluble upon addition of the acid. Both of these $Pb^{2+}$ and $Mn^{2+}$ where now separated as precipitates and the experiment was done. | Deep |
| STD33 | I firstly asked myself, what's my aim and what are my variables. I then put myself in the examiner's shoes, authority wise. I planned my steps in such a manner that any other student could carry it out. | strategic |

*No students were placed under the surface approach

It was deemed necessary to compare the results of the ASIIS to those of the DUQ in order to determine the nature of the correlation. This way it was possible to make judgements about the consistency of the categorisation of students by approach. This was also a form of data triangulation based on the two different types of data collected (Cohen et al., 2011). Table 4.7 shows the approaches assigned to each student based on the data collected using the ASIIS and DUQ.

Table 4.7 Comparison of students' approaches from ASIIS and DUQ

| Participant | Approach from ASIIS | Approach from DUQ | | Participant | Approach from ASIIS | Approach from DUQ |
|---|---|---|---|---|---|---|
| **STD1** | strategic | strategic | | STD26 | strategic | strategic |
| **STD2** | strategic | strategic | | STD27 | strategic | strategic |
| **STD3** | strategic | strategic | | STD28 | strategic | deep |
| **STD4** | strategic | strategic | | **STD29** | strategic | strategic |
| **STD5** | strategic | deep | | **STD30** | strategic | strategic |
| **STD6** | deep | strategic | | **STD31** | strategic | strategic |
| **STD7** | strategic | strategic | | **STD32** | strategic | strategic |
| **STD8** | strategic | deep | | **STD33** | deep | strategic |
| **STD9** | strategic | strategic | | **STD34** | strategic | strategic |
| **STD 10** | strategic | strategic | | **STD35** | strategic | deep |
| **STD11** | strategic | strategic | | **STD36** | strategic | strategic |
| **STD12** | deep | deep | | **STD37** | deep | strategic |
| **STD13** | strategic | strategic | | **STD38** | deep | deep |
| **STD14** | deep | deep | | **STD39** | strategic | strategic |
| **STD15** | strategic | strategic | | **STD40** | strategic | strategic |
| **STD16** | strategic | deep | | **STD41** | strategic | deep |
| **STD17** | strategic | strategic | | **STD42** | strategic | strategic |
| **STD18** | deep | strategic | | **STD43** | strategic | strategic |
| **STD19** | strategic | strategic | | **STD44** | strategic | strategic |
| **STD20** | strategic | strategic | | **STD45** | strategic | strategic |
| **STD21** | deep | deep | | **STD46** | strategic | strategic |
| **STD22** | deep | strategic | | **STD47** | strategic | strategic |
| **STD23** | strategic | strategic | | **STD48** | strategic | strategic |
| **STD24** | deep | strategic | | **STD49** | strategic | deep |
| **STD25** | strategic | strategic | | **STD50** | strategic | deep |

The number of students under the deep approach based on the DUQ data was 12 and 38 for the strategic approach compared to 10 and 40 from the ASIIS data respectively. No students were classified under the surface approach for both the DUQ and ASIIS data.

The data shown in Table 4.7 was transformed to quantitative data by assigning ordinal values to each of the three approaches to investigations. The deep approach was assigned a value of 1, the strategic approach a value of 2 and the surface approach a value of 3. This meant the approaches were arranged in rank order deep (1) as the best approach to surface (3) as the worst of the three approaches. The two sets of data (ASIIS and DUQ) were then loaded onto SPSS 23 and processed to determine the nature of the correlation between them. The Spearman rank order correlation factor was used for this study as it is recommended for ordinal data (Cohen et al., 2011).

The two data sets from the ASIIS and DUQ gave Spearman's rank order correlation of .868 as reflected in Table 4.8. This is considered to be a strong positive correlation (Cohen et al., 2011).

Table 4.8 Spearman's rank order correlation based on ASIIS and DUQ data

| | | | **ASIIS** | **DUQ** |
|---|---|---|---|---|
| Spearman's rho | ASIIS | Correlation Coefficient | 1.000 | -.024 |
| | | Sig. (2-tailed) | . | **.868** |
| | | N | 50 | 50 |
| | DUQ | Correlation Coefficient | -.024 | 1.000 |
| | | Sig. (2-tailed) | **.868** | . |
| | | N | 50 | 50 |

38 of the 50 students' approaches in the two data sets in Table 4.7 matched hence the strong positive correlation. Only 12 students' approaches did not match. One possible explanation to the mismatch is that when these students were asked to describe their approaches in their own words in the semi-structured questionnaire, they tended to do it more accurately compared to when responding to questions on the Likert scale.

The data from the focus group discussions was also used to categorise the participants according to their approaches to investigations from a learning perspective. Each of the 32 students who were part of the focus group (FG) discussions were asked to describe how they went about planning, designing and carrying out this type of practical work, the strategies they used, the challenges they faced and how they overcame them and what they learned just like in the semi-structured questionnaire. There difference was that during the focus group discussions there was probing and subsequent clarification of responses.

The categorisation of the students was based on their descriptions of how they approached investigations and the coding was done using the characteristics of the three strategies in Tables 2.3 as was done with the data from the DUQ. Examples of statements that were used to categorise students are shown in Table 4.9.

Table 4.9 Exemplar statements used to categorise students by approach to investigations from a learning perspective (Focus group discussions, Jun 04, 2015)

| Participant | **Statement from focus group discussion** | **Approach to investigations from a learning perspective** |
|---|---|---|
| STD38 | It's all about understanding the question, knowing what is being talked about in the design question, like the motive of the design, the reason why they want us to pursue that investigation. That is why we get them correct, because we are able to understand the questions. We are able to tackle them very well, we understand what is being asked in the questions. …. Sometimes I actually picture myself wearing a lab coat actually working for some company hands-on. Sometimes when we are in the lab for a practical session I see myself in industry one day. | Deep |
| STD15 | We should be exposed to, sort of exam conditions. We will face these conditions in the exam. You are not given the experiment before. We just meet up with it in the exam. So, I think for now we should always work as if we are in an exam because we develop the experience to brainstorm and to think for ourselves. | Strategic |

*No students were placed under the surface approach

Based on the focus group discussions data, 11 students were classified under the deep, 21 under strategic and none under the surface approach. The distribution of students by approach based on data from all three sources is shown in Figure 4.1. The results show small differences between the distribution of students by approach using data from the semi-structured questionnaire and focus group discussions. However, they are bigger differences (seven) in the numbers of students falling under deep and strategic approaches when data from the ASIIS and focus group discussions are compared.

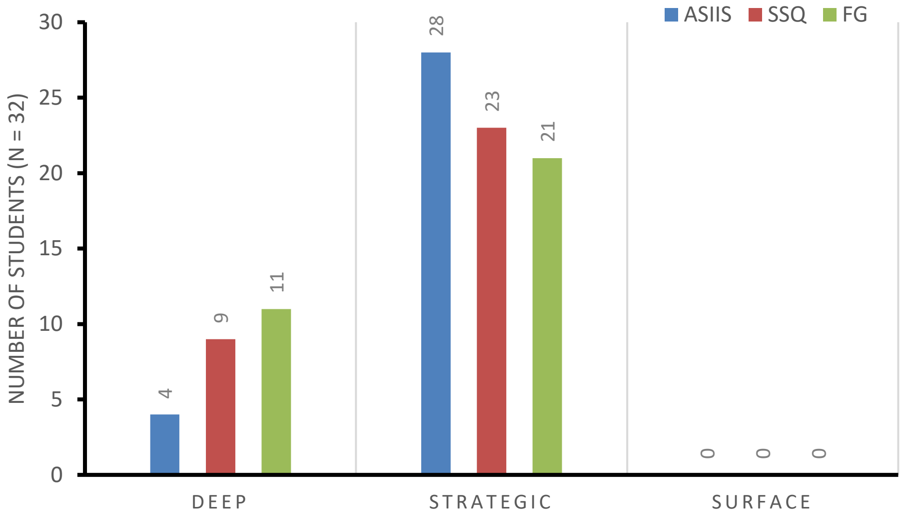



Figure 4.1 Comparison of frequencies of students' approaches to investigations: ASIIS, DUQ and FG data

The approaches to investigations of 32 students, determined from the three data sources, were analysed to check for the any patterns. The data from this analysis is shown in Table 4.10.The approaches were not always matched. 17 of the 32 students were categorised in the same manner in all three cases with 16 falling under the strategic approach and only one under the deep approach. These results show that half of this subgroup of students were purely strategic in their approach to investigations. Of the remainder, 10 were classified as strategic twice and deep once, while 4 fell under strategic once and twice for the deep approach. One of the thirty two students was categorised as strategic twice and the surface approach once.

Table 4.10 Summary of students' approaches based on ASIIS, DUQ and FG data

| **ASIIS + DUQ + FG** | **Frequency** |
|---|---|
| Deep + Deep +Deep | 1 |
| Deep + Deep + Strategic | 4 |
| Deep + Strategic + Strategic | 10 |
| Strategic + Strategic + Strategic | 16 |
| Strategic + Strategic + Surface | 1 |
| **Total** | **32** |

## 4.3 Discussion of students' approaches to investigations from a learning perspective

In this section, evidence from the research data was presented to give answers to the first question on students' approaches to investigations from a learning perspective. The approaches to learning theoretical framework was used to make sense of the findings related to this research question. The distinct approaches, deep, strategic and surface were identified by scholars as the approaches adopted by students in their learning endeavours and these were used to categorise students with respect to how they do investigations.

An analysis of the group data on students' preferences for teaching, resources, and examinations showed that they were inclined towards a deep rather than a surface approach for three of the items under 'Supporting understanding'. While the students indicated a predisposition to doing investigations with little or no teacher assistance, thinking for themselves and demonstrating their mastery of chemistry concepts, they had less agreement with the statement when it came to investigations that took them beyond the scope of their chemistry practical syllabus. This tallies with the predominance of the strategic approach (highlighted in chapter four) where students were conscious of the syllabus specifications and preferred to channel all their efforts to what they thought would be the subject for examination.

The mean agreement scores for items (h) and (e) in Table 4.4 under 'Transmitting information' are unexpectedly high given that all the students were categorised as having either deep or strategic approaches. Having textbooks with descriptions of investigations that can be clearly learned and a syllabus that specifies the investigations that would feature in the final examination would promote surface and linear approaches. Perhaps the students meant that the textbooks they use do not have examples which they could refer to and learn to design, plan and carry out investigations on their own. It is also possible that the students felt that the scope of the investigations was not clearly delimited in their A-Level chemistry syllabus judging by the moderate mean agreement score for item (e) on 'A chemistry practical syllabus that clearly states the investigations that we will be examined on'. ZIMSEC states that the scope of the investigations will not be limited to the examples given in the syllabus booklet (ZIMSEC, 2012b). The moderate mean agreement score for 'Chemistry teachers who encourage us to think for ourselves and show us how they themselves think' and the low mean agreement score for 'Practical examinations that need only assess us on investigations described in our chemistry textbooks and in past examination papers' are not surprising given that none of the students were categorised under the surface approach (Table 4.5). The moderate and low mean scores for 'Chemistry teachers who tell us exactly what to do during investigations' possibly means that the students want more autonomy when they do investigations, which would promote a deep approach.

The most common approach used by A-Level students in designing, planning and carrying out investigations, across all data sources, was found to be strategic. A small proportion of the students used the deep approach. The prevalence of the strategic approach was also reported in a quantitative study by Nordin, Wahab, and Dahlan (2013) in their study with Malaysian trainee teachers as the participants. Although their focus was not necessarily on investigations but on learning various courses, the significantly high ratings of the strategic and deep approaches are comparable. In the current study, it was interesting to note the changing distribution of the numbers of students classified under each approach for the survey quantitative questionnaire (ASIIS) data, qualitative semi-structured questionnaire (DUQ) and focus group discussions (FG) data. Perhaps this justifies the researcher's decision to adopt a mixed methods research methodology on the premise that using a multiplicity of data collection methods can lead to a better understanding of the phenomenon under study. By using a Likert scale type of survey questionnaire such as the ASIIS, the truthfulness of the data is not guaranteed as some participants may deliberately give false responses (Cohen et al., 2011). These authors continue to say:

> We have no way of knowing if the respondent wishes to add any other comments about the issue under investigation. It might be the case that there is something far more pressing about the issue than the scale includes but which is condemned to silence for want of a category. (p. 388).

The open questions in DUQ may have allowed to describe their approaches without the restriction imposed by the Likert type items in the ASIIS. Focus groups allowed the students to express themselves even better orally and the researcher to seek clarifications where necessary. Focus group data allowed me to do triangulation with data from the ASIIS and DUQ. Variations in the distribution of the students across the three data sources possibly points to the differences between what the students think of themselves and what they actually do during investigations.

In an earlier study by Biggs (1991) high school students of Chinese origin in both China and Australia were found to be inclined towards a strategic approach while their

English counterparts (in the same contexts) scored high on the surface approach. As was discussed in chapter two, since the participants' A-Level chemistry curriculum is an adaptation of the one designed by the University of Cambridge International Examinations (UCLES), the differences in the approaches are worth noting. While Biggs (1991) focused on learning across many subject areas, it is unlikely that there would be major differences in the findings if the study was specifically on investigations. The similarities between the approaches used by Chinese and Zimbabwean students perhaps point to the similarities in their epistemological beliefs about teaching and learning, and other contextual factors as is dealt with in greater detail in a later chapter which provides answers to why the participants of this study approached investigations the way they did.

The existence of a small proportion of students with a deep approach shows that approaches to investigations are not always uniform even within a cohort of students doing the same subject (Laurillard, 2005). These findings are also similar to those of Bilgin and Crowe (2008) whose study on university statistics students from different countries indicated that approaches vary from student to student.

There are at least three possible explanations for the absence of students under the surface approach. Firstly, the students who study Chemistry at A-Level are high achievers who excelled in their O-level examinations. Secondly, their career aspirations demand that they work towards achieving good grades in order to meet the university entry requirements. It is also possible that they knew that a surface approach is negative hence responded accordingly.

The summary of results in Table 4.10 where the approach associated with each student were collated shows that at least 14 of the participants could be as viewed deep-strategic students and only three percent as surface-strategic. A combination of approaches was also reported by Gijbels et al. (2005) in their detailed quantitative study of 133 Dutch second year law students' approaches to learning. They preferred to describe the occurrence of such combinations of approaches as *dissonant* or *disintegrated*. With this description, they seemed to imply that a combination of approaches was not as result of conscious choices by the participants but rather as conflicting behaviours.

The findings on the participants' preferred types of teaching, learning resources and practical examinations were consistent with deep learning although most of the students came across as strategic. The high scores of the items related to independent learning and examinations which bring the best out of them imply that the students are inclined towards constructivist teaching and learning which is linked to a deep approach and should be encouraged (Biggs, 1999). The relatively high scores on ‘a syllabus textbooks that have descriptions of some investigations prescribed for A-Level Chemistry’, can be viewed as students yearning for a better understanding of examiners’ expectations through more specific assessment guidelines and exemplar high scoring answers to guide them as they prepare for high stakes examinations in which they want to achieve good grades.

## 4.4 Conclusion

This chapter was dedicated to the findings and discussions with respect to the first research question on how students approached investigations from a learning point of view. Most of the participants were classified under the strategic approach based on data from three different sources, a survey questionnaire, a semi-structured questionnaire and focus group discussions. The relatively high ratings also recorded for the deep approach in the ASIIS gave credence to the fact that it is not uncommon for students to use a combination of approaches. The existence of participants with unmatched approaches across the three data sources advanced the idea that students’ approaches to investigations were dynamic. Alternatively, they were not self-regulated students and did not know what they were doing. It is also possible that they were confused and were trying everything to succeed.

# CHAPTER 5
# THE DESIGNING PERSPECTIVE

In Chapter Four, I presented and discussed students' approaches to investigations from a learning perspective in which the profiling of students was done based on the data collected using the ASIIS. In this chapter, the focus is on providing evidence to answer the second research question on students' approaches to investigations from a design perspective. The corresponding findings were interpreted based on the interpretive framework which has three approaches; iterative, linear and divergent.

The A-Level Chemistry practical component requires students to design and carry out short term investigations which last for anything between 30 minutes and one hour. The students are expected to demonstrate their ability to select and set up the appropriate apparatus, determine the correct quantities of substances to use, show awareness of laboratory safety rules and precautions, enumerate the experimental steps and demonstrate a sound mastery of the relevant concepts (ZIMSEC, 2012b). To gain an understanding of the students' approaches with respect to designing investigations, data was gathered through a semi-structured questionnaire, focus group discussions and the write-ups they produced during their practical sessions.

## 5.1 Students' approaches to investigations from a designing perspective

***Assertion 2:* The majority of the students used an iterative or linear approach when doing investigations.**

### Approaches to investigations based on DUQ data

Students were asked to describe how they approached investigations in the questionnaires and their responses were coded and categorised based on the part of the theoretical framework which deals with the approaches from a designing perspective which covers three approaches: *iterative, linear* and *divergent* (Roberts et al., 2010). The students were categorised based on their descriptions of how they designed and carried out investigations and each one of them was placed in one of the three approaches.

31 students were classified under the iterative approach, 17 under the linear approach and only two under the divergent approach. Those who fell under the iterative approach gave detailed descriptions of how they went about designing/planning and executing their investigations. They comprehensively outlined how they dealt with any challenges they encountered while doing the investigations that often involved retracing their steps in the experimental design to identify any errors and redoing the investigation until they got the desired results. One student's response was a typical example of those that were categorised under the iterative approach:

> I read the requirements carefully and I studied the apparatus and reagents I was given to use. I did a plan and carried out a sample of the experiment. Then, after I (had) proven that my plan was possible, I wrote on my answer sheet the design and then carried it out recording the observations. … I was stuck when I discovered that I did not use one of the reagents since I did not know its use. However, I went back to my question, re-studied it and checked on my qualitative notes. I then realised the step at which the reagent was to be used. Then, I solved the challenge by repeating the whole investigation. (STD16 DUQ, May 21, 2016)

Two students indicated that they often asked for help from their Chemistry teacher, the laboratory technician or colleagues when they were convinced that they were not doing the science investigation the right way. One of them had this to say:

> Firstly, I added NaOH until in excess to the solution containing $Mn^{2+}$ and $Pb^{2+}$. I then filtered the mixture to obtain a residue and filtrate. I used my qualitative notes to have a general idea on how cations react in (with different) reagents. …. Yes, I had difficulties in obtaining the precipitate containing $Mn^{2+}$ ions. In order to solve this problem, I had to ask for the teacher's help then I repeated the experiment using the information that I got. (STD3 DUQ, May 21, 2016)

A total of 17 students demonstrated a linear approach to designing and carrying out investigations. These students came up with only one way of doing the investigation based on what they could remember from practical work done before and what their Chemistry teacher said in previous post practical discussions. The quotes below illustrate this:

> Qualitative analysis notes are provided, so I just used the notes to deduce a reasonable procedure and the theory that I learned in previous lessons as a tool to make the deductions. ... I didn't have any challenges, the procedure I designed worked for me. (STD22 DUQ, May 21, 2016)

> I used knowledge from O-level and some theory from the topic of reaction kinetics to design the investigation.….. I just designed the experiment and stuck with it. I had no reason to change. Also there was no time for me to change anything. (STD28 DUQ, May 21, 2016)

> I had encountered such an experiment at O-Level which was a precipitation reaction where one would measure the time it took for the cross to disappear, the cross was drawn on a paper and it was placed under the beaker. I had to keep in mind what our teacher said we should do

> when designing and carrying out investigations. …. Never got stuck because I just used the procedure I had designed. (STD50 DUQ, May 21, 2016)

Two students were classified under the divergent approach. The first case was that of participant code named STD24 who deviated from the given instructions and was consequently unsuccessful in performing the science investigation. He wrote:

> After reading and understanding the aim of the design, I recalled we once discussed with our teacher in O-Level and I outlined procedures to the best of my ability. …. I introduced a reagent of my own that wasn't on the list of reagents we were supposed to use. (STD24 DUQ, May 21, 2016)

In the second case of a divergent approach, STD25 failed to interpret the problem resulting in a design that was not feasible. The participant wrote:

> I first put in mind the physical state in which my $Na_2S_2O_3$ was provided. Then I thought about how I could make the whole comparative experiment procedure i.e. making different concentrations. The strategy used was of reading between the lines so that I could at least understand the question. …. The investigation was very challenging and I couldn't solve the problem. (STD25 DUQ, May 21, 2016)

**Approaches to investigations based on data from the analysis of students' scripts**

Students' write ups on one investigation were analysed in order to determine the approaches they used. I was aware of the limitations of analysing just one set of scripts. The students in one school were doing a different investigation compared to those in the other school most of the weeks. Analysing scripts for different investigations would have been problematic so I chose to use the one common investigation done by all the students. Coincidentally the same science investigation was done by all the students in the two schools during the third week of the data collection process. The investigation was of a quantitative nature where students were required to investigate the effect of the concentration of sodium thiosulphate ($Na_2S_2O_3$) on the rate of reaction (with sulphuric acid). The students were to make do with a list of the materials provided for the investigation hence had limited options in terms of the investigation procedure. This implied that the science investigation was not completely open. Variations in the experimental procedure could only arise from the quantities that each student decided to use while the essence of the procedure remained the same. A copy of the question paper is presented in Appendix R.

This investigation was not a test instrument administered for the purposes of this research but just another practical activity planned, administered and marked independently by the chemistry teachers. This was ideal because it allowed the researcher to collect data under the same conditions the participants work without the influence of a research project. The marking of the science investigation was based on a marking scheme provided by ZIMSEC. The marking scheme had the suggested plan for the investigation, with an outline of the experimental procedure and expected results. The breakdown of the allocation of marks was also indicated with the maximum possible mark being 13. At least 9 of the marks were allocated to the planning stage and the rest were for data processing and interpretation. Copies of the marked scripts were made and used as data sources for this study with the consent of all the participants. The marks obtained by the students in this science investigation were computed to produce the histogram is shown in Figure 5.1.

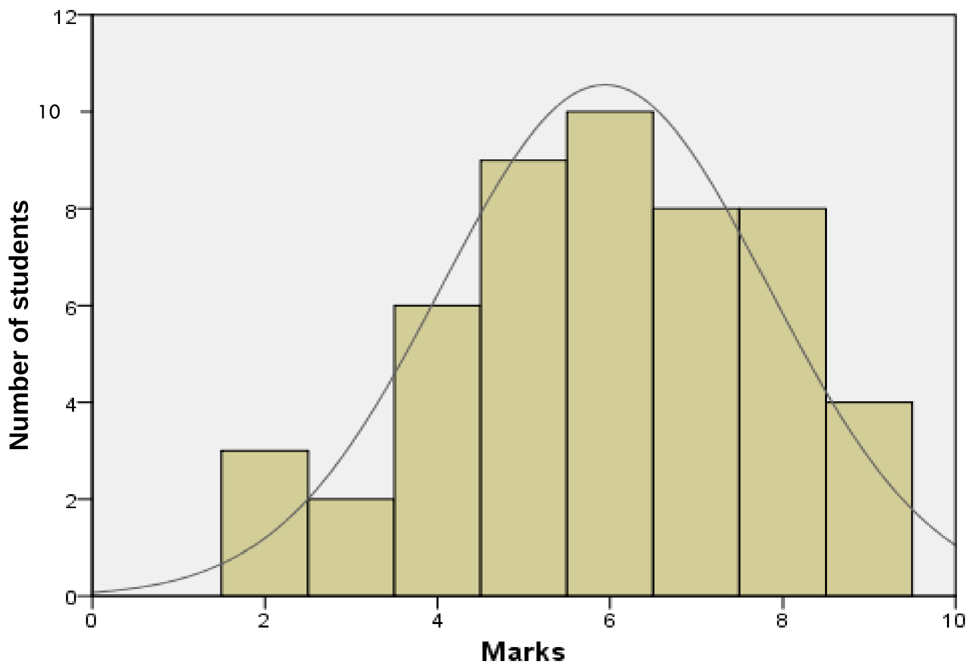



Figure 5.1 Distribution of marks for one investigation

The histogram shows that the bulk of the students achieved between 5 and 8 out of 13. 20 of the students achieved a mark below 7 and the top mark was below 9 out of 13. Given that this was a past examination question, from November 2011, it is possible that the question was not entirely unfamiliar to the students and yet the performance was not very impressive. While I am aware of the small sample of participants for the current study, this finding mirrors what is reflected in the examiners' reports that students generally perform badly.

The tool used to analyse the data from the script analysis was designed based on the part of the theoretical framework which deals with the approaches to science from a designing perspective described in chapter two (Table 2.2). The characteristics of the iterative, linear and divergent approaches were the foundation of the analytical tool. Table 5.1 shows how approaches were assigned to students based on an analysis of their work.

Table 5.1 Analytical tool for assigning approaches based on script analysis (adapted from Roberts, Gott & Glaessier, 2008)

| **Approach** | **Characteristics** |
|---|---|
| Iterative | - A clear attempt (but not always successful) to modify the original plan in the light of tactical defects - crossings/cancellations/ and changed statements leading to an improved procedure<br>- First plan done at the back of question paper or a separate piece of paper and then transferred to script<br>- Evidence of repeated tests/measurements only until they (students) were are satisfied with the data<br>- Trial runs - student tries out the proposed plan, makes any necessary changes before writing the correct procedure<br>- Changed data processing method or abandoned their plans altogether in the face of problems or data which wasn't 'working'<br>- Evidence of reflective practice |
| Linear | - Student makes a plan and sees it through to the end.<br>- Student has a clear plan, often seen as unalterable in the face of accumulating evidence.<br>- No evidence of changes to original plan (no cancellations/crossings or scribbling at the back of the question paper/ separate sheet of paper) even when the plan is apparently wrong.<br>- They are unable to take stock of the position they find themselves in, and when the data proves inadequate, they are unable to improve it. |
| Divergent | - Scatter-gun approach, no discernible plan<br>- Haphazard collection of data (tests, observations or measurements)<br>- No/incorrect/incomplete data collection and processing |

Each student's script was analysed separately, writing notes describing what they were doing at each stage of the investigation. By comparing these notes with the characteristics of each of the three approaches, it was possible to classify the students. Three exemplar scripts, representing each of iterative (STD5), linear (STD2) and divergent (STD25) approaches are presented with comments that assisted in classifying them.

**The iterative approach: exemplar script**

STD5

2 ASSESSMENT OF PLANNING SKILLS

For Examiner's Use

You are provided with an aqueous mixture of FA2 containing $Pb^{2+}$ and $Mn^{2+}$ ions.

You are also provided with aqueous sodium hydroxide and dilute hydrochloric acid.

You are required to plan and carry out an experiment in which by using the above reagents only, the two cations in FA2 can be separated in different precipitates.

(a) Give a description of your proposed sequence of numbered steps.

1) ~~Add NaOH~~ FA2 to the test tube
~~First add NaOH(aq) to the mixture in a test tube doit drop by drop (excess) and observe change of colour and solubility.~~
~~2) Record the observations obtained.~~
~~3) An off-white precipitate insoluble in excess is obtained~~
~~4) Filter the mixture and the residue is then added to HCl till excess.~~
~~5) Record the observations of solubility~~
~~6) Add HCl to the filtrate left in the test tube~~
~~7) Record solubility.~~

PLAN

1) Add FA2 to the test tube
2) Add NaOH to the test tube with FA2 drop by drop till the precipitates form (one soluble and the other insoluble)
3) Filter the precipitates to observe a filtrate and residue.
4) React ~~with~~ residue with HCl till excess and record
5) React filtrate with HCl till excess and record your observations.

[4]

3

9189/6 N2011

The planning stage:

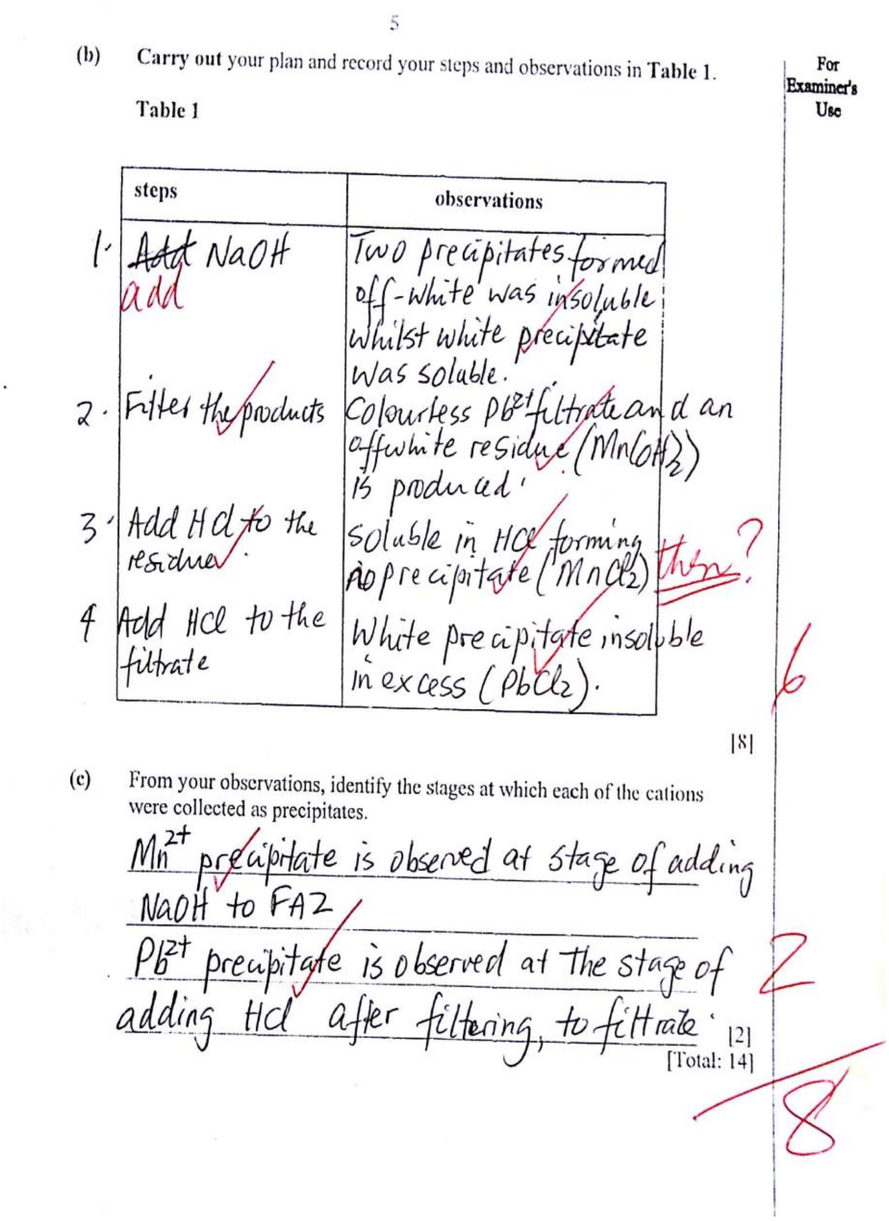
First attempt

- *Student changes $NaOH_{(aq)}$ in favour of FA2 in step 1.*
- *Student crosses out all the seven steps and starts afresh.*

Second attempt

- *Steps 1 and 2 are different from those in first attempt. Ideas in step 1 of first attempt now presented as two separate steps.*
- *Step 3 of first attempt suggests that only one precipitate would be formed when $NaOH_{(aq)}$ is added but step 2 in second attempt shows that the student is now aware that a mixture of precipitates is obtained.*
- *Some steps in the first attempt were consolidated in the second attempt thereby reducing the number from seven to five.*
- *Evidence of good substantive and procedural knowledge.*
- *Evidence of reflective practice*

- *A good mark of 3 out of 4 reflects an improved plan.*



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(b) Carry out your plan and record your steps and observations in Table 1.

For Examiner's Use

Table 1

| steps | observations |
|---|---|
| 1. ~~Add~~ NaOH add | Two precipitates formed off-white was insoluble whilst white precipitate was soluble. |
| 2. Filter the products | Colourless $Pb^{2+}$ filtrate and an offwhite residue ($Mn(OH)_2$) is produced. |
| 3. Add HCl to the residue. | Soluble in HCl forming no precipitate ($MnCl_2$) then? |
| 4 Add HCl to the filtrate | White precipitate insoluble in excess ($PbCl_2$). |

6

[8]

(c) From your observations, identify the stages at which each of the cations were collected as precipitates.

$Mn^{2+}$ precipitate is observed at stage of adding NaOH to FA2

$Pb^{2+}$ precipitate is observed at the stage of adding HCl after filtering, to filtrate.

2

[2]

[Total: 14]

8

Figure 5.2 Exemplar script for the iterative approach

Implementation of the plan

- *Good marks obtained for the table of results and inferences.*
- *No evidence revisions (no crossings)*
- *Evidence of good substantive knowledge – student can link theory with practice*
- *It is possible that the student tried the first plan without recording the results on this template, did not get the expected outcomes and then came up with an improved plan in the second attempt.*

*The linear approach:* An exemplar script from STD2 is shown in Appendix K. The evidence on the script suggests that during the planning stage, the student came with one plan and produced an experimental procedure lacked some of the necessary detail. Flaws in the procedure and data collection are also evident in the incorrect observations recorded. The student did not revise the plan in the wake of incorrect results or he did not realise results were incorrect. The data collection and processing was incomplete. The student failed to link the relevant theory with observations to come with the expected inferences. There is evidence of limited substantive knowledge. A low mark was achieved.

*The divergent approach*: An exemplar script for this approach was obtained from STD25 and is shown in Appendix K. In planning stage, the student came up with three steps of which only one was credited. The plan shows poor substantive and procedural knowledge. During the implementation of the plan, all the steps were not correctly stated. Incorrect observations were recorded and there is no evidence of revision and improvement of the procedure. No inferences were arrived at in part (c). The student was unable to link observations with the relevant theory. A very low mark was achieved by the student. A summary of the results of the analysis of students' scripts are reflected in Table 5.2

Table 5.2 Distribution of students by approach based on the analysis of scripts

| Approach | Number of students |
|---|---|
| Iterative | 23 |
| Linear | 24 |
| Divergent | 3 |

The number using the iterative and linear approaches was about equal with only three students showing evidence of using a divergent approach. 46% of the students used the iterative approach in doing the science investigation. These students demonstrated a good command of the relevant substantive and procedural knowledge required for the successful planning and execution of the science investigation. In general, these students scored more than 50% of the marks allocated for this science investigation. The 48% who used a linear approach demonstrated a satisfactory or good substantive and procedural knowledge but with some flaws in the experimental procedure and processing or interpretation of results. It was clear in the scripts of those who used a divergent approach that they lacked a credible understanding of the theoretical aspects of the science investigation. This was often compounded by a limited competence in integrated process skills. Consequently the plans were incomplete, experimental results were not processed and the students performed badly in the science investigation.

**Comparing data from DUQ and analysis of scripts**

The two data sets were tested for reliability by determining their Cronbach's alpha coefficient of internal consistency using SPSS 23. The high alpha coefficient ($\alpha = .757$) showed that there was internal consistency (Cohen et al., 2011). There was a positive correlation ($\rho = 0.599$ between the students' approaches to investigations based on the two data sets as shown in Table 5.3.

Table 5.3 Spearman's rho based on data from DUQ and scripts analysis

| | | | **DUQ** | **Scripts** |
|---|---|---|---|---|
| Spearman's rho | DUQ | Correlation Coefficient | 1.000 | .599** |
| | | Sig. (2-tailed) | . | .000 |
| | | N | 50 | 50 |
| | Scripts | Correlation Coefficient | .599** | .000 |
| | | Sig. (2-tailed) | .000 | . |
| | | N | 50 | 50 |

** Correlation is significant at the 0.01 level (2-tailed).

The positive correlation reflected in Table 5.4 is supported by the fact that nearly 80% of the approaches were matched between the two sets of data. This is shown in Table 5.4.

Table 5.4 Matching of approaches based on data from DUQ and scripts analysis

| | **Approaches** | **Frequency** |
|---|---|---|
| **Matched** | iterative + iterative | 23 |
| | linear + linear | 15 |
| | divergent + divergent | 1 |
| **Unmatched** | iterative + linear | 8 |
| | linear + divergent | 1 |

There was a notable difference in the distribution of students by approach when the data sets from DUQ and the analysis of scripts were compared. This is illustrated in Figure 5.3. There was a 16% drop in the number of students associated with the iterative approach when their scripts were analysed. Consequently, the number of students classified under the linear approach dropped by 14%. This observation is backed by the eight instances of unmatched approaches (iterative + linear) in Table 5.4. It is possible that when the students described what they did in the DUQ, they gave accounts that were not evident on their scripts.

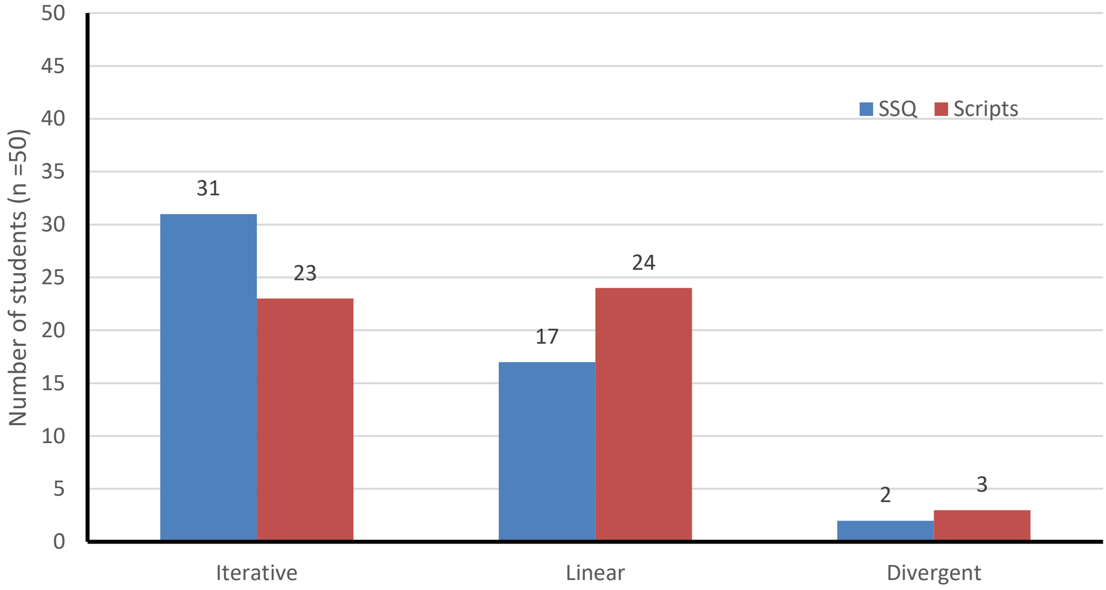



Figure 5.3 Distribution of students by approach: DUQ and script analysis data

It is also possible that some students did rough drafts of their plans or recorded data from trial runs on separate pieces of paper that were not handed in for marking. This would imply that such students were then classified under the linear approach. This inference is supported by what the following two students wrote in the DUQ:

> First, I had to relax and read the whole question to acquire complete understanding of the question. Then I had to underline certain key terms to know exactly what I was dealing with. Tried to recall if I had done the experiment or similar experiment before. Drafted my steps before writing them in the proper way on my question paper bearing in mind that the simple basics my teacher taught me. (STD42 DUQ, May 21, 2016)

> First of all, I read the question, understood it and underlined the key terms and important information needed. Then, before writing on the answer paper I made a rough plan on the sequence or order of the experiment. I made an imagination in my mind of what will be happening and how I would be carrying out the investigation. After doing all this I put the

> plan on the final answer paper and carried out the investigation in sequence as on the design plan. (STD43 DUQ, May 21, 2016)

Another possible explanation would be that the students assumed the ideal approach to investigations was iterative but fell short when it came to execution. The number of students falling under the divergent approach is comparable. The corresponding students were relatively accurate in describing how they approached investigations from a designing perspective given that this was reflected in their scripts.

**Results of the focus group discussions**

During the focus group discussions, all the participants were again asked to describe how they went about designing and carrying out investigations. They were also asked to explain how they dealt with any challenges they encountered as they carried out the investigations. The results were captured, put into NVivo 11 and then coded. The mother node was *Approach from a designing perspective* and the child nodes were *iterative, linear* and *divergent*. Of the 32 focus group participants, 18 were classified under the iterative approach, 13 as using a linear and only one under the divergent approach. These results were compared with those obtained from the DUQ and the analysis of scripts using Figure 5.4. While the trend in the results of the focus group discussions is similar to that of DUQ data, the number of participants under each approach are different. There was a 12.5 % decrease in the number of students classified under the iterative approach moving from DUQ to focus group discussions data and a further 9% decline with respect to results of the analysis of scripts. Consequently, there was an increase in the number of students associated with a linear approach in the order DUQ, focus group discussions and scripts. The same student whose narrative was consistent with the divergent approach also fell under the same approach based on the analysis of his script. This student apparently had a good understanding of how he approached investigations.

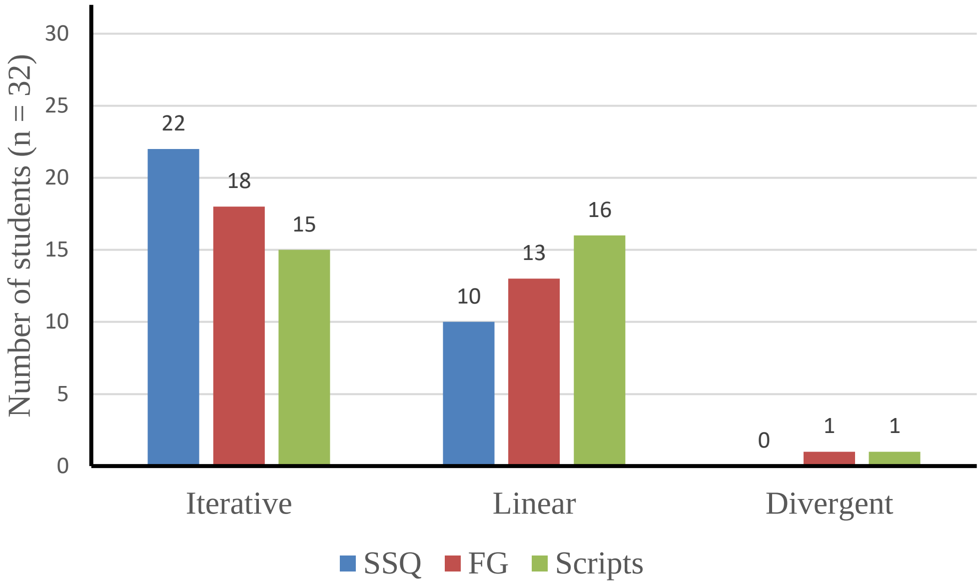



Figure 5.4 Comparison of approaches based on DUQ, FG and script analysis

## 5.2 Discussion of students' approaches from a designing perspective

The findings of this study reveal that most of the participants used the iterative approach in their designing of investigations based on the semi-structured questionnaire data. The analysis of scripts and focus group discussions showed marginal differences in the frequencies of the iterative and linear approaches. The divergent approach had significantly low frequencies in all the three data sources. These findings contrast with those of Hammann et al. (2008) whose study showed that only a few students were associated with the iterative approach. Other studies (Ercan & Tasdere, 2011; Kanari & Millar, 2004) found out that participants were incompetent in one or more process skills. Data from the analysis of scripts and focus group discussions, where comparable numbers of the participants adopted the linear approach as a direct consequence of limitations in process skills (such as designing, planning and data collection and processing), support the findings from these studies.

The differences in the distribution of the participants by approach across data sources as depicted in Figures 5.3 and 5.4 is another demonstration of how the use of more than one data source can lead to a better understanding of the phenomenon under study. Bearing in mind the size of the sample, important observations can be made. Firstly, the probing done during the focus group discussions might have allowed the participants with unmatched approaches to express themselves better than they did when they wrote their responses to the items on the DUQ (Cohen et al., 2011). Secondly, what the students say they do during investigations (SSQ and focus group discussions) is not necessarily translated into practice. It is possible that some students failed to implement their approaches from the DUQ and focus group discussions as they faced various challenges when they did the actual investigations. As a result, some strategic students might have ended up using a linear approach. One can also argue that an analysis of students' write-ups on its own may not be enough to determine whether the participants are cognisant of what is considered to be the ideal approach to investigations in literature (Roberts et al., 2010).

In earlier studies, Hackling and Garnett (1995) and Watson (1994) had shown that a divergent approach lead to poor results and performances and that iteration was not prevalent in their participants. As such, studies that use students' work on investigations, are more revealing as they do not just help to categorise students by approach, but also highlight the exact process skills that are weak in students. Such a deeper understanding leads to more useful recommendations for the respective Chemistry teachers who work with these students.

The experimental study by Roberts et al. (2010) showed that students shifted towards an iterative approach as a result of deliberate intervention strategies. Parallels can be drawn with the current study whose participants were in their final year of high school studies and preparing for a high stakes examination. It can be argued that the instructional strategies that the students had experienced might have been instrumental in the majority of them adopting either an iterative or linear approach. This is discussed further and in greater detail in the next chapter.

A small proportion (2 of 50) reported that they asked for assistance from their teacher when they felt they were stuck in an investigation. They then modified their investigation procedures and obtained better results. While the number was small, seeking assistance ultimately lead to an iterative approach. This can be viewed as *assisted iteration* since it is based on information gathered from other people.

Students' approaches from learning and design perspectives were tabulated together to identify patterns and profile the approaches based on the emerging combinations. The combinations of approaches from the two perspectives were named *hybrid* approaches. These were: deep-iterative, deep-linear, strategic-iterative, strategic-linear, surface-linear and surface-divergent. Only data from the ASIIS and DUQ were used since these questionnaires were answered by all the 50 students. Only 32 students took part in the focus group discussions. If the approaches from the different ASIIS and DUQ did not match, the better approach (the one that leads to better results) took precedence. There were no definite intermediate approaches hence I decided to classify such students under the better approach. For example, if a student's approach was deep from ASIIS data and strategic from DUQ data (or vice-versa) then the student was classified as using the deep approach. In the same vein, if a student was classified under iterative and linear based on DUQ and analysis of scripts respectively, then they were classified under the iterative approach. Based on this example, the hybrid approach was named deep-iterative. A hybrid approach was determined for each of the 50 students who took part in this study and a summary of the results is presented in Table 5.5.

Table 5.5 A summary of the hybrid approaches to investigations

| **Hybrid approach** | **Number of students** |
|---|---|
| Deep-iterative | 8 |
| Deep-linear | 10 |
| Strategic- iterative | 23 |
| Strategic-linear | 8 |
| Strategic-divergent* | 1 |
| Surface-linear | 0 |
| Surface-divergent | 0 |
| **Total** | **50** |

It is logical that students capable of linking their theoretical conceptual understanding to the investigations (deep approach) or those who were aiming to achieve good grades (strategic approach) would also use an iterative approach during their designing, planning and carrying of the said practical activities. This resulted in the deep-iterative and strategic approaches. Predictably, the hybrid strategic-iterative had the highest frequency (23 out of 50) given that the separate approaches were also popular. In the event of time limitations or other constraints, iteration gave way to a linear approach leading the hybrids of deep-linear and strategic-linear. These two hybrids can be viewed as *contrived approaches* given that they are an adaptation to the existence of one or more contextual factors. The unanticipated hybrid approach of strategic-divergent that was associated with only one participant can be described as a *nonsense hybrid* approach. In practice, strategic students would have sound substantive and procedural knowledge enabling them to be relatively successful in doing investigations. The combination of strategic and divergent approaches is therefore considered a mismatch given that divergent refers to doing stuff that never gets to the answer.

The theoretical hybrid approaches of surface-linear (rote memorisation, regurgitation and execution of a plan of an investigation done before) and surface-divergent (rote memorisation, incoherent regurgitation of an investigation done previously without success) drew none of the participants. This was consistent with the fact that none of the participants were classified under the surface approach (Table 4.7).

## 5.3 Conclusion

In this chapter, students' approaches to investigations from a designing perspective were the focal point. Evidence from the data collected for the purposes of his study was presented to support the assertion that the majority of the participants employed the iterative and linear approaches. These findings were not entirely in agreement with the reviewed literature which revealed that none or very few students used the iterative approach unless they were taught in ways that encouraged it. An analysis of the students' approaches from the two different approaches, the learning and designing perspectives lead to hybrid approaches with the most common one being the strategic-iterative approach. The participants' understandings of investigations and the influence of various contextual factors on their approaches is dealt with in the next chapter.

# CHAPTER 6
# WHY THIS APPROACH?

The preceding chapter described and discussed the approaches, from a designing perspective, used by A-Level chemistry students when doing investigations. In this chapter, the first focal point is the participants' understanding of investigations. The assumption is that students' understanding of investigations plays a part in how they approach them. The second focal point of this chapter explores why the participants approach investigations the way they do. Assertions on why students approached investigations the way they did were drawn from all the data sources, that is, the survey questionnaire, semi-structured questionnaire and focus group discussions. The historical and prevailing context of practical work in high school science as well as the epistemological beliefs about teaching and learning as described and discussed to in chapter two are taken into account in order to put the approaches into perspective.

## 6.1 Students' understanding of investigations

In the semi-structured questionnaire, participants were asked to express their understanding of investigations, how different they were from other forms of practical work, the role they played in chemistry education and the relevance of investigations with respect to their future studies and professions. The data from the participants' responses were loaded into NVivo 11 with mother nodes from which child nodes were derived. The corresponding NVivo 11 output (Appendix N) was then used to come up with a broad assertion from which two sub-assertions were drawn.

***Assertion 3*: There was no common understanding of an investigation with some students focusing on inquiry and others on process skills. Investigations were viewed as practical work which serves a variety of roles.**

In the literature review section of this thesis in chapter two, it was pointed out that Miller's (2010) definition of an investigation was adopted for this study. She defined an investigation as "a practical activity in which students are not given a complete set of instructions to follow, but have some freedom to choose the procedures to use, and to decide how to record, analyse and report the data collected" (p. 2). An understanding of how the participants conceptualised investigations was derived from their responses to direct open-ended questions in the DUQ and during the focus group discussions. In the DUQ (Appendix G) students were asked to outline their understanding of an investigation, and its differences with other types of practical work. In the same instrument, they were asked to explain the importance of investigations in chemistry education and their relevance to their future studies and professions. These same questions were also asked during the focus group discussions with the benefit of probing to get clarity on the participants' perceptions. For each form of data source, the participants' responses were summarised and tabulated to show the different understandings and perceptions together with their frequencies.

***Sub assertion 3a*: More than half of the students understood an investigation as practical work with a focus on inquiry while the others understood it in terms of the components of process skills.**

*Focus on inquiry*: The participants were asked to describe what they understood by an investigation and how different it is from other types of practical work in the DUQ. Their responses were coded and put into categorises to obtain frequencies. A total of 30 students gave understandings of an investigation with characteristics of inquiry. Of these 30, ten participants indicated that investigations are a form of discovery learning often characterised by the uncertainty of results. One expressed this idea well by saying, "An investigation is when one wants to find the significance of a substance in another and how one substance affects a reaction. It's all about discovering, it's different from other types of practical work" (STD37, DUQ, May 21, 2015). STD15's understanding of an investigation made specific reference to qualitative analysis by saying that, "It is an experience of deducing behaviour of sample compounds in chemistry whose identity we don't know. It requires thinking and application of my understanding of chemistry. It requires caution and it's enjoyable and adventurous" (DUQ, May 21, 2015).

There was some support (8 of 50) for the idea that investigations were practical activities where you were required to come up with your own design. This was highlighted as what distinguishes investigations from other types of practical work as reflected in the following quotes from two different students:

> It is a practical activity carried out after designing it yourself. It becomes an investigation when you look for ions by your own design. It is different from other practical work because this one is done after designing it yourself. (STD2 DUQ, May 21, 2015)

> An investigation is a practical you undertake after designing your own experimental procedure. In other types of practical work, you carry out a plan that has been provided for you. All you have to do is set it up, collect the data and process it. (STD3 DUQ, May 21, 2015)

The students who participated in the focus group discussions echoed this understanding of investigations. They all agreed that the main distinguishing factor between investigations and other types of practical was that you ‘design it yourself’, that one comes up with their own procedure rather than just follow instructions given on a worksheet. STD15 said, “The investigations test me to design, you don’t just do experiments which come with instructions and you are there to just carry out” (Focus Group Discussion 2, June 4, 2015). STD20 supported this sentiment by saying, “I think when you design it’s different from other practical work where you are told what to do. In Chemistry, you have to design the practical and carry it out and see if it actually works” (Focus Group Discussion 3, June 4, 2015). An interesting contribution came from STD41 who linked his understanding of investigations to why it was his preferred type of practical work:

> I would prefer the investigations because in other practical activities, I just following instructions. In investigations, it’s like I have a problem, can you help me. It’s more I am giving out the information, I am solving a problem. I am using the knowledge that I have acquired. It feels like I am being appreciated for studying the theory. It’s not like following instructions. (STD41 Focus Group Discussion 7, June 04, 2015)

Seven participants were convinced that investigations represented the way scientists work and that this is how we come to know about the world around us. This is evident in the following statement by one student who also said investigations may involve manipulating variables:

> An investigation is a method of acquiring results based on a study, its' an investigation because you're able to change variables … like conditions …. like what scientists do. It requires you to think. An investigation allows us to work like real scientists and see how Chemistry can be used for a good cause. (STD26 DUQ, May 21, 2015)

Apart from appreciating that investigations reflect how scientists work, four students went further to link them with how scientific knowledge is generated. One of these students said:

> An investigation is a practical activity that gives one the opportunity to acquire a deep understanding of science ideas and concepts by experimenting. This is how scientists came up with the different theories and laws that we study during our Chemistry lessons. (STD49 DUQ, May 21, 2015)

While stating that investigations are associated with how scientists work, one student pointed to the iterative nature of these practical activities by stating that they are characterised by trial and error:

> An investigation is a process whereby scientific based procedures are carried out in order to cater for the future problems that require science solutions. A matter of trial and error makes it an investigation until the solution comes out. That's what scientists do in the real world. (STD26 DUQ, May 21, 2015)

A small proportion (3 of 50) of the DUQ respondents referred to investigations as a form of practical work that involves problem solving. To this end one student said, “In an investigation, one is required to come up with ideas to tackle a problem whereas in other types of practical work one only needs to follow instructions” (STD41, DUQ, May 21, 2015). According to another student, an investigation “makes you relate and think certain methods to resolve Chemistry problems” (STD30, DUQ, May 21, 2015).  A broader understanding of problem solving in relation to investigations came from STD42 who went further by saying, “It is an investigation because you will be trying to understand and solve a problem. It is different because each time it is something new and fun” (DUQ, May 21, 2015). It seems like STD42 was cognisant of the fact that problem solving implies that the student has not done a similar practical activity before. A student (STD18) reiterated this point when he said, “In investigations, it’s like I have a problem, can you help me. It’s more like, I am giving out the information, I am solving a problem. I am using the knowledge that I have acquired in a new context” (Focus Group Discussion 2, June 04, 2015). However, there was no idea of general support for this idea during the focus group discussions.

*Focus on process skills*: 20 of the participants who took part in the DUQ expressed an understanding of an investigation which was limited to one or two process skills such as experimenting, hypothesising, inferring and observing.  In their responses, they focused on aspects of the process as defining characteristic of an investigation. It is possible that language deficiencies could have played a significant part given that all of the participants were native Zimbabweans who had English as their second or third language. Some of the statements from these participants are captured in Table 6.1 together with the related process skills. The process skills and the frequencies of the coding were: experimenting (9); observing (5); hypothesising (4); inferring and defining variables (2). Some students mentioned two process skills.

Table 6.1 Examples of participants' understanding of an investigation in terms specific process skills (DUQ, May 21, 2015)

| **Participant** | **Understanding of an investigation** | **Process skill(s)** |
|---|---|---|
| STD19 | In an investigation you hypothesise and experiment | hypothesising |
| STD20 | An investigation is more complicated as one has to observe every single detail. | observing |
| STD21 | A practical is an investigation because you will be experimenting in order to find results of something unknown to you. | experimenting |
| STD23 | It becomes an investigation from the fact that you have to infer from your results. | inferring |
| STD25 | Yes, it is different in that in any investigation you will be hypothesising and manipulating variables | hypothesising<br>defining variables |

***Sub-assertion 3b*: A-Level chemistry students viewed investigations as serving multiple roles such as to: develop process skills; important for future studies and profession; develop higher order cognitive skills and deepen conceptual understanding**

All the participants who took part in this study responded to Question 8 of the DUQ by enumerating one or more reasons why investigations are part of the Advanced Chemistry Level curriculum. Table 6.2 below summarises their responses in descending order of frequency.

Table 6.2 Student responses to questions dealing with the role of investigations

| **Role of investigations in chemistry education** | **Frequency of response (n =102)** |
|---|---|
| 1. To develop process skills important | 42 |
| 2. Important for future studies and chosen profession | 23 |
| 3. It develops higher order cognitive abilities (e.g. problem solving) | 18 |
| 4. To deepen conceptual understanding (to link theory with practice) | 17 |
| 5. They have an affective value (they are fun to do) | 3 |

*Some students mentioned more than one role

*Process skills:* Half of the participants were aware that investigations play a significant role in developing process skills such as manipulative skills, observation, measuring/taking readings, planning, recording, processing and analysing experimental data. No student mentioned all the process skills associated with an investigation. Some students identified more than one skill in their responses such as observing and inferring. For example, one student wrote, “Every time I do an investigation, I enhance my practical skills such as observation and deductions from every observation” (DUQ, May 21, 2015). Others focused on designing by saying, “because one is able to design an experiment for a particular investigation” (STD4, DUQ, May 21, 2015) or planning since investigations help “students do develop planning skills” according to STD37 (DUQ, May 21, 2015). One student stated that this type of practical work was instrumental in assisting “students to acquire practical skills and knowledge on how to do investigations” (STD36, DUQ, May 21, 2015).

At least 17 of the participants saw the relevance of doing investigations beyond the classroom context. They mentioned that investigations helped them “to link what we do theoretically to what happens practically in day-to-day situations. To teach us to think and apply what we learn theoretically to day-to-day challenges” (STD29, DUQ, May 21, 2015). “Investigations are part of the syllabus because they make a person ready for day-to-day industry and they open the mind. They improve our scientific literacy” (STD45, DUQ, May 21, 2015). These responses matched the curriculum aim (ZIMSEC, 2012b), something which would please curriculum designers. The data gathered for this study did not provide clear evidence to explain how this was developed. It was, however established during the focus group discussions and through conversations with Chemistry teachers that each student was given a copy of the syllabus at the beginning of the A-Level course but the teachers never took time to go through the syllabus aims with the students. The teachers had only highlighted the sections describing the content, learning outcomes and structure of the examination papers.

*Important for future studies and profession*: From the responses, about half mentioned that investigations prepared them for future studies and their intended professional careers. All the participants indicated their chosen careers as engineering or medicine. They were also able to give concrete examples of where and how the skills would be useful in their future professional lives. They viewed the development of manipulatives skills and laboratory techniques as of major importance. According to STD13:

> The role of investigations is to prepare one for future applications in careers in which one may pursue in the future. At A-Level, it is very important for us to familiarise with the skills and techniques used in Chemistry (so) that it might be easier for the students at University level. (DUQ, May 21, 2015)

These participants were aware that the process skills acquired through doing investigations were required beyond university life. A typical response was that investigations “help us to develop our investigation skills as we go to universities and for the jobs that have Chemistry as a requirement" (STD17, DUQ, May 21, 2015). This was supported by another student who said, "When we become workers we will definitely need the skills we are developing now" (STD38, DUQ, May 21, 2015).

*Higher order cognitive skills*: As many as 18 of the participants indicated that investigations were instrumental in developing higher order cognitive abilities such as innovativeness, problem solving and creativity. An interesting statement made by one of the participants was as follows:

> Investigations enable us to think quickly on our feet in order to solve problems as quickly as possible like me. I would like to save many lives as a doctor and to do that I will have to be creative and at my best in problem solving. (STD14, DUQ, May 21, 2015)

The same ideas were expressed by other students who did not necessarily link the development of higher order skills to their future professions. They said, "It allows us to think on our own, more specifically to think outside the box" (STD24, DUQ, May 21, 2015) and "to create some innovative minds in science students" (STD28, DUQ, May 21, 2015).

During all the focus group discussions, the ability to 'think outside the box' was raised by the selected participants. Only 18 of all the student participants had mentioned this in their DUQ responses. The ability to think outside the box was viewed as an important skill necessary to come up with useful innovations and solve problems in industry (professional life) and everyday life as explained by one of the students who wanted to become a doctor:

> Designing investigations teaches us to think outside the box. Every time we do them we are faced with new situations, new problems which do not necessarily require routine solutions. This is important because when I become a doctor I will at some point deal with patients with new diseases or health conditions which will require new diagnostic techniques and treatment. (STD9, DUQ, May 21, 2015)

Another student who wanted to study some branch of engineering shared the same idea:

> I want to be an engineer. Engineers often invent things and this often requires thinking outside the box because they will be dealing with what no one has done before. I think that's what the person who invented the light bulb did. (DUQ, May 21, 2015)

*Conceptual understanding*: A number of the students (17 out of 50) mentioned that investigations help them to deepen their understanding of chemistry concepts by linking theory and practise. These participants thought that they did investigations "in order to make the balance between understanding Chemistry as theory and its practical application in our lives" (STD15, DUQ, May 21, 2015). Some added that the role of investigations "is to understand properties of substances personally, not just to be told by the teacher. One can understand a concept better by doing the relevant investigations" (STD39, DUQ, May 21, 2015). Another idea was that "investigations make it easy to grasp the concepts we learn in our theory lessons" (STD26, DUQ, May 21, 2015). These statements from the participants arguably show that they saw investigations as an ideal teaching and learnings strategy that enabled them to acquire a deep understanding of chemistry concepts.

*Affective value*: Only three of the 50 students mentioned the affective value of investigations based on the available data. They appreciated that investigations were 'fun' to do. The said participants thought "it's fun doing investigations" (STD16, DUQ, May 21, 2015) and that "it is different from other types of practical work because each time it's something new and fun" (STD42, DUQ, May 21, 2015). The novelty of each investigation seemed to generate interest, excitement and expectations in the participants although this was only recognised by a small proportion.

During the focus group discussions, the participants were also asked to describe the role of investigations in chemistry education. All the focus group data were coded using NVivo 11 and the output was used to produce the summary in Table 6.3 in descending order of frequency.

Table 6.3 The role of investigations (Focus Group discussions data)

| Role of investigations in chemistry education | | Frequency of response (n = 32) |
|---|---|---|
| 1. | It develops higher order cognitive abilities (e.g. problem solving, creativity, innovativeness) | 16 |
| 2. | Important for future studies and chosen profession | 15 |
| 3. | To develop process skills | 14 |
| 4. | To deepen conceptual understanding (to link theory with practice) | 10 |
| 5. | They have an affective value (they are fun to do) | 1 |

While the top four roles remain the same for both the semi-structured and focus group data, the order based on their frequencies is not the same. The development of process skills fell to third position. This was perhaps due to the phrasing of the question or the fact that participants felt obliged not to repeat what their colleagues had said. Also, the top two roles can be worded differently hence ended up with higher frequencies during the focus group discussions. In the DUQ, the participants were writing their responses without conferring, hence they did not know what their colleagues were writing.

The affective value of investigations was only acknowledged by one participant during the focus group discussions. This mirrored the low frequency registered by the DUQ data. During the focus group discussions, it was established that while the majority of the students believed that investigations can be fun, the ones they did and the circumstances under which they did them took away most of the excitement. In one of the focus group discussions, one student expressed this strongly:

> I rarely enjoy doing investigations because I am always under pressure to finish the experiments. I think if we had more time we would enjoy them more, but as it is, the focus is on completing the tasks and getting a good mark. I always come to the laboratory on Thursdays worrying about how I will perform and hence the pressure takes away the fun side of it. I enjoy the demonstrations that our teacher does during our theory lessons. (STD14, Focus Group Discussion 1, June 2015)

## 6.2 Why students approached investigations the way they did

In chapters four and five, A-Level chemistry students' approaches to investigations are presented together with the relevant supporting evidence from the data collected for this study. The first section of this chapter was dedicated to the participants' understanding of investigations. In this last section on the findings of this study, the researcher draws from all the relevant data to make inferences to respond to the fourth research question on why students approached investigations the way they did. To this end a broad assertion was enunciated.

***Assertion 4*: A number of factors shaped the A-Level chemistry students' approaches to investigations but success in examinations dominated**

This assertion was further broken down into four sub-assertions, which are elaborated separately in the sections that follow.

***Sub-assertion 4a:* The approaches students used were strongly influenced by the need to obtain high marks from the examinations.**

In chapter two, the educational context in Zimbabwe was highlighted and the fact that only two universities in the country offer degrees in engineering and medicine. It is not practical for these two universities to absorb all those who pass A-Level Sciences and want to pursue degrees in the fields of engineering and medicine hence they have deliberately set high entrance requirements. The entry requirements for the males is three A’s and at least two A’s and a B for the females in three of the following subjects: Chemistry, Physics, Biology and Mathematics. Almost all the students who participated in this study indicated in the DUQ that their preferred career was in some branch of engineering or medicine as their aspiration as shown in Table 6.4.

Table 6.4 Participants' preferred careers after A-Level studies

| **Preferred career** | **Number of participants (n = 50)** |
|---|---|
| Medicine | 23 |
| Engineering | 19 |
| Engineering or Medicine | 5 |
| Don’t know yet | 2 |

The need to meet the performance criteria for admission into the engineering or medical schools set by the universities meant that getting A’s was a priority for the students. In the focus group discussions, they shared their sentiments in this regard as exemplified by the following conversation:

> Tami: Somebody referred to marks. He said I do my best to get good marks. Do you find your approach to this kind of practical work as being driven by the need to get an A at the end of the day?
>
> STD31: As for me, I work for those A’s. That’s the general feeling, we want to get an A at the end of the day because we are not in a set up whereby we are taught to do things for research’s sake or something like that. What we are taught is, you need to get A’s and leave school with good grades so that you can study engineering or medicine. That is the traditional way we are taught generally.
>
> STD50: I think the idea is to get A’s.
>
> (Focus Group Discussion 6, June 04, 2015)

STD45 was more candid in expressing the pressure that comes with examinations and his concerns about performances in investigations:

> I don’t think I will ever enjoy doing investigations here. I always get a low mark. There is so much pressure on me to perform well but I never get them right. This affects my overall mark in practical work because I spend so much time on this section and eventually fail to finish the other practical exercises especially during the end of term practical examinations. (STD45, Focus Group Discussion 8, 2015)

What the students said was corroborated by what one the chemistry teachers, Fidel, said in a separate interview when explaining why the students appeared intrinsically driven to do investigations.

> Tami: You say they have a genuine desire to do investigations, what drives them? Is it the need to get good marks or it is the desire to acquire the related skills?
>
> Fidel: Basically, what I can say is Zimbabwean education is highly competitive now. They need those high marks in order to get good grades at the end of the day so that they can go and pursue their programmes of interest at university level. The reason is it wasn't instilled in them at a young age. If this had been the case, yes, they would have the desire to acquire the skills but now the focus is on getting high marks so that they can go and pursue their programmes of interest at university level. Maybe when they are doing their degrees and so on that's when they will have the desire to acquire the skills and realise that what they were doing at A-level was a preparation for the future.
>
> (Fidel interview, June 04, 2015)

There was evidence that the students who showed a deep approach understood why it was ideal for lifelong learning. STD49 was very convincing in the following conversation:

> STD49: Personally, I think of the skill first. I should not focus on the marks because they won't get me anywhere but the skills that I acquire at present are going to help me in the future. Marks are just there for the record whereas skills are for life.
>
> Tami: But you need 15 points to go to the university?
>
> STD49 Yes, I do need 15 points to go to the university but I need to get the skills first because if I get a high mark today, maybe it's a once off thing but if I get the skills, I will be better prepared for the final exam and any investigations that I have to do in future.
>
> Tami: So, you would rather have the skills than a high mark. What about you (STD40)?
>
> STD40: Yes, I agree because the reason why we are doing these investigations is because we will need to apply all those skills in future.
>
> (Focus Group Discussion 7, June 04, 2015)

The existence of students (like STD40) with a deep approach to investigations and a self-constructed understanding of its benefits, in an environment which promotes a strategic approach, suggests that it is possible to promote this approach which is associated with meaningful learning. They go against the tide of the approaches favoured by their teachers' teaching strategies (and what their colleagues are doing) in pursuit of long-term goals sometimes at the expense of good academic grades.

**Sub-assertion 4b: The pressure of examinations influenced the instructional strategies adopted by teachers and the approaches used by the learners**

*Reliance on past examination papers*: There was a conspicuous overreliance on past examination papers as the sources of investigations done by the students in the two schools. This inevitably led to the dominance of the strategic approach as alluded to in chapter four. In the DUQ students were asked to indicate all the sources of the investigations they did during their practical sessions. Table 6.5 summarises the data in descending order. Some students gave more than one response, and in total 66 separate responses could be coded from the 50 students as some students gave more than one source of questions. Almost all the participants (49 out of 50) indicated that past examination papers were the source of the investigations they do each week. Textbooks were mentioned by ten students and seven students said their teachers made up the questions for the investigations they did.

Both chemistry teachers confirmed in separate interviews that they relied mainly on past examination papers for the investigations they assigned to their students. The reasons for using past examination papers as the main source of investigations were that it helped them maintain the curriculum standards and that they had access to the marking guidelines from the examination board. The following excerpt comes from an interview with one of the chemistry teachers, Fidel (not real name), who confessed that he only used past examination papers.

Tami: In terms of the variety of investigations, do you have other sources apart from past exam papers?

Fidel: At the moment, no. I always use the past exam papers.

Tami: You feel comfortable with them. Why?

Fidel: Mainly I will be looking at the structure of the questions and the trends of the questions in the final examinations.

Tami: So, it helps you to stay on track rather than deviate from the assessment guidelines.

Fidel: Yes.

(Fidel interview, June 04, 2015)

The second chemistry teacher, Raul (not real name), mentioned a range of sources of the investigations he assigned to his students in the following excerpt from the interview.

Tami: Some of the students say that the scope of the investigations that you do is limited. They would want to see it broadened to include everyday life problems.

Raul: If you look at our syllabus, it’s highlighted that the scope of the investigations to be done under A-Level Chemistry is not limited to the few examples mentioned in the syllabus booklet. I think it depends on the competence and resourcefulness of the teacher. If you are not innovative you will overlook that part. And as teacher if you overlook one section of the syllabus, it will cascade down to the students. You will be in the same boat.

Tami: So, you are happy with how the syllabus states the scope of the investigations.

Raul In fact the syllabus advocates for a constructivist approach. Some of the designs….. you find them in the Form 3 and 4 chemistry textbooks. So, if you overlook that content from Form 3 and 4, they will find the investigations difficult. There is need for you to link the content to what they did in the lower forms for them to construct their knowledge basing on previous knowledge.

Tami: So, what are your other sources of the investigations that you assign to your students apart from the past exam papers? Do you use other sources?

Raul: I normally get them from the internet. I download from the internet. Of course, I use past exam papers. Even reference books, especially A-Level Chemistry by Philip Mathews. It has a lot of investigations and model answers.

Tami: Do you have a copy of the book mentioned?

Raul: I normally use the one in the library.

Tami: Okay, it's in the library. So, we can have a look at it after this interview.

Raul: Okay.

(Raul interview, June 04, 2015)

Although Raul sounded convincing and aware of the syllabus specifications on investigations, which highlighted that the scope of investigations was unlimited, my observation of teacher practices provided no evidence of this effect. When I checked his schemes of work I found out that all the investigations he had assigned to his students from the beginning of the year were all from past examination papers. I also checked in Raul's school library and the text he referred to was not part of the library stock putting further doubt on his use of it.

The dependence on past examination papers was coupled with an emphasis on examiners' expectations since marking was based on the marking schemes sourced from the examination board. The two chemistry teachers gave feedback to their students at different times. In School A, the teacher would only give feedback in the following practical session after marking the students' scripts. In School B, the teacher preferred to hold post-practical conferences, immediately after the practical, where he discussed with the group how they should have done each investigation. When I asked him at the end of one of these post-practical conference sessions, he indicated that he preferred to revise the work when it was still fresh in the minds of the students. During the feedback sessions, both chemistry teachers gave the students the solutions provided in the ZIMSEC marking schemes. Ultimately, the feedback was about the do's and don'ts in a practical examination. The following are direct quotations of what Fidel and Raul said in separate feedback sessions in their respective schools:

> Gentlemen, some of you did not present their experimental procedures in the form of numbered steps. *Examiners* will penalise you heavily for that. In some cases, there was indication of the quantities used. I have said this many times, *examiners* will penalise you for that. There was a lot of cancelling (crossing of work) in many of your scripts. The work was dirty. Please be neat when you write you do your write-ups. *Examiners* won't be happy with dirty work. You also need to demonstrate to the *examiners* that you understand the theory related to the investigation. In this investigation, many of you did not demonstrate a sound knowledge of first order reactions. *Examiners* want to see that you can correctly use the theory of first order reactions to interpret your own experimental results. Even if the measurements are not accurate, *examiners* will give you credit for processing and interpreting them correctly. (Fidel, Observation, May 28, 2015)

> (After giving back scripts from the previous practical session.) Let me start by reminding you of the need for neatness in your write-ups. There is a lot of crossing in some of your scripts. Some of you forgot to number their experimental steps as I have repeatedly said. I will always penalise you for this and this will also cost you in the *final examination*. There was also a general weakness in explaining why you were doing each step. *Examiners* will not give you full credit for such steps. Now here are copies of the *marking scheme* for this investigation. Please go through it and take note of what *examiners* look for, what the *examiners* give marks for, and see where you fell short. When you are done, you can proceed and do today's investigation. (Raul, Observation, May 28, 2015)

The quote from Fidel shows that he mentioned examiners six times. Raul's quote shows that he referred to examiners' expectations, the final examination and the marking scheme on five occasions. This was characteristic of all the post-practical conferences or feedback sessions that were attended by the researcher during the data collection period. The emphasis on examiners' expectations was very strong. It is possible that this emphasis translated into a predominantly strategic approach to investigations by the students. In the same vein, those who were competent in linking the relevant theory to the investigation of the day were then associated with a deep approach

*Classroom organisation*: The organisation of the practical sessions possibly conditioned the students to work as if they were writing an examination in many respects. A workstation was prepared for each student, thus giving emphasis to individual work in every practical session. This is shown in Figure 6.1.

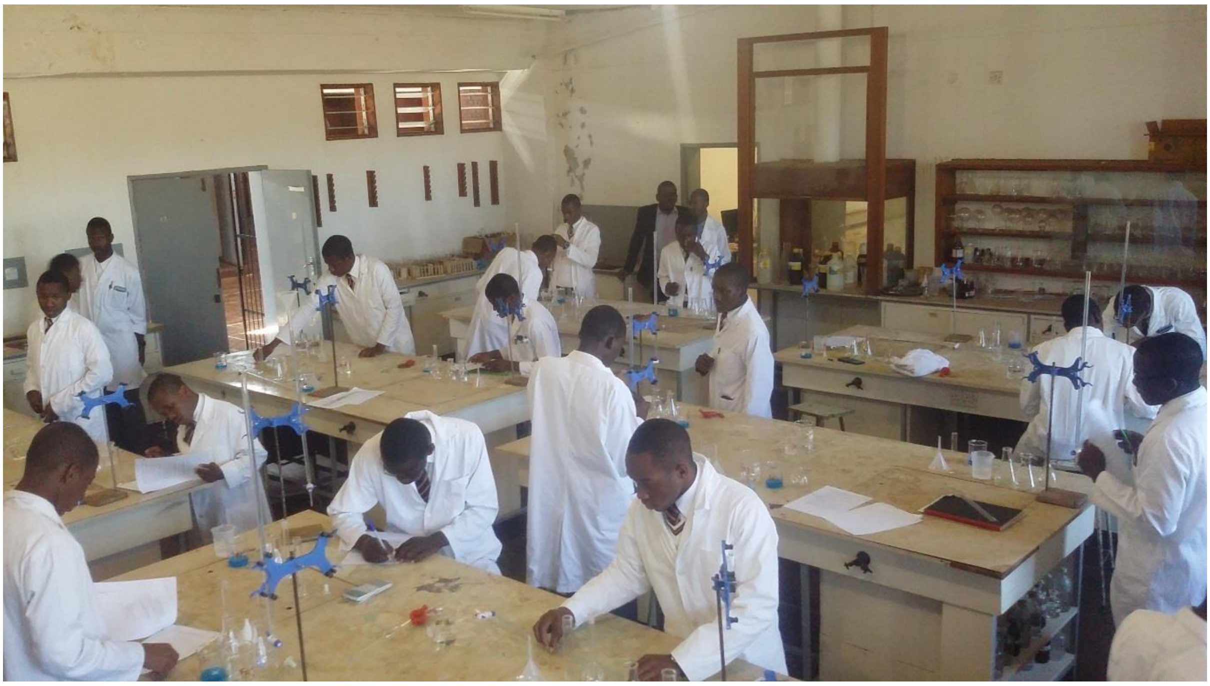


Figure 6.1 Students doing an investigation individually at School B

Faced with a past examination question paper, most of them may have imagined themselves in their final examination, something which would have created pressure for them to behave as they would do in a high stakes examination. This could be the reason for the pronounced strategic approach as students sought to meet their teachers' (examiner's) expectations in order to score good marks. This could also have compelled students to do thorough preparation before each practical session, since they were aware that they would be working individually, leading to a significant number of students showing a deep approach.

The students tended to use an iterative or linear approach but without necessarily getting the investigations right as revealed by the script analysis. They were reluctant to consult with their teacher or colleagues even when they were aware of the fact that they did not know how to do the investigations. In all the practical sessions observed, students were seen asking for assistance from either the teacher or colleagues in only one session in one of the two schools. Even then, it was only five students of the 23 students in the group. In the other school, none of the students consulted anybody during the practical sessions for the duration of the data collection period. This was quite surprising because the teachers kept reminding them that they could get assistance from anyone if they needed it. During the focus group discussions, the explanation offered by the students for this behaviour was that they were always conscious of the fact that they will not be able to consult with anyone in their final examination hence the need to treat each practical session as an examination. They wanted to be assessed based on their own work, without any assistance, so that they would have a true reflection of their performance, learn from their mistakes and take measures to rectify them before the final examination. The following contribution from one of the students during the sixth focus group discussion is testimony to this:

> I think we have to work under exam conditions all the time because in an exam it's one man for himself and God for us all. ……. the investigations that we do in the class are actually preparation for what is to come in the future. So, if you learn to do them on your own you will have a great advantage. (STD46, Focus Group Discussion 6, June 04, 2015)

*Time factor*: Time constraints may have influenced 48% of the students (Table 5.2) to adopt a linear approach based on the analysis of scripts. Even when they knew that their results were incorrect, there was never enough time to redo the investigations. During the focus group discussions, some participants expressed this freely as reflected in the following conversations from three focus group discussions:

Tami: You have mentioned the aspect of time. Do you generally feel that time is a constraint when you do investigations? Are they so challenging that you always find yourselves running short of time?

STD15: I think we need more time to express ourselves fully.

Tami: All of you feel that you time is a major constraint. (All nod heads in agreement). So, you feel you know your stuff but you are not given enough time.

STD15: Yah. We feel the pressure.

(STD15, Focus Group 1, June 04, 2015)

Tami: Do you feel you are given enough time to do what you want to do when you carry out investigations?

STD46: Not all the time.

Tami: So, time is a constraint.

STD46: Yah. When the practical is too hard, you need to think of many things, how you are you going to tackle the question. Most of the time, time is too little.

Tami: You agree with him Hope.

STD47: I think in an exam situation, whereby you are given a question in limited time, there won't be any room for broad thinking. You just think of one or two ways of doing the investigation because if you think of more ways time will be against you. So you think of one way and do your write-up.

Tami: Could that be one reason why you don't do well because you are always under pressure?

STD38: Science is a very interesting subject. There are many ways that can get you to one point. Obtaining your objective…. there are so many ways of doing that. Sometimes when you get a worksheet, you have so many ideas and very little time. At the end of the day, you wonder if the pathway you took is right or wrong. Sometimes you just do it for the sake of finishing the design but when you are given more time, you explore all your ideas to see whether they are correct.

(Focus Group Discussion 6, June 04, 2015)

Tami: Now assume you have got a plan, you carry it out and you don't get the results that you expected. What next? What do you do in such a situation?

STD45: Under exam conditions, I just leave it like that.

Tami: Even when you know you didn't do it right?

STD45: If I am practising, I will have the time. I can rectify it.

Tami: You are saying it's different. If you are here on a Thursday afternoon you have opportunities to rectify your mistakes but in an exam, like the midyears, no chance.

STD45: No, because of time.

Tami: So, you people are telling me that time is a major constraint when you do your investigations? You never seem to have enough time.

STD45: Time is enough but maybe during an examination we are under pressure.

(Focus Group Discussion 8, June 04, 2015)

All three conversations illustrate that the time allocated to the investigations posed a huge influence on the approaches adopted by the students. The comment by STD38 was particularly interesting because he shows the tension being displayed between choosing an approach they want to and the one they can in the given time constraints.

***Sub-assertion 4c*: The students' approaches to investigations were influenced by their prior chemistry practical experiences**

*Prior practical experiences*: An outline of the structure of the science curriculum in Zimbabwe was made in Chapter two. The science curriculum in general and Chemistry in particular, has a strong emphasis on practical work and one of the three examination papers is solely on practical work. Category C of the assessment objectives outlined in the syllabus booklet is dedicated to experimental skills and investigations. Under this assessment objective, "students should be able to plan an investigation, select techniques, apparatus and materials" (ZIMSEC, 2012c, p. 6). A look at the detailed outline of the ZIMSEC practical syllabus reveals that:

> The questions in the practical paper may include an observational problem in which the candidate will be asked to investigate, by specified experiments, an unknown substance or mixture. The exercise may include simple chromatography, tests for oxidising and reducing agents, and filtration. (ZIMSEC, 2012c, p. 28)

It is clear, based on the syllabus specifications that the investigations done at O-Level are limited to qualitative analysis. Given the documented pressure to produce good results in Zimbabwean schools, it is highly unlikely that teachers and students will commit time to doing investigations that are not directly specified in the syllabus. The limited scope of the investigations possibly implies that many O-Level graduates will be underprepared to deal with investigations involving quantitative measurements and calculations, such as those under reaction kinetics, chemical energetics and other topics. Some of the participants expressed this shortcoming when they pointed out that designing and planning investigations was an aspect introduced to them late in their high school life.

> Tami: So, you feel that because it (doing investigations) started late in your education, it means that you lack the skills and you have limited time, so you don't actually perform at the level that you want?
>
> STD9: Yes, I am only doing it for 2 years and there might come a question that I won't be able to deal with.
>
> Tami: Okay, something that is outside what you know.
>
> STD9: Yes, we need more experience.
>
> Tami: Do you agree with her? (Referring to STD14).
>
> STD14: I agree with her (STD9).
>
> Tami: You definitely want this to start at lower levels.
>
> STD14: Yes, because from primary level up to Upper Sixth I would have met several questions, different types. So, when it comes to the final examination a question that will come I will have met it before. But now, (we are doing it) just for two years. Maybe I won't even … maybe a question that will come I won't be familiar with it.
>
> Tami: Your idea is that if we start early to assess these skills then it will expose people so that they have a good chance of finding a question that they would have dealt with before, in the final examination.
>
> STD14: Yes, but we don't expect to see exactly the same question. We just feel we should do investigations in all the topics by the examinations.
>
> Tami: So, right now you think you won't have enough time to look at all the questions before the final exam.

STD14: Yes. We have been doing investigations for a year now and that is not enough to cover all the angles.

(Focus Group Discussion 1, June 04, 2015)

The limited practical experiences in investigations at lower levels may have influenced the students to adopt a strategic approach due to the pressure to succeed in the public examinations. When they got to A-Level, they focused on mastering what was required of them to obtain high marks. Doing a variety of investigations at lower levels was perceived as one way of enhancing their chances of doing well at A-Level assuming that they would have done something similar to what will come in the final practical examination. During all the focus group discussions, the participants were concerned that the limited scope of investigations at lower levels had deprived them of opportunities to sharpen their process skills especially those related to the use of apparatus. Limited manipulative skills were seen as a hindrance to the successful designing, planning and execution of investigations.

Tami: Fine. Somebody said, it is good to do investigations, but it is starting very late in high school. This must start way back in primary school. Do you agree with that?

STD7: Yes. Doing investigations at lower levels would be good for us.

Tami: Why would that be a good idea?

STD11: Because if you do the same thing for many years you become good at it. Practice makes perfect. (The others nod their heads in agreement)

STD15: I think it's also good because we develop the kind of skills …. like we learn to handle apparatus much better. Like… right now we haven't used some of the apparatus, and when we start using them now, we sort of develop tremors. Planning or designing an investigation with apparatus you haven't seen or used before is difficult.

(Focus Group Discussions 2, June 04, 2015)

In all the eight focus group discussions, the students seemed to be aware that doing guided investigations and experiments of a recipe type, which were largely confirmatory in nature, did not fully develop in them the various scientific methods, which would be useful in their chosen future professional careers. The following quotes from two different focus group discussions clearly express this view:

> I think we should not restrict it and do investigations where we come up with something new. Right now, we just deal with what some people already know. Maybe we will be able to come up with something new because there are a lot of things still to be discovered. (STD12, Focus Group Discussion 4, June 04, 2015)

> Generally, if you look at the investigations we do, they limit you to the theory that you have already done, that you understand and it doesn't give you an opportunity to discover more rather than just focusing on what you already know, what someone else has taught you. So, I think it's limiting us. (STD47, Focus Group 6, June 04, 2015)

Having looked at the A-Level chemistry syllabus and spoken to the participants, the researcher took interest in the nature of the practical work suggested in the prescribed and commonly used textbooks at O-level. The textbooks were analysed to determine the types of practical work under the various chemistry topics. Table 6.5 shows a summary of the findings.

Table 6.5 A summary of the types of practical work in O-level chemistry textbooks

| **Book title, author and year** | **Open-ended investigations** | **Guided investigations (recipe type)** | **Verification experiments (recipe type)** |
|---|---|---|---|
| Chemistry for 'O' Level (Briggs, 1997) | 0 | 15 | 12 |
| Pure Chemistry: Notes and Questions (Kasipillai, 1999) | 0 | 10 | 12 |
| Step Ahead Physical Science (Chavunduka & Zivanayi, 2013) | 0 | 15* | 10* |

* Chemistry section only, Physics section disregarded.

The data in Table 6.5 suggests that the recipe type of practical work is abundant in the O-Level chemistry textbooks. The lack of opportunities to do open-ended investigations at this level means that when students get to A-Level, they are under prepared in this component of practical work. Consequently, it possible that when students get to A-Level, weaknesses in integrated process skills, induced by the context, influence the majority of them to adopt a strategic approach as they worked hard to meet examiners' expectations and score high marks.

***Sub-assertion 4d*: The students' approaches to investigations were influenced by their knowledge of the related chemistry topics and competence in process skills.**

There was some evidence that students' depth in substantive and procedural knowledge had a major influence on how they approached investigations. During the focus group discussions, it emerged that those who were associated with the deep and strategic approaches felt that their understanding of the theory, related to the investigations they did, was strong. These students made deliberate efforts to read a lot in preparation for their practical work. It would appear that they saw a connection between what they did in the theory lessons and the investigations they did on Thursdays. The same students also tended to use the iterative approach when designing, planning and carrying the investigations. It can therefore be inferred that these students combined sound substantive knowledge and procedural knowledge to good effect. During first focus group discussion, STD2 and STD8 were very articulate in explaining why they did well in investigations:

> They are linked with the theory we do. Most of the times we get to do designs on the things we have been doing in theory for example enthalpy change of reactions. Most of the designs are based on the theory we do, so you just apply. (STD2, Focus Group Discussion 1, June 04, 2015)

> I read a lot of theory which is related to the investigations we do so I find it easy to design and plan the investigations because I perfected on the theory side so both (theory and practical work) are … they are linked. So, it's easy. (STD8, Focus Group Discussion 1, June 04, 2015)

It was interesting to note that the 23 students who were associated with the iterative approach based on the analysis of scripts seemed to apply the stages of the PSC.  One of the students' account of how he approached investigations showed that he actually started with problem perception and reformulation before going to design and plan the investigations:

> It's all about understanding the question, knowing what is being talked about in the question rubric, like the motive of the design, the reason why they want us to pursue that investigation. You then proceed and plan the experiment, how you are going to collect the data and process it. That is why we get them correct, because we are able to understand the questions. We tackle them very well, we understand what we need to do first before putting pen to paper or touching any materials. (STD38, Focus Group Discussion 5, June 04, 2015)

As discussed in a later section, an analysis of the comments suggested that this was a result of how they were taught. Their teachers emphasised the algorithm reflected in the PSC, which the more capable students mastered and implemented. Figure 6.2 shows Fidel going through the steps he expected his students to follow when doing investigations. This was witnessed during the pre-practical conference of the first practical session observed during the data collection phase. This was at the beginning of the term and Fidel seemed to be reminding the students, after a long school holiday, what he expected of them with respect to investigations. I also felt that he was doing it as a response to my presence, that is, he wanted to show me that he was doing enough to guide his students as investigations were concerned. While this picture is a relevant piece of evidence, one should keep in mind the researcher's influence during the practical session where it was taken.

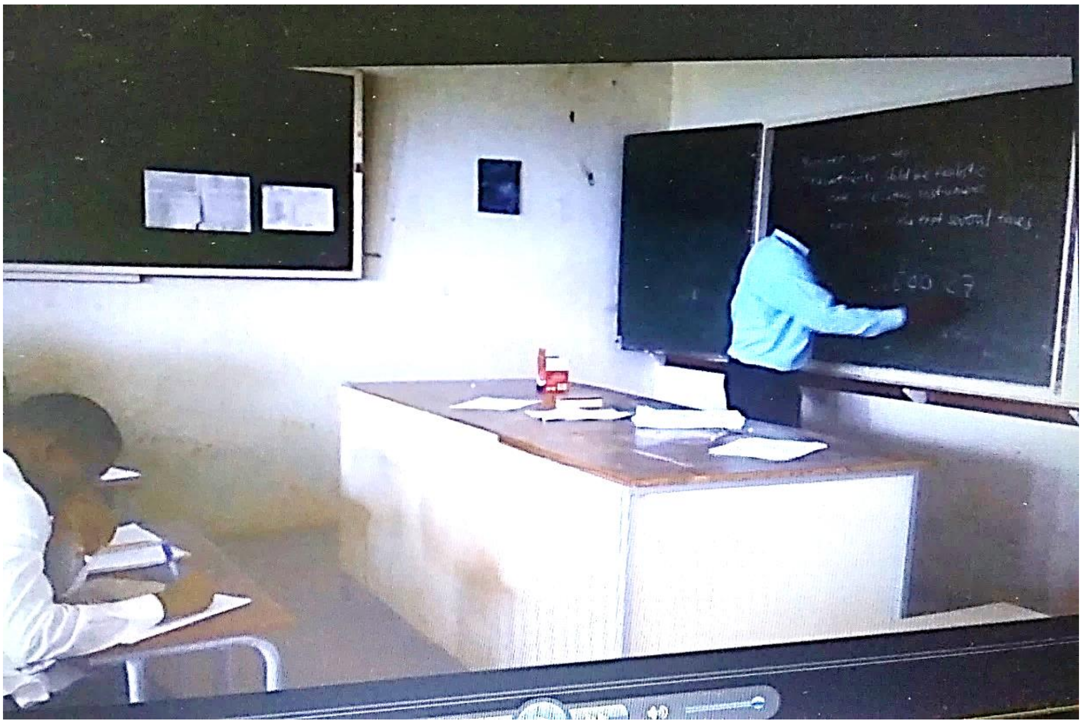


Figure 6.2 Fidel outlining the steps in doing investigations

There was consensus during the focus group discussions that the teachers were doing a great job in preparing students for investigations. This could have been a further contributing factor influencing their choice of a strategic approach. They remembered and executed what their teachers expected them to do when designing, planning and carrying out investigations. Part of a conversation with STD23 during third focus group discussion is representative of how appreciative the participants were of their teachers work.

STD23: The teacher teaches so well that we are able to tackle this kind of questions.

Tami: All credit to him. You don't claim any credit for that.

STD23: Just a little bit.

(Focus Group Discussion 3, June 04, 2015)

During the focus group discussions, students expressed how instructional strategies influenced their approaches. One student said,

I think the way in which we were taught when we started doing the investigations was good. I follow the steps that we were taught by our teacher and we imagine what the results should look like while we are designing and planning the experiments. ….. I also relate the

> investigations to the theory that we do in order to make sense of the results. (STD33, Focus Group Discussion 5, June 04, 2015)

A total of 11 students who showed a deep or strategic approach based on the ASIIS and DUQ data were then categorised as using a linear or divergent approach when their scripts were analysed. It is possible that while they felt they knew the theory involved, designing and planning the investigations remained a huge challenge to an extent that they preferred the recipe type of practical work. This implies that their process skills (procedural knowledge), especially the integrated ones, were not sufficiently developed. Some of the participants were not shy to express their weakness with respect to investigations:

> I don't think it's easy for me because I find it easy to just follow instructions than design and plan my own. I don't usually perform very well in designing because sometimes like I would not know what the examiner would be expecting from me so I just find myself guessing. But when instructions are given you are following writing everything that you see that's all. (STD15, Focus Group Discussion 2, June 04, 2015)

Shortcomings in data collection, especially when they were dealing with reactions in which colour changes were involved, were a concern to some participants. This was more pronounced in investigations involving titrations.

> You can be asked to design or plan an investigation where you have to observe the colour and you are not quite sure whether you have reached that kind of colour that you are expected to get. Whether it is a pale or dark colour they want. So, you realise that the titre value that you are going to get is far away from the one they want. So, you can score less marks whilst you know what to do but not knowing the right time to stop adding the titre. (STD49, Focus Group Discussion 7, June 04, 2015)

Challenges with procedural knowledge extended to data processing and interpretation. They found it difficult to decide what calculations to perform. Stoichiometry was a hurdle irrespective of the syllabus component they were dealing with. The following conversation from the eighth focus group discussion was revealing.

Tami: You said you don't do well in investigations of a quantitative nature, why?

STD36: Quantitative because it requires a lot of thinking compared to qualitative because of the calculations.

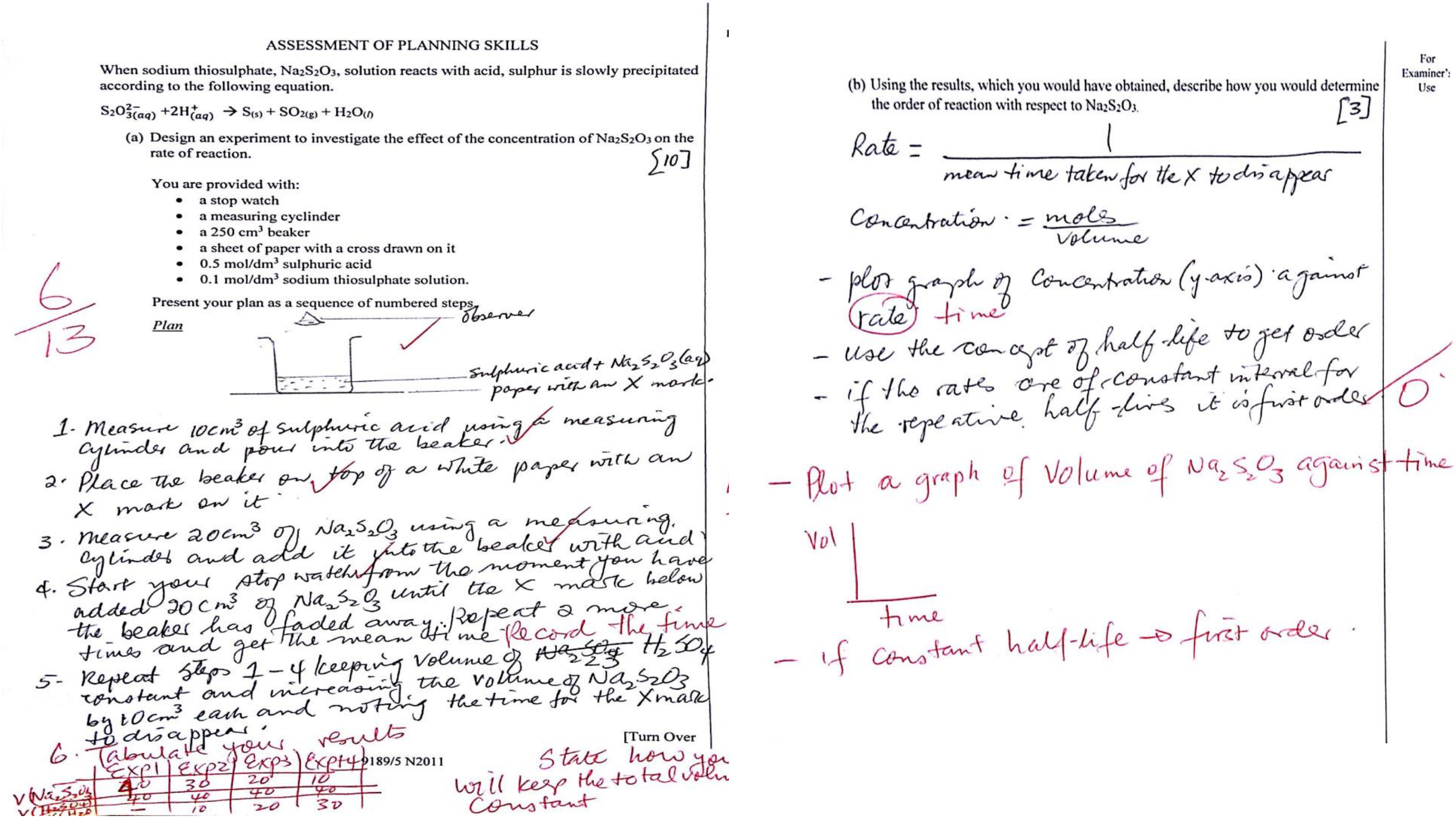
STD27: We are comfortable with the calculations but we are not very good at processing our results.

Tami: So, you collect your data and you don't know what do to with it? Do you generally perform badly in calculations even in the theory sections of your syllabus?

STD45: Yes, specifically stoichiometry. (All of them nod their heads in agreement)

(Focus Group Discussion 6, June 4, 2015)

Students' shortcomings with data processing were encountered frequently during the analysis of the participants' scripts. The teachers' comments on the marked scripts also referred to these shortcomings. The direct consequence of this shortcoming was that the interpretation of results was often incorrect or not done at all. This meant the resultant strategy could be linear, if students had some knowledge; or divergent, if students did not have any relevant knowledge required for successful data processing. Figure 6.3 shows one marked script where the student had challenges with planning as well as data recording, processing and interpretation.



ASSESSMENT OF PLANNING SKILLS

When sodium thiosulphate, $Na_2S_2O_3$, solution reacts with acid, sulphur is slowly precipitated according to the following equation.

$S_2O_{3(aq)}^{2-} + 2H_{(aq)}^{+} \rightarrow S_{(s)} + SO_{2(g)} + H_2O_{(l)}$

(a) Design an experiment to investigate the effect of the concentration of $Na_2S_2O_3$ on the rate of reaction. [10]

You are provided with:

- a stop watch
- a measuring cyclinder
- a 250 cm³ beaker
- a sheet of paper with a cross drawn on it
- 0.5 mol/dm³ sulphuric acid
- 0.1 mol/dm³ sodium thiosulphate solution.

Present your plan as a sequence of numbered steps.

*Plan*

6/13

Observer
Sulphuric acid + $Na_2S_2O_3$(aq)
paper with an X mark.

1. Measure 10cm³ of sulphuric acid using a measuring cylinder and pour into the beaker.
2. Place the beaker on top of a white paper with an X mark on it.
3. Measure 20cm³ of $Na_2S_2O_3$ using a measuring cylinder and add it into the beaker with and
4. Start your stop watch from the moment you have added 20cm³ of $Na_2S_2O_3$ until the X mark below the beaker has faded away. Repeat 2 more times and get the mean time Record the time
5. Repeat steps 1 – 4 keeping volume of ~~$Na_2S_2O_3$~~ $H_2SO_4$ constant and increasing the volume of $Na_2S_2O_3$ by 10cm³ each and noting the time for the X mark to disappear.
6. Tabulate your results

| | Exp1 | Exp2 | Exp3 | Exp4 |
|---|---|---|---|---|
| V $Na_2S_2O_3$ | 40 | 30 | 20 | 10 |
| V ($H_2SO_4$) | 40 | 40 | 40 | 40 |
| V ($H_2O$) | — | 10 | 20 | 30 |

State how you will keep the total volume constant

[Turn Over

9189/5 N2011

(b) Using the results, which you would have obtained, describe how you would determine the order of reaction with respect to $Na_2S_2O_3$. [3]

Rate = 1 / mean time taken for the X to disappear

Concentration = moles / Volume

- plot graph of Concentration (y-axis) against ~~rate~~ time
- use the concept of half-life to get order
- if the rates are of constant interval for the repeative half-lives it is first order

0

- Plot a graph of Volume of $Na_2S_2O_3$ against time

Vol / time

- if constant half-life → first order.

For Examiner's Use

Figure 6.3 STD48's marked script with teacher's comments in red

There was a notable difference in how students approached quantitative and qualitative investigations. Investigations of a qualitative nature were deemed more manageable because of the access to the notes for qualitative analysis. This enabled the students to produce good plans of the experimental procedure by referring to the given table of notes since they didn't have to memorise all the reactions and colours of the different products. The participants were also likely to be iterative in their approaches since they had some notes to refer to, which enhanced their chances of identifying errors and changing the procedure in the event of unsuccessful investigations. If the investigations were of a quantitative nature (that is, involving reaction rates, energy changes, volumetric analysis and others), success depended on how much substantive knowledge they carried in their heads. For example, in rates of reactions, they needed to remember the definition and graphical representation of a first order reaction in order to successfully design, plan and carry out a related investigation. A weak understanding of first order reactions would normally lead to a divergent approach or a linear approach while the more capable students would show iteration in their approach. STD7 expressed this common sentiment during the second focus group discussion.

> I think in qualitative analysis, it is easier to do the investigations since we are provided with the qualitative analysis notes unlike in quantitative analysis where we do not have any notes. You have to use your theoretical understanding and try to link it to the investigation. (STD11, Focus Group Discussion 2, June 04, 2015)

## 6.3 Discussions of findings

Two research questions were answered in this chapter. The first of them was about A-Level chemistry students' understanding of investigations. Within the literature reviewed, there are a number of different definitions or understandings of investigations and their relationship to practical work. In this study, I found a similar trend with a multitude of meanings. One group of students referred to an investigation as inquiry based practical work by describing it as a type of discovery learning, how scientists work and how science knowledge is generated seemed to agree with Woolnough and Allsop (1985) who also went further to highlight the open-endedness nature of such practical work. However, the idea of discovery learning has been challenged by some educators among them Millar (1989) who argue that students may fail to 'discover' what is intended making it problematic. Also in line with inquiry was the idea that an investigation is a practical activity designed by oneself. This is supported by the more recent definition of an investigation put forward by Millar (2010) which recognises that this type of practical work gives students greater autonomy in designing, planning and execution. A few students reported that investigations were problem solving activities, an understanding put forward by Gott and Duggan (1995) and Woolnough and Allsop (1985).

Another group of students defined or described an investigation in terms of one process skills or the other (experimenting, observing, hypothesising and inferring), which formed part of the definition suggested by Millar (2010). It was also evident during the focus group discussions that while participants could not always accurately express in their own words how they understood investigations, they were ready to accept Millar's definition as they found it to be in line with their thinking and experiences. It can therefore be inferred that the participants' understandings were self-constructed rather than learned from textbooks and/or discussions with their chemistry teachers, otherwise there would have been more uniformity in their responses in the DUQ.

The role of investigations in chemistry education was understood by all participants in a variety of ways that were all supported by literature. The most common of these was the development of process skills and higher order cognitive skills as put forward by Gott and Duggan (1995), and Moeed (2013). All the participants intended to study for either a medical or engineering degree at university and nearly 50% of them were convinced doing investigations gave them skills that were required at tertiary level and in their careers. A further 34% pointed out that by doing investigations they acquired skills which were applicable in everyday life. Cumming (2002) argued for the need for developing scientific literacy and this was certainly appreciated by a few of the participants.

The role of investigations in deepening conceptual understanding through hands-on-minds-on activities was highlighted by 34% of the participants. This is similar to the view of Cumming (2002) who acknowledges the constructivist orientation of investigations through promoting discovery learning. The participants seemed to appreciate that investigations advance the notion of meaningful learning (Hodson, 1990; Roberts & Gott, 2004) as a form of experiential learning (Moeed, 2013; So, 2003). Such an epistemological belief about learning science through investigations can only be developed in constructivist learning spaces (Chai, 2010).

The second research question addressed in this chapter is about why students approached investigations the way they did. The broad assertion crafted to answer this question was composed of three sub assertions covering the need to succeed in examinations, instructional strategies, prior chemistry practical experiences as well as knowledge of relevant chemistry topics and competence in process skills. Success in the final examinations seemed to influence students' approaches to investigations the most, as it permeated through all the other factors.

The participants were in agreement that the instructional strategies employed by their chemistry teachers were instrumental in developing the requisite process skills and theoretical understanding. This would normally lead to a predominantly deep approach but the data from the focus group discussions suggested that the need to score high marks in the practical examination and achieve the highest possible overall grade influenced most of students to adopt a strategic approach (Figure 4.1). Based on what one of the teachers said about the need for the students to get A's in the final examination (Fidel interview, 4 June, 2015), there is a likelihood that this focus on achieving good grades might have influenced his own instructional strategies which in turn translated into the adoption of the strategic approach by most of the students. Studies in the UK (Abrahams, 2005; Nott & Wellington, 1999) have established that teachers and students respond to the assessment demands placed on them by employing instructional strategies and approaches which they feel will result in good grades. The influence of examinations was also reported by Moeed (2010) when he explored the links between learning, motivation and internal assessment in New Zealand secondary schools.

In a separate study, Laurillard (2005) also asserted that students adopt a rational approach (to investigations) as dictated by the prevailing priorities. The rational approach in the context of the current study appears to be strategic, with elements of deep learning (deep-strategic), given the focus on achieving high grades.

The qualitative data obtained from the DUQ and focus group discussions for this study also provided further insight into the participants' cognitive processes when they do investigations. While Gijbels et al. (2005) described the displaying of characteristics from two different approaches as disintegrated or dissonance, I prefer to refer to them as *compound* approaches. This is because the deep-strategic participants showed that they had a strong theoretical understanding of the concepts related to the investigations they did but were also conscious of the examiners' or their teachers' expectations. Those who came across as surface-strategic were clear in their minds that their strategy was to remember experimental procedures done before as well as follow their teachers' instructions to the letter.

There seems to be carefully planned scaffolding (Chin & Brown, 2000) by the chemistry teachers to assist their students to master the process skills for them to be competent in doing investigations. It seems the instructional strategies encourage reflective practice (Roberts et al., 2010) leading to an iterative approach from a designing perspective. Based on the evidence gathered for the current study during the pre- and post-practical conferences, there was an element of drilling in an effort to help students internalise the stages of the PSC with constant reference to examiner's expectations. This was reinforced by the overreliance on past examination papers that was witnessed throughout the data collection period and supported by the qualitative data collected. The use of past examination papers was seen as a way to adhere to the standard of investigations recommended in A-Level chemistry syllabus. The chemistry teachers' reference to 'dirty work', 'neatness' and 'a lot of crossing' during feedback sessions can be linked to the relatively high frequency of the linear approach based on the analysis of students' scripts as described in chapter five. It is possible that the lack of evidence for the iterative approach in the scripts of some students who had been classified as such using data from the DUQ can be linked to the teachers' insistence on neatness. Alternatively, students did rough drafts of their designs and experimental procedures on separate pieces of paper and then transferred their final drafts to the scripts that were handed in for marking. Overall, a hybrid *strategic-iterative* emerged as the dominant approach to investigations.

The use of individual work stations coupled with time restrictions seemed to create conditions reminiscent of the final examinations resulting in some being inclined to work without consulting anyone even when they knew they did not know how to do the investigations. In the absence of co-operative work, some students seemed capable of coming up with only one way of doing a particular investigation where they failed to deal with any limitations thus reflecting a linear approach. In the worst cases, the students then used a divergent approach as reflected in the analysis of scripts. These working conditions possibly created psychological hurdles (Watts (1994) which affected students' beliefs about their self-efficacy when they do investigations.

The analysis of the scripts also showed that higher marks were achieved by students who worked iteratively on their own and some who were classified as linear. It can therefore be argued that the more capable students have a linear approach to standard investigations (those they find easy). However, if they find the investigations difficult they adopt an iterative approach as they see something wrong and retry.

In their study Gijbels et al. (2005) observed that students' approaches were a response to the learning context created by their teachers and this seemed to be the case with A-Level chemistry students. As Laurillard (2005) put it "the teacher plays an important part in forming their perceptions of what is required and what is important" (p. 144). The recipe type and confirmatory nature of the investigations done at O-Level and below highlighted by some of the participants during all the focus group discussions may have deprived the students of opportunities to develop integrated process skills before enrolling for A-Level. This meant that they were ill-prepared to deal with investigations resulting in some of them having a linear or divergent approach (Table 5.2).

Roberts et al. (2010) identified a skills gap in pre-service teachers that was inherited from school. An identical skills gap, with respect to process skills, was a common worry highlighted by the participants as they move from O-Level to A-Level Chemistry. The nature of the assessment of practical skills at lower levels appears to be a key contextual factor which influences how practical work is done Biggs (1991). The schools' decision to opt for the economical Alternative to Practical Examination in O-Level Chemistry has possibly conditioned both teachers and students to focus on the theoretical aspects of the subjects even though investigations are emphasised in the corresponding syllabus (ZIMSEC, 2012c). This has possibly been a contributing factor to the observed and reported challenges with substantive and procedural knowledge at A-Level in this study. The students' self-efficacy in investigations at A-Level was therefore, to some extent, shaped by their prior learning (Li et al., 2013). Students' competence in the five types of knowledge (facts, concepts, strategies, procedures and beliefs) to do investigations as problem solving practical activities (Mayer & Wittrock, 2006) becomes more influential at A-Level. Conditions in previous grades had led to the underdevelopment of procedural knowledge which Hammann et al. (2008) consider to be key to success in investigations. Sound procedural knowledge ensures that students are able to systematically design, plan and carry out investigations with reflective practice and iteration.

## 6.4 Conclusion

In this chapter, two research questions were answered. First, students understood an investigation to be inquiry based practical work serving multiple roles. The predominant understandings of an investigation were that it is a form of discovery learning, it is how scientists work, and it is a problem-solving type of practical work. According to the students, the multiple roles served by investigations were: to develop process skills; to prepare students for future studies and professional life; to develop higher order cognitive abilities and deepen conceptual understanding. The affective value of investigations was only mentioned by a few students.

Second, the findings on why students approached investigations the way they did showed that success in examinations had a major influence. Instructional strategies, students' prior chemistry experiences as well their knowledge of chemistry topics and competence in process skills were the other contextual factors which influenced their approaches. These contextual factors led to the use of approaches which were deemed to be effective in achieving good results in public examinations. This resulted in combinations of approaches such as deep-iterative, strategic-iterative, strategic-linear, surface-linear and surface-divergent. The conditions under which the investigations were done did not always support the students' preferred approaches.

Having provided responses to the questions that guided this study, in the next chapter, I summarise the findings, revisit the theoretical framework and research design before presenting the research implications.

# CHAPTER 7
# SUMMARY, LIMITATIONS AND IMPLICATIONS

The purpose of this study was to explore A-Level chemistry students' approaches to investigations. The foci of the study were the students' approaches to investigations from both learning and designing perspectives, their (students) understandings of investigations and why they approached them the way they did. This chapter's purpose is to present a summary of the methodology, findings, a discussion of the implications of the study and the relevant recommendations for educators and further research.

## 7.1 Summary of the methodology and methods used

A pragmatic paradigm was adopted for this study with the consequential use of a mixed methods approach (Creswell, 2013). In the absence of a fitting mixed methods research design, a quasi-convergent parallel design was crafted to accomplish this study. A purposive sample of 50 students and two teachers acted as the participants of this study. Quantitative data was collected through a Likert scale type of survey questionnaire to determine their approaches to investigations from a learning perspective. Qualitative data was collected through a semi-structured questionnaire (DUQ), focus group discussions, document analysis (scripts and textbooks) and classroom observations. While all 50 participants responded to the DUQ, only 32 (in groups of four) were involved in the focus group discussions. Part of the data from these two data sources was systematically used to determine the approaches to investigations from a learning perspective which allowed for triangulation (Cohen et al., 2011). The rest of the qualitative data was then used to determine the students' approaches to investigations from a designing perspective, their understanding of investigations and why they approached this type of practical work the way they did. Given that not all the qualitative data was transformed into quantitative data but that some of it was used to address the qualitative research questions of this study, this amounted to a deviation from the conventional convergent parallel design.

## 7.2 Limitations of the study

This study used a quasi-convergent parallel mixed methods design. While this methodological approach has been explained, and justified by the researcher in chapter three of this thesis, it is acknowledged that the research design is subject to scrutiny and refinement. A purposive sample of 50 A-Level chemistry students from two neighbouring schools. While the context in which Zimbabwean high schools offering A-Level Chemistry operate is similar, contextual factors, such as the instructional strategies used by the chemistry teachers may be different to those in other schools thereby limiting the scope of the qualitative data obtained from the completed semi-structured questionnaires and focus group discussions. This naturally affects the extent to which the findings of this study can be generalised.

Piloting of the ASIIS and DUQ was done prior to the main data collection process to ascertain their validity. However, these instruments could be improved given the differences in the data collected. The data collection lasted only one school term, a trimester. Perhaps a longer data collection period would have resulted in more investigations observed and preparation and post lectures could be attended which would have improved my understanding of the students' approaches.

## 7.3 Summary of the findings

A synopsis of the findings of this study is outlined in sections covering each of the research questions. Based on both the quantitative and qualitative data collected from the participants, assertions were formulated to represent the study's major findings. A graphical presentation of a summary of the findings is shown in Figure 7.1.

***Research question 1*: How do students approach investigations from a learning perspective?**

The findings from all the data sources of this study revealed that the majority of the participants were inclined towards the strategic approach, a few towards the deep approach and none came across as predisposed towards the surface approach. Moving from the survey questionnaire data to the semi-structured data, the proportion of students classified under the deep based on the survey questionnaire was greater than from the semi-structured to focus group data. The predominance of the strategic approach confirmed findings reported in studies on Chinese (Biggs, 1991) and Malaysian students (Nordin et al., 2013). In some cases, the students' approaches from the different data sources did not match. This is in line with an assertion by Gijbels et al. (2005) who argued that students tend to employ a mix of approaches and that approaches to learning can be viewed as dynamic.

An analysis of the A-Level chemistry students' preferences for teaching and practical examinations showed that they preferred to do investigations which developed independent thinking and teaching strategies which supported this. This view of teaching and learning by doing investigations seemed to explain the generally high mean agreement scores ($M > 4.00$) for the deep approach even though the students who were viewed as strategic.

***Research question 2*: How do students approach investigations from a designing perspective?**

Most the students used an iterative or linear approach in designing, planning and carrying out investigations. While there were notable differences in the number of students falling under each approach based on the DUQ and focus group data, an analysis of scripts produced approximately the same number of students classified under the iterative and linear approaches. These differences possibly mean that the participants were probably aware of the iterative approach to investigations but did not always implement it in practice. An 80% match between the approaches based on the data from the semi-structured questionnaire and analysis of scripts was a cause to believe that the findings were reliable. The high frequency of the iterative approach in this study is not in line with earlier studies which reported fewer students using this approach due to deficiencies in process skills (Ercan & Tasdere, 2011; Hammann et al., 2008; Kanari & Millar, 2004). This may be because Zimbabwean A-Level chemistry students are select group of high achievers from O-Level.

A consolidation of the findings on the approaches to investigations from both perspectives produced hybrid approaches, namely deep-iterative, deep-linear, strategic-iterative, strategic-linear, surface-linear and surface-divergent. The dominant approaches were found to be the strategic-iterative, deep-linear, deep-iterative and strategic linear in descending order.

***Research question 3*: What are the students' understandings of investigations?**

The students' understanding of an investigation is that it is inquiry based practical work serving a variety of roles. The predominant understandings of an investigation were that it is a form of discovery or experiential learning, it is how scientists work, a practical activity where the experimental procedure is not given and a problem-solving type of practical work. These understandings of an investigation are captured in the working definition proposed for this study with ideas drawn from Gott and Duggan (1995), Millar (2010), and Woolnough and Allsop (1985). The students also understood investigations as playing multiple roles. These were: to develop process skills; to prepare students for future studies and professional life; to develop higher order cognitive abilities and deepen conceptual understanding. Very few students gave responses associated with the affective value of investigations, which was not surprising given that the majority of them were strategic in their approach to investigations. Investigations were not viewed as activities that made doing science enjoyable but as necessary learning activities which would enable one to achieve good grades in the final examinations.

***Research question 4*: Why do students approach investigations the way they do?**

A number of factors shaped the A-Level chemistry students' approaches to investigations but success in examinations dominated. The approaches were influenced by their chemistry teachers' instructional strategies. The chemistry teachers were found to be over reliant on past examination papers as their source of investigations. The teachers tended to drill the students on how they should approach investigations. The teachers' preferred approach resembled the stages of the PSC (Roberts et al., 2010). The teachers didn't seem to be aware of the PSC but used examiners' reports to explain to their students how they should design, plan and carry out investigations. This was done during the pre- and post-practical conferences where the teachers oriented students on the investigations of the day or gave feedback on those already done. This teaching strategy consequently reinforced a strategic approach in the majority of the students. The inadvertent emphasis on the stages of the PSC resulted in the practising of the iterative approach by a relatively large proportion of the participants. With most of the students concurring that time was often a constraint during their practical sessions, it was not surprising that the linear approach was slightly more frequent than the iterative approach based on data from script analysis.

The competitive nature of the educational context of this study influenced students to adopt a more strategic approach in a bid to achieve high marks in the practical examination. Given the existence of only two universities in the country offering degrees in the medical and engineering fields, only the best stood a chance of getting places to study their preferred degree programmes. Such a scenario was also reported by Moeed (2010) in the Australian context. To compound this, the schools' prize giving days only recognised one student per subject per year group, resulting in fierce competition between students, consequently favouring a strategic approach.

In the Zimbabwean educational context, Chemistry is studied as an independent subject from O-Level where many schools opt for the Alternative to Practical examination for economic and logistical reasons. These meant that most of the chemistry teaching at this level was effectively theoretical as there was no pressure to do practical work. The textbooks used at this level do not emphasise on students designing, planning and carrying out investigations although it is a syllabus requirement. Most of the practical work found in the textbooks comes with full experimental procedures. This shortcoming in the teaching and learning materials meant that most, if not all, the practical work done under O-Level Chemistry was of the recipe type since the teachers depended on the available textbooks and past examination papers to plan their lessons. The participants of this study therefore cited poor preparation from O-Level as one of the reasons they approached investigations the way they did.

This study found out that when students felt comfortable with the theoretical aspects of Chemistry, they were more inclined to use deep and iterative approaches although other contextual factors often led to the use of strategic and linear approaches. The limited practical work done at lower levels meant that students enrolled for A-Level Chemistry with limited process skills (procedural knowledge) and hence struggled to design, plan and carry out investigations independently. A linear approach was therefore more prevalent in practice. A graphical summary of the findings of this study is shown in Figure 7.1.

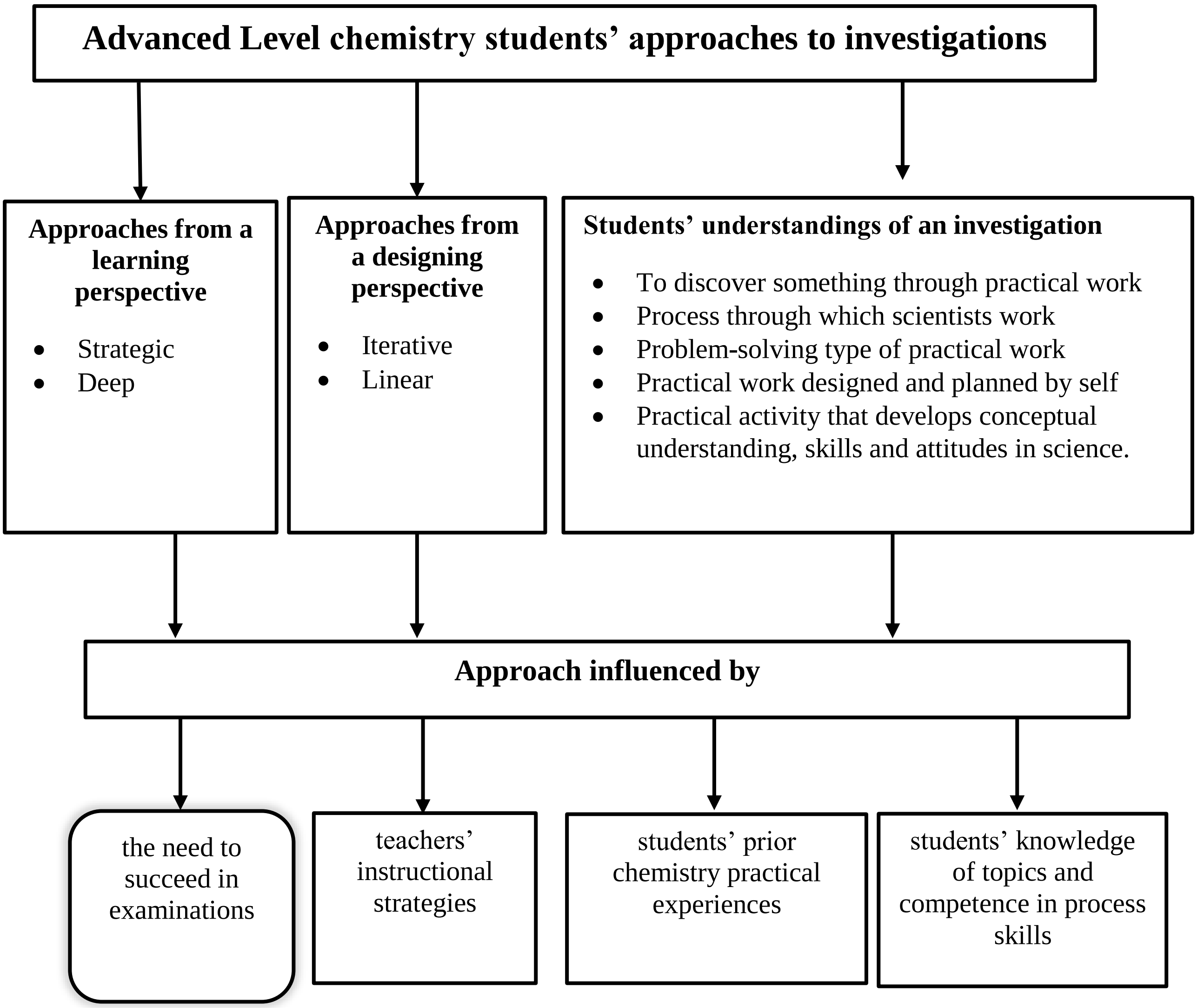



Figure 7.1 A graphical summary of the findings

## 7.4 Implications for Chemistry teachers

Exploring A-Level chemistry students' approaches unearthed findings which are potentially useful for chemistry education particularly in the context of this study. The findings touch on both chemistry curriculum design and implementation with respect to practical work and investigations in particular.

The procedural knowledge deficiencies, which lead to the less favourable linear and divergent approaches could be minimised by subscribing to the practical examination rather than the Alternative to Practical option at O-Level. The Alternative to Practical is a theoretical examination were students are not required to the actual practical activities.

Subscribing for the practical examination would guarantee that students at this level do more practical work ahead of the examination, thus developing the much-needed process skills which are relevant for designing, planning and carrying out investigations at A-Level. Given that the O-Level chemistry textbooks have a lot of guided investigations and other practical activities whose experimental procedures are fully described, there is an opportunity for chemistry teachers to twist some of them into unguided investigations. Doing more investigations as per the syllabus specifications would assist in promoting the more ideal deep and iterative approaches.

An introduction to practical work in Chemistry at A-Level should include a treatment of the different types of practical work ranging from demonstrations, experiments and the different forms of investigations. It is my assumption that students with a good theoretical understanding of an investigation, and how different it is from other forms of practical work, would be more inclined towards deep and iterative approaches. If students are aware of the purpose of investigations, their chances of approaching them in ways that satisfy this purpose will be enhanced.

The teaching and learning context is heavily influenced by the nature of the assessment of practical skills. Perhaps a shift from the current examination structure, with a final practical examination, to a school based assessment of practical skills through long term science investigation projects would be a better option. This mode of assessing practical skills has been implemented successfully in the United Kingdom. Given that the A-Level Chemistry is adapted from the one designed by UCLES, there is a chance that this can work in the context in which this study was undertaken. However, this would require action research with a few selected high schools as the first step in bringing about this change in the assessment structure. Based on lessons learnt from such a pilot project, the school-based assessment would then be extended to all the high schools offering the subject. Doing long term investigation projects, especially where students have full autonomy, allows students to work like real scientists do in the professional world (Woolnough & Allsop, 1985). Arguably, long term investigations would help promote the iterative approach and deep learning of the science concepts involved. The existence and thought of a high stakes practical examination tends to compel student to adopt a strategic approach which is often coupled with a linear approach when time is limited. Science fairs (expos) are a proven way of developing process skills through projects as part of a competition. Participation in science fairs gives students opportunities to develop higher order cognitive skills including integrated process skills such as designing and planning investigations with greater autonomy (Ramnarain, 2011). Another advantage of science fairs is that science projects are done in a social environment without the pressure of academic grades. Projects for science fairs, especially if done starting from lower high school levels, would give students better preparation for A-Level chemistry practical work and help develop more effective approaches.

## 7.5 The hybrid approaches

Research in investigations has largely focused on students' competences in the various process skills (Germann et al., 1996), the level of autonomy students have when doing this type of practical work (Ramnarain, 2011) and the role of substantive and procedural knowledge (Roberts et al., 2010). Although the study by Roberts et al. (2010) was insightful and led to the identification of approaches from a designing perspective (iterative, linear and divergent), the links with what students learned from investigations was not apparent. Research by other scholars (Biggs, 1987b, 1991, 1999; Entwistle, 2004) explored and/or explained students' approaches to learning (deep, strategic and surface) in general within subject domains or collections of these at various educational levels. Many of these studies have been exclusively quantitative or qualitative and they generally acknowledged that students' approaches to learning are dynamic and depend on, among other factors, the nature of the tasks. In the wake of this assertion, this mixed-methods study focused on a specific component of A-Level Chemistry and brought together two theoretical frameworks in one study, that is, approaches to investigations from a learning and designing perspectives.

The consolidation of two perspectives in exploring how A-Level chemistry students approach investigations led to the emergence of what I refer to as *hybrid approaches.* This categorisation of approaches to investigations was borne out of combining each student's approaches from learning and designing perspectives. This categorisation also recognises that investigations have two major foci, deepening of conceptual understanding and the development of process skills. A characterisation of the hybrid approaches has been done to assist with framing future research on approaches to investigations. The characterisation was done drawing from the ideas of Houghton (2004) and extending the adaptation reflected in Table 2.3 by incorporating what has been learned through this study. The *hybrid approaches* that emerged from the findings of this study are deep-iterative, deep-linear, strategic-iterative, strategic-linear, surface-linear and surface-divergent. The emergent hybrid approaches and their characteristics are shown in Appendix L. Table 7.1 shows a section of Appendix L illustrating how the deep-iterative hybrid approach is characterised.

Table 7.1 Exemplar characterisation of the hybrid approaches to investigations

| **Approaches** | **Characteristics** | **Encouraged by students who have/are:** | **Encouraged by teachers who:** |
|---|---|---|---|
| Deep-iterative | - students focus on developing good substantive and procedural knowledge required to successfully do investigations<br><br>- students successfully apply the problem-solving chain<br><br>- students construct knowledge through doing investigations<br><br>- students relate new and previous knowledge gained through investigations and otherwise<br><br>- students can link investigations to real life and the everyday work of real scientists | - a desire to do investigations driven by intrinsic curiosity<br><br>- sound and appropriate substantive and procedural knowledge which is required to do investigations<br><br>- a positive view of investigations leading to high confidence in ability to do them<br><br>- an ability to identify errors in designing, planning and execution of investigations | - demonstrate good understanding and personal interest in investigations<br><br>- relate new material to what students already know and understand as well as linking theory to investigations<br><br>- bring out the structure of the subject and role of investigations in Chemistry education<br><br>- adopt active (hands-on-minds-on) teaching and learning approaches and confront students' weaknesses in substantive and procedural knowledge<br><br>- use investigative problems that are thought provoking and incorporate concepts from different topics of the subject |

The characterisation of these approaches needs refinement through further research. It is also worth noting that while the majority of these approaches were detected in this study, the surface-linear and surface-divergent categories did not manifest but were theoretical extrapolations made based on the trends in the data. As has been highlighted under the perceived limitations of this study, it is my assumption that larger samples will result in the manifestation of all the hybrid approaches, including surface-linear and surface-divergent.

## 7.6 Conclusions

Doing this study led me to extend my theoretical understanding of how students approach investigations at high school level. As a point of reflection, I found students' approaches to be heavily influenced by contextual factors associated with a third world country with limited opportunities for tertiary education. It was also ironic that one of the findings of this study was that the majority of the students used the iterative approach when doing investigations. This mirrors in many respects how I experienced this study. It was an iterative process characterised by many false starts, revisions and changes based on experience, and the generation and refinement of new ideas based on the findings. This approach is valued as it has, in my view, strengthened the validity and reliability of the answers to my research questions.

## REFERENCES


Abrahams, I. (2005). *Between rhetoric and reality: The use and effectiveness of practical work in secondary school science*. Unpublished PhD Thesis. University of York, UK.

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science *International Journal of Science Education, 30*(14), 1945-1969. doi:10.1080/09500690701749305

Abrahams, I., & Reiss, M. J. (2012). Practical work: Its effectiveness in primary and secondary schools in England. *Journal of Research in Science Teaching, 49*(8), 1035 –1055.

Abrahams, I., Reiss, M. J., & Sharpe, R. M. (2013). The assessment of practical work in school science. *Studies in Science Education, 49*, 209-251.

Abruscato, J. (2000). *Teaching children science: A discovery approach* (5th ed.). Needham Heights, MA: Allyn & Bacon.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1-12.

Angus, D. (2004). The revised approaches to studying inventory (RASI) and its use in management education. *Active learning in higher education*, *5*(1), 56-72.

Aydin, A. (2013). Representation of science process skills in chemistry curriculum for grades 10, 11 and 12/Turkey. *International Journal of Education and Practice, 1*(50), 51-63.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: Freeman.

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology, 52*, 1-26.

Bazely, P., & Richards, L. (2000). *The NVivo qualitative project book*. London: Sage Publications.

Bell, J. (2010). *Doing your research project: A guide for first time researchers in education, health and social science*. Berkshire: Open University Press.

Biggs, J. B. (1987a). *Learning process questionnaire manual*. Melbourne: Australian Council for Educational Research.

Biggs, J. B. (1987b). *Student approaches to learning and studying*. Melbourne: Australian Council for Educational Research.

Biggs, J. B. (1987c). *Study process questionnire manual*. Melbourne: Australian Council for Educational Research.

Biggs, J. B. (1991). Approaches to learning in secondary and tertiary students in Hong Kong: some comparative studies. *Educational Research Journal*, *6*, 27-39.

Biggs, J. B. (1999). What the student does: Teaching for enhanced learning. *Higher Education Research and Development, 18*(1), 57-75.

Biggs, J. B., Kember, D., & Leung, D. Y. P. (2001). The revised two factor study process questionnaire. *British Journal of Educational Psychology, 71*(133-149).

Bilgin, A., & Crowe, S. (2008). Approaches to learning in statistics. *Asian Social Science, 4*(3), 36-42.

Blaxter, L., Highes, C., & Tight, M. (2006). *How to research.* (3 ed.). New York, NY: Open Unversity Press.

Briggs, J. G. R. (1997). *Chemistry for 'O' Level* (3 ed.). Singapore: Longman.

Buehl, M. M., & Alexander, P. A. (2001). Beliefs about academic knowledge. *Educational Psychology Review, 13*, 385-418.

Cano, F. (2007). Approaches to learning and study orchestrations in high school students. *European Journal of Psychology of Education, 22*(2), 131-151.

Carin, A. A., Bass, J. E., & Contant, T. L. (2005). *Methods for teaching science as inquiry.* (9th ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

Chai, C. S. (2010). Teachers' epistemological beliefs and their pedagogical beliefs: A qualitative case study among Singaporean teachers in the context of ICT-support reforms. *The Turkish Online Journal of Educational Technology, 9*(4), 128-139.

Chavunduka, K., & Zivanayi, W. (2013). *Step ahead physical science*. Cape Town: Pearson.

Chin, C. (2003). Facilitating science investigations: some suggestions for the teacher. *Teaching and Learning, 24*(2), 141-151.

Chin, C., & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching, 37*(2), 101-138.

Chin, C., & Kayalvizhi, G. (2002). Open-ended investigations in science: a case study of primary 6 pupils. *Journal of Science and Mathematics Education in Southeast Asia, 25*(1), 70-94.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7 ed.). London: Routledge.

Creswell, J. W. (2009). *Research design: qualitative, quantitative and mixed methods approaches.* Thousand Oaks, CA: Sage Publications.

Creswell, J. W. (2013). Steps in conducting a scholarly mixed methods study. Retrieved from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1047&context=dberspeakers.

Creswell, J. W., & Clark, V. L. P. (2011). *Designing and conducting mixed methods research* (2 ed.). Thousand Oaks, CA: Sage Publications.

Cumming, J. (2002). *An introduction to science investigations: Student teachers learning to work on process skills with children aged 4-11*. Paper presented at the Annual Conference of British Educational Research Asociation, University of Exter, London. http://www.leeds.ac.uk/educol/documents/00002393.htm

Cuthbert, P. F. (2005). The student learning process: Learning styles or learning approaches? *Teaching in Higher Education, 10*(2), 235-249. doi:1080/1356251042000337972

De Boer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York, NY: Teachers College Press.

Descombe, M. (2008). Communities of practice: A research paradigm for the mixed methods approach. *Journal of Mixed Methods Research, 2*(3), 270-283.

Dillon, J. (2008). A review of the research on practical work in school science. Retrieved from http://score-education.org/media/3671/review_of_research.pdf

Donnison, S., & Penn-Edwards, S. (2012). Focusing on first year assessment: surface or deep approaches to learning? *The International Journal of the First Year in Higher Education, 3*(2), 9-20.

Eick, C., Meadows, L., & Balkcom, R. (2005). Breaking into inquiry. *The Science Teacher, 72*(7), 49-53.

Entwistle, N. J. (1981). *Styles of learning and teaching: An integrated outline of educational psychology for students, teachers and lecturers*. Chichester: John Wiley.

Entwistle, N. J. (2004). Approaches to learning and levels of understanding: influences and responsibilities. Retrieved from http://www.ed.ac.u./etl/project/html

Entwistle, N. J., Hanley, M., & Hounsell, D. (1979). Identifying distinctive approaches to studying. *Higher Education, 8*, 365-380.

Entwistle, N. J., McCune, V., & Tait, H. (2013). *Approaches and study skills inventory for students (ASSIST): Report of the development and use of the inventories*. Retrieved from http://www.researchgate.net/publication/260291730_Approaches_and_Study_Skills_Inventory_for_Students_(ASSIST)_(incorporating_the_Revised_Approaches_to_Studying_Inventory_-_RASI

Entwistle, N. J., & Peterson, E. R. (2004). Conceptions of learning and knowledge in higher education: Relationships with study behaviour and influences of learning environments. *International Journal of Educational Research, 41*, 407 -428.

Entwistle, N. J., & Tait, H. (1994). *The revised approaches to studying inventory*. Edinburgh: University of Edinburgh Centre for Research on Learning and Instruction

Entwistle, N. J., Tait, H., & McCune, V. (2000). Patterns of response to an approache to studying inventory across contrasting groups and contexts. *European Journal of the Psychology of Education, 15*, 33-48.

Ercan, F., & Tasdere, A. (2011). Identification of teacher candidates' skills in designing experiments with various assessment tools. *Western Anatolia Journal of Educational Science.*, 231-238.

Espinosa-Bueno, J. S., Labastida-Pina, D. V., Padilla-Martínez, K., & Garritz, A. (2011). Pedagogical content knowledge of inquiry: An instrument to assess it and its application to high school in-service science teachers. *US-China Education Review, 8*(5), 599-614.

Felder, R. M., & Brent, R. (2005). Understanding students differences. *Journal of Engineering Education, 94*(1), 57-72.

Gallagher, J. J., & Tobin, K. G. (1991). Reporting interpretive research. In J. J. Gallagher (Ed.), *Interpretive research in science education* (Vol. 4). NARST Monograph: Kansas State University.

Geertz, C. (1983). *Thick description: towards an interpretive theory of culture*. New York, NY: Basic Books.

Germann, P. J., Aram, R., & Burke, G. (1996). Identifying patterns and relationships among the responses of seventh-grade students to the science process skill of designing experiments. *Journal of Research in Science Teaching, 33*, 79-99.

Gijbels, D., van de Watering, G., Dochy, F., & van de Bossche, P. (2005). The relationship between students' approaches to learning and the assessment of learning outcomes. *European Journal of Psychology of Education, 20*(4), 327-341.

Gott, R., & Duggan, S. (1995). Practical work: its role in the understanding of evidence in science. *International Journal of Science Education, 18*(7), 791-806. doi:10.1080/0950069960180705

Gott, R., & Duggan, S. (2007). A framework for practical work in science and scientifc literacy through argumentation. *Research in Science and Technology Education, 25*(3), 271-291. doi:10.1080/02635140701535000

Greene, J. C., Caracelli, v. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and Policy Analysis, 11*(3), 255-274.

Guba, E. G., & Lincoln, Y. S. (2005). Paradigmatic controversies, contradictions, and emerging confluences. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (3 ed., pp. 191-215). Thousand Oaks, California: Sage Publications.

Guthrie, G. (2010). *Basic research methods: An entry to socoial science research*. Thousand Oaks, California: Sage Publications.

Hackling, M. W., & Garnett, P. J. (1995). The development of expertise in science investigation skills. *Australian Science Teachers Journal, 41*(4), 80-86.

Hammann, M., Ehmer, M., Grimm, T., & Phan, T. T. H. (2008). Assessing pupils' skills in experimentation. *Journal of Biological Education, 42*(2).

Hammer, D., Russ, R., Mikeska, J., & Scherr, R. (2008). Identfying inquiry and conceptualising students' abilities. In R. Duschl & R. Grandy (Eds.), *Establishing a consensus agenda for K-12 science inquiry* (pp. 138-156). Rotterdam, NL: Sense Publishing.

Hodson, D. (1990). A critical look at practical work in school science. *School Science Review, 70*(256), 33-40.

Hodson, D. (1993). Rethinking old ways: towards a more critical approach to practical work in school science. *Studies in Science Education, 22*, 85-142.

Hodson, D. (2009). *Teaching and learning about science: language, theories, methods, history, traditions and values.* The Netherlands: Sense.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundation for the 21st century. *Science Education, 88*, 28-54.

Hogan, K. (1999). Relating students' personal frameworks for science learning to their cognition in collaborative contexts. *Science Education, 83*(1), 1-32.

Houghton, W. (2004). Engineering subject centre guide : Learning and teaching theory for engineering academics. Retrieved from http://creativecommons.org/licenses/by-nc-nd/2.5/

Jackson, S. J. (2008). *Research methods: A modularapproach*. Belmont, California: Thomson Wadsworth.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*, *33*(7), 14-26.

Kanari, Z., & Millar, R. (2004). Reasoning from data: How students collect and interpret data in science investigations. *Journal of Research in Science Teaching, 41*(7), 748-769.

Kasipillai, C. (1999). *Pure chemistry: Notes and questions*. Singapore: The Star Books Private Limited.

Kazembe, T. C., & Musarandega, A. (2012). Student performance in A-level chemistry examinations in Makoni District, Zimbabwe. *Eurasian Journal of Physics & Chemistry Education, 4*(1), 1-29.

Keiler, L. S., & Woolnough, B. E. (2002). Practical work in school science: The dominance of assessment. *School Science Review, 83*, 83-88.

Kennedy, J., Lyons, T., & Quinn, F. (2014). The contiunuing decline of science and mathematics enrolments in Australian schools. *Teaching Science*, *60*(2), 34-46.

Khan, S. (2007). Model-based inquiries in chemistry. *Science Education, 91*, 887-905.

Labbas, R. (2013). Epistemology in education: Epistemological development trajectory. *Journal of International Education and Leadership 3*(2), 1-10.

Laurillard, D. (2005). *Styles and approaches in problem-solving.* (F. Marton, D. Hounsell, & N. Entwistle Eds. 3 ed.). Edinburgh: University of Edinburgh, Centre for Teaching, Learning and Assessment.

Li, W. T., Liang, J. C., & Tsai, C. C. (2013). Relational analysis of college chemistry-major students' conceptions of and approaches to learning chemistry. *Chemistry Education Research and Practice, 14,* 555-565.

Lock, R. (1990). Open-ended, problem-solving investigations. *School Science Review, 71*(256), 63-72.

Lotter, C., Singer, J., & Godley, J. (2009). The influence of repeated teaching and reflection on preservice teachers' views of inquiry and nature of science. *Journal of Science Teacher Education, 20*(6), 553-582. doi:10.1007/s10972-009-9144-9

Lunetta, V. N., Hofstein, A., & Clough, M. P. (2007). Learning and teaching in the school science laboratory: An analysis of research, theory, and practice. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 393-441). New Jersey, NJ: Lawrence Erlbaum Associates.

Mahootian, F., & Eastman, T. E. (2008). Complementary frameworks of scientific inquiry: Hypothetico-deductive, hypothetico-inductive, and observational-inductive. *World Futures, 65*(1), 61-75. Retrieved from  doi:10.1080/02604020701845624

Mandina, S. (2012). An evaluation of Advanced Level chemistry teaching in Gweru district schools, Zimbabwe. *Asian Social Science, 8*(10).

Marshall, C., & Rossman, G. (2006). *Designing qualitative research* (4 ed.). Thousand Oaks, CA: Sage Publications.

Marshall, C., & Rossman, G. (2011). *Designing qualitative research* (5 ed.). Thousand Oaks, CA: Sage Publicataions.

Martin-Hansen, L. (2002). Defining inquiry. *The Science Teacher, 69*(2), 34-37.

Marton, F., & Saljo, R. (1976). On qualitative differences in learning: Outcome and process *British Journal of Educational Psychology, 46,* 4-11.

Maxcy, S. J. (2003). Pragmatic threads in mixed methods research in the social sciences: The search for multiple modes of inquiry and the end of the philosophy of formalism. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 51-89). Thousand Oaks, California: Sage Publications.

Mayer, R. E., & Wittrock, M. C. (2006). Problem solving. In P. A. Alexander & P. A. Winne (Eds.), *Handbook of educational psychology* (pp. 287-303). Mahwah, NJ: Lawrence Erlbaum.

McLelland, C. V. (undated). Nature of science and the scientific method. Retrieved 12 May 2014, from Geological Society of America http://www.geosociety.org/educate/NatureScience.pdf

McPherson, G. R. (2001). Teaching and learning the scientific method. *The American Biology Teacher 63*(4), 242-245.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation* (2 ed.). San Francisco, CA: Jossey-Bass.

Mertens, D. M. (2010). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative and mixed methods* (3 ed.). Thousand Oaks, CA: Sage Publications.

Miles, M. B., & Huberman, A. M. (1994). *An expanded sourcebook: Qualitative data analysis* (2 ed.). Thousand Oaks, CA: Sage Publications.

Millar, R. (1989). What is scientific method and can it be taught? In J. J. Wellington (Ed.), *Skills and processes in science education: A critical analysis* (pp. 165-178). London: Routledge.

Millar, R. (1997). *Students' understanding of the procedures of scientific enquiry*. York: Centre for Innovation and Research in Science Education, University of York.

Millar, R. (2004). *The role of practical work in the teaching and learning of science*. Paper prepared for the committee of high shool science laoratories: Role and Vision. Washington, DC: National Academy of Sciences.

Millar, R. (2009). *Analysing practical activities to assess and improve effectiveness: The practical activity analysis inventory (PAAI)*. York: Centre for Innovation and Research in Science Education, University of York.

Millar, R. (2010). Practical work. In J. Osborne & J. Dillon (Eds.), *Good practice in science teaching: What research has to say* (2 ed.). Maidenhead: Open University Press.

Moeed, A. (2010). *Science investigation in New Zealand secondary schools: Exploring the links between learning, motivation and internal assessment in year 11*. (PhD Thesis), Victoria University, New Zealand.

Moeed, A. (2011). Teaching to investigate in Year 11 science, constrained by assessment. *New Zealand Annual Review of Education, 20*(2010), 74-101.

Moeed, A. (2013). Science investigations that best supports student learning: Teachers' understanding of science investigation. *International Journal of Environmental and Science Education, 8*, 537-559. doi:10.12973/ijese.2013.218a

Moeed, A. (2015). *Science investigation: Student views about learning, motivation and assessment*. Singapore: Springer

Mogre, V., & Amalba, A. (2015). Approaches to learning among Ghanaian students following a PBL-based medical curriculum. *Education in Medicine Journal, 7*(1), 38-44.

Morgan, D. L. (2007). Paradgims Lost and Pragmatism Regained: Methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research, 1*(1), 48-76.

Nolen, A., & Talbert, T. (2011). Qualitative assertions as prescriptive statements. *Educational Psychology Review, 23*(2), 263-271.

Nordin, N., Wahab, R. A., & Dahlan, N. A. (2013). Approaches to learning among trainee teachers: Malaysian experiences. *Procedia - Social and Behavioral Sciences, 105*(2013), 284-293.

Nott, M., & Wellington, J. (1999). The state we're in: Issues in key stage 3 and 4 science. *School Science Review*, *81*(294), 13-18.

OECD. (2006). *Evolution of student interest in science and technology studies policy report*. Paris: Organisation for Economic Co-operation and Development Global Science Forum.

Onwuegbuzie, A. J., & Leech, N. L. (2005). On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies. *Interantional Journal of Social Research Methodology, 8*(5), 375-387. doi:10.1080/13645570500402447

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education, 25*(2), 177-196. doi:10.1007/s10972-014-9384-1

Ozgelen, S. (2012). Students' science process skills within a cognitive domain. *Eurasia Journal of Mathematics, Science and Technology Education, 8*(3), 283-292.

Padilla, J. M. (1990). The science process skills. *Research Matters - to the Science Teacher, 9004 (1 March 1990)*. Retrieved from https://www.narst.org/publications/research/skill.cfm

Patton, M. Q. (2002). *Qualitative evaluation methods* (2 ed.). Thousand Oaks, CA: Sage Publications.

Ramnarain, U. (2011). Teachers' use of questioning in supporting learners doing science investigations. *South African Journal of Education, 31*, 91-101.

Ramnarain, U., & Hobden, P. A. (2015). Shifting South African learners towards greater autonomy in scientific investigations. *Journal of Curriculum Studies, 47*(1), 94-121. doi:10.1080/00220272.2014.966153

Ramsden, P. (1992). *Learning to teach in higher education*. London: Routledge

Roberts, R. (2009). Can teaching about evidence encourage a creative approach in open-ended investigations? *School Science Review*, *90*(332), 31-38.

Roberts, R., & Gott, R. (2004). Assessment of Sc1: Alternatives to coursework? . *The School Science Review, 58*(131), 103-108.

Roberts, R., Gott, R., & Glaesser, J. (2010). Students' approaches to open-ended science investigation: The importance of substantive and procedural understanding. *Research Papers in Education, 25*(4), 377-407. doi:DOI: 10.1080/02671520902980680

Sadi, O., & Dagyar, M. (2015). High school students' epistemological beliefs, conceptions of learning, and self-efficacy for learning biology: A study of their structural models. *Eurasia Journal of Mathematics, Science & Technology Education, 11*(5), 1061-1079.

Salili, F., Hwang, C. E., & Choi, N. F. (1989). Teachers' evaluative behavior: The relationship between teachers' comments and perceived ability in Hong Kong *Journal of Cross-Cultural Psychology, 20*, 115-132.

Schommer, M. (1994). Synthesizing epistemological beliefs research: Tentative understandings and provocative conclusions. *Educational Psychology Review, 6*(4), 293-319.

Sheeba, M. N. (2013). An anatomy of science process skills in the light of the challenges to realize science instruction leading to global excellence in education. *Educationia Confab 2*(4), 108-123.

Smith, C. F., & Mathias, H. (2010). An investigation into medical students' approaches to anatomy learning in a systems-based prosection course. *Clinical anatomy, 23*(1), 106-114.

Smith, E. (2011). Staying in the science stream: patterns ot participation in A-level science subjects in the UK. *Educational Studies, 37*(1), 59-71. doi:10.1080/03055691003729161

So, W. W. (2003). Learning science through investigations: An experience with Hong Kong primary school children. *International Journal of Science and Mathematics Education, 1*, 175-200.

Speth, C. A., Namuth, D. M., & Lee, D. J. (2007). Using the ASSIST short form for evaluating an information technology application: Validity and reliabilty issues. *Informing Science Journal, 10*, 107-119.

Svennevig, J. (2001).
Abduction as a methodological approach to the study of spoken interaction. *Norskrift, 103*(1-22).

Tait, H., & Entwistle, N. J. (1996). Identifying students at risk through ineffective study strategies *Higher Education, 31*, 97-116.

Tang, X., Coffey, J. E., Elby, A., & Levin, D. M. (2010). The scientific method and scientific inquiry: Tensions in teaching and learning. *Science Education, 94*(1), 29-47.

Tanriverdi, B. (2012). Pre-service teachers' epistemological beliefs and approaches to learning. *Procedia - Social and Behavioral Sciences 46 ( 2012 ) 2635 – 2642 46*(2012), 2635-2642.

Tashakkori, A., & Creswell, J. W. (2007). Exploring the Nature of Research Questions in Mixed Methods Research. *Jornal of Mixed Methods Research, 1*(3), 207-2011.

Toh, K. A., Boo, H. K., & Yeo, K. H. (1997). Open-ended investigations: performance and effects of pre-training. *Research in Science Education, 27*(1), 131-140.

Toplis, R., & Allen, M. (2012). ‘I do and I understand?’ Practical work and laboratory use in United Kingdom schools. *Eurasia Journal of Mathematics, Science & Technology Education, 8*(1), 3-9.

Trigwell, K., & Prosser, M. (1996). Congruence between intention and strategy in science teachers' approach to teaching. *Higher Education*, *32*, 77-87.

Trigwell, K., Prosser, M., & Waterhouse, F. (1997). Relations between teachers' approaches to learning and students' approaches to learning. *Higher Education, 37*(1), 57-70.

Trumbull, D. J., Bonney, R., & Grudens-Schuck, N. (2005). Developing materials to promote inquiry: lessons learned. *Science Education, 88*(6), 601-645. doi:10.1002/sce.20081

Tsai, C. C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education, 82*, 473-489.

Tytler, R. (2007). Re-imagining science education: Engaging students in science for Australia‘s future *Australian Education Review*. Victoria, Australia: ACER Press.

Wahyuni, D. (2012). The research design maize: Understanding paradigms, cases, methods and methodologies. *JAMAR, 10*(1), 69-80.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching, 38*(5), 529-552.

Watson, J. R. (1994). Pupils’ engagement in practical problem solving: A case study. *International Journal of Science Education, 16*(1), 27-43.

Watson, J. R., Goldsworthy, A., & Wood-Robinson, V. (1998). *Interim report to the QCA from teh ASE/King's College Science Investigations in Schools (AKSIS) Project*. Retrieved from London, King's College: http://www.kcl.ac.uk/sspp/departments/education/web-files2/aksis.pdf

Watts, M. (1994). Describing problem solving: A core skill in the curriculum. In M. Watts (Ed.), *Problem Solving In Science And Technology*. London: David Fulton.

Wellington, J. (1998). *Practical work in school science. Which way now?* London: Routledge.

Wellington, J. (2000). *Teaching and learning secondary science: contemporary issues and practical approaches*. London: Routledge.

Windschitl, M., Thompson, J., & Braaten, M. (2007). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science. *Science Education, 92*(5), 941-967. doi:10.1002/sce.20259

Woolnough, B. E. (1991). Setting the scene. In B. E. Woolnough (Ed.), *Practical science* (pp. 3-9). Milton Keynes: Open University Press.

Woolnough, B. E., & Allsop, T. (1985). *Practical work in science*. Cambridge: Cambridge University Press.

Yin, R. K. (2009). *Case study research: design and methods* (4 ed.). Thousand Oaks, CA: Sage Publications.

Zimbabwe School Examinations Council (ZIMSEC). (2010). *Advanced level chemistry (9189) November 2010 Paper 6 examiner's report*. Retrieved from http://www.zimsec.co.zw/REPORTS/CHEMISTRY_06_NOV10.pdf

Zimbabwe School Examinations Council (ZIMSEC). (2011). *Advanced level chemistry (9189) November 2011 Paper 5 examiner's report*. Harare: ZIMSEC

Zimbabwe School Examinations Council (ZIMSEC). (2012a). *Advanced level chemistry (9189) November 2012 Paper 5 examiner's report*. Harare: ZIMSEC

Zimbabwe School Examinations Council (ZIMSEC). (2012b). *Advanced level syllabus, chemistry (9189)*. Retrieved from http://www.zimsec.co.zw/A_SYLLABUS/A_CHEMISTRY.pdf. 146

Zimbabwe School Examinations Council (ZIMSEC). (2012c). *O-Level chemistry syllabus (5071)*. Retrieved from http://www.zimsec.co.zw/O_SYLLABUS/O_CHEMISTRY.pdf. ZIMSEC. (2010). *Advanced level chemistry (9189) November 2010 Paper 6 examiner's report*. Retrieved from http://www.zimsec.co.zw/REPORTS/CHEMISTRY_06_NOV10.pdf

# APPENDICES

## Appendix A Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

27 November 2014

**Mr Tamirirofa Chirikure 213574583**
**School of Education**
**Edgewood Campus**

**Protocol reference number: HSS/1519/014D**
**Project title: Exploring Students' Approaches to Science Investigations in Advanced Level Chemistry: A Zimbabwean study**

Dear Mr Chirikure

**Expedited Approval**

In response to your application dated 17 November 2014, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol have been granted **FULL APPROVAL.**

**Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.**

**Please note: Research data should be securely stored in the discipline/department for a period of 5 years.**

**The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.**

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

..................................................
**Dr Shenuka Singh (Chair)**

**/px**

cc Supervisor: Professor PA Hobden
cc Academic Leader Research: Professor P Morojele
cc School Administrator: Ms B Bhengu and Mr SN Mthembu

**Humanities & Social Sciences Research Ethics Committee**
**Dr Shenuka Singh (Chair)**
**Westville Campus, Govan Mbeki Building**
**Postal Address:** Private Bag X54001, Durban 4000
**Telephone:** +27 (0) 31 260 3587/8350/4557 **Facsimile:** +27 (0) 31 260 4609 **Email:** ximbap@ukzn.ac.za / snymanm@ukzn.ac.za / mohunp@ukzn.ac.za
**Website:** www.ukzn.ac.za

## Appendix B Permission to do research in Mashonaland Central, Zimbabwe

REF: C/440/1MC

*All communications should be addressed to:*
*"The Provincial Education Director*
*Mashonaland Central Province"*
*Telephone: +263 171 6948/6996/7134/6994*
*Fax: +263 271 6997*

ZIMBABWE

**Ministry of Primary and Secondary Education**
**Mashonaland Central Province**
**P.O. Box 340**
**Bindura**
**Zimbabwe**

05 September 2014

**Mr Tamirirofa Chirikure**
Science and Technology Education Cluster
CU 135 (Ground Floor), Main Tutorial Building
School of Education, College of Humanities
University of KwaZulu-Natal, Edgewood Campus
Private Bag X03, Ashwood 3605
South Africa

**RE: PERMISSION TO CARRY OUT RESEARCH**

Reference is hereby made to your letter dated 30 August 2014.

I am pleased to inform you that the Provincial Education Director has granted you permission to carry out research in our schools.

**Research Title: Exploring Students' Approaches to Investigations in Advanced Level Chemistry: A Zimbabwean Study.**

You are advised to submit a copy of your thesis to the Ministry of Primary and Secondary Education upon completion.

Mr Douglas Chitsa

**FOR PROVINCIAL EDUCATION DIRECTOR**

Mashonaland Central Province

/cc

## Appendix C Informed consent - chemistry teachers

Science and Technology Education Cluster
CU 135, Main Tutorial Building
School of Education, College of Humanities
Edgewood Campus
University of KwaZulu-Natal
Private Bag X03
Ashwood 3605, South Africa

Dear Chemistry Teacher

**Re: Informed Consent**

My name is Tamirirofa Chirikure. I am a PhD student studying at the University of KwaZulu-Natal's School of Education in the College of Humanities. My research title is **Exploring Students' Approaches to Investigations in Advanced Level Chemistry: A Zimbabwean Study.**

The objectives of this study will be as follows: to describe the characteristics of the investigations done by Advanced Level Chemistry students, to understand the role of investigations as perceived by Advanced Level Chemistry students, to explore Advanced level Chemistry students' approaches to investigations and to explain why the students approach them the way they do.

You are kindly requested to be a participant in this research by filling in questionnaires and taking part in individual or focus group interviews. These activities will last about twenty (20) minutes each. In addition, I require your permission to examine your practical work books, observe and video record your practical sessions for an entire school term.

Please note that:

- Your participation is voluntary.
- Your confidentiality is guaranteed as your input will not be attributed to your person.
- Any information you volunteer will not be used against you and the data collected will be used for the purposes of this research only.
- All the data collected will be stored in in a secure place and destroyed after five (5) years.
- You have the choice to participate, not to participate or to stop participating in the research any anytime without the risk of incurring any penalty.
- Your involvement is purely for academic purposes only. There are no financial benefits involved.
- At the end of the data collection process, copies of transcripts of all the interviews, audio and video recordings will be made available to you for cross-checking.
- A copy of the final draft thesis will be made available to you upon completion.

If you need further information please contact the following people:

1. Professor Paul Hobden (my supervisor)
   School of Education, College of Humanities
   Cu 102, Main Tutorial Building, Edgewood Campus
   University of KwaZulu-Natal
   Private Bag X03
   Ashwood 3605, South Africa
   Email: hobden@ukzn.ac.za
   Telephone: +27 31 260 3447

2. Research Office: HSSREC – Ethics
   University of KwaZulu-Natal
   Govan Mbeki Building
   Private Bag X54001,Durban 4000
   South Africa
   Tel: +27 31 260 4557   Fax: +27 31 260 1609

If you agree to take part in this research study please sign and submit the attached declaration form.
Your participation will be greatly appreciated.

Yours faithfully,

Tamirirofa Chirikure

Cell: +27 735 764 572
Tel: +27 31 260 3470
Email: chirikure@ukzn.ac.za

**DECLARATION**

I ___________________________________________________ (full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project and I consent to participating in the research project.

I understand that:

- I will participate voluntarily and am at liberty to withdraw from the project at any time should I so desire with no negative consequences.
- I voluntarily give permission for the study's activities to be digitally recorded.
- I give permission for my Chemistry scheme/plan/prep books and practical activities to be used as a source of data.
- My identity will not be disclosed and that a pseudonym will be used to protect my identity.

I hereby: *(please tick in the appropriate box in table below)*

| | |
|---|---|
| Agree to be audio-recorded | |
| Do not agree to be audio-recorded | |

I hereby: *(please tick in the appropriate box in table below)*

| | |
|---|---|
| Agree to be video-recorded | |
| Do not agree to be video-recorded | |

__________________________ __________________________

Signature of participant Date

## Appendix D Informed consent – Advanced Level chemistry students

Science and Technology Education Cluster
CU 135 (Ground Floor)
Main Tutorial Building
School of Education, Edgewood Campus
University of KwaZulu-Natal
Private Bag X03
Ashwood 3605, South Africa

Dear Chemistry Student

**Re: Informed Consent**

My name is Tamirirofa Chirikure. I am a PhD student studying at the University of KwaZulu-Natal's School of Education in the College of Humanities. My research title is **Exploring Students' Approaches to Investigations in Advanced Level Chemistry: A Zimbabwean Study.**

The objectives of this study will be as follows: to describe the characteristics of the investigations done by Advanced Level Chemistry students, to understand the role of investigations as perceived by Advanced Level Chemistry students, to explore Advanced level Chemistry students' approaches to investigations and to explain why the students approach investigations the way they do.

You are kindly requested to be a participant in this research by filling in questionnaires and taking part in individual or focus group interviews. These activities will last about twenty (20) minutes each. In addition, I require your permission to examine your practical work books, observe and video record your practical sessions for an entire school term.

Please note that:

- Your participation is voluntary.
- Your confidentiality is guaranteed as your input will not be attributed to your person.
- Any information you volunteer will not be used against you and the data collected will be used for the purposes of this research only.
- All the data collected will be stored in in a secure place and destroyed after five (5) years.
- You have the choice to participate, not to participate or to stop participating in the research any anytime without the risk of incurring any penalty.
- Your involvement is purely for academic purposes only. There are no financial benefits involved.
- At the end of the data collection process copies of transcripts of the interviews, audio and video recordings will be made available to you for cross-checking.
- A copy of the final draft thesis will be made available to you upon completion.

If you need further information please contact the following people:

1. Professor Paul Hobden (my supervisor)
   Science and Technology Education Cluster
   Cu 102 (Ground Floor), Main Tutorial Building
   Edgewood Campus
   University of KwaZulu-Natal
   Private Bag X03
   Ashwood 3605
   Email: hobden@ukzn.ac.za
   Telephone: +27 31 260 3447

2. Research Office: HSSREC – Ethics
   University of KwaZulu-Natal
   Govan Mbeki Building
   Private Bag X54001
   Durban 4000
   South Africa
   Tel: +27 31 260 4557   Fax: +27 31 260 1609

If you agree to take part in this research study please sign and submit the attached declaration form.

Your participation will be greatly appreciated.

Yours faithfully,

Tamirirofa Chirikure

Cell: +27 735 764 572
Tel: +27 31 260 3470
Email: chirikure@ukzn.ac.za

**DECLARATION**

I ________________________________________________ (full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project and I consent to participating in the research project.

I understand that:

- I will participate voluntarily and am at liberty to withdraw from the project at any time should I so desire with no negative consequences.
- I voluntarily give permission for the study's activities to be digitally recorded.
- I give permission for my Chemistry practical work books and scripts to be used as a source of data.
- My identity will not be disclosed and that a pseudonym will be used to protect my identity.

I hereby : *(please tick in the appropriate box in table below)*

| | |
|---|---|
| Agree to be audio-recorded | |
| Do not agree to be audio-recorded | |

I hereby : *(please tick in the appropriate box in table below)*

| | |
|---|---|
| Agree to be video-recorded | |
| Do not agree to be video-recorded | |

__________________________ ________________________

Signature of participant Date

# Appendix E Approaches to Investigations Inventory for Students (ASIIS)

Thank you for agreeing to take part in this study.

This questionnaire has been designed to allow you describe, in a systematic way, how you go about doing investigations. The technique involves asking you a substantial number of questions which overlap to some extent to provide good overall coverage of different ways of doing investigations. Please respond truthfully, so that your answers will **accurately** describe your actual approach to investigations and this will help you go through this questionnaire **quickly**.

**Background information**

Name/identifier: ______________________________ Age in years: __________ Sex: M / F

School/identifier: _____________________________

## A. Approaches to Investigations

This questionnaire requires you to indicate your relative agreement or disagreement with comments about how you do investigations. Please work through the comments, giving your immediate response. In deciding your answer, think about investigations in Chemistry. It is also important to answer all the questions. Please check that you have after answering the last question.

**1 = disagree 2 = disagree somewhat 3 = unsure 4 = agree somewhat 5 = agree**

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | I manage to find conditions for doing investigations that allow me to get on with my work easily. | 1 | 2 | 3 | 4 | 5 |
| 2 | When doing an investigation, I keep in mind how best to impress the marker. | 1 | 2 | 3 | 4 | 5 |
| 3 | Often I wonder if the investigation I am doing is worthwhile. | 1 | 2 | 3 | 4 | 5 |
| 4 | I usually set out to understand for myself the meaning of what we have to learn from investigations. | 1 | 2 | 3 | 4 | 5 |
| 5 | During practical sessions and examinations, I organise my time carefully to make the best use of it. | 1 | 2 | 3 | 4 | 5 |
| 6 | I find I have to concentrate on just memorising the procedures to practical work done before. | 1 | 2 | 3 | 4 | 5 |
| 7 | I go over my investigation designs carefully to check the reasoning and that it makes sense. | 1 | 2 | 3 | 4 | 5 |
| 8 | Often I fear I am drowning in the shear amount of investigations we have to cope with. | 1 | 2 | 3 | 4 | 5 |
| 9 | I look at the results carefully and try to reach my own conclusions about the investigations I am doing. | 1 | 2 | 3 | 4 | 5 |
| 10 | It's important for me to feel that I am doing as well as I really can in investigations. | 1 | 2 | 3 | 4 | 5 |
| 11 | I try to relate the investigations I do to the work I cover in the theory lessons. | 1 | 2 | 3 | 4 | 5 |
| 12 | I tend to read very little beyond what is actually required to pass in investigations. | 1 | 2 | 3 | 4 | 5 |

| 1 = disagree 2 = disagree somewhat 3 = unsure 4 = agree somewhat 5 = agree | | | | | | |
|---|---|---|---|---|---|---|
| 13 | Regularly I find myself thinking about ideas from investigations when I am doing other things. | 1 | 2 | 3 | 4 | 5 |
| 14 | I think I am quite systematic and organised when it comes to preparing for a practical examination. | 1 | 2 | 3 | 4 | 5 |
| 15 | I look carefully at the teacher's comments on my investigations to see how to get higher marks next time. | 1 | 2 | 3 | 4 | 5 |
| 16 | There is nothing on investigations in Chemistry that I find interesting. | 1 | 2 | 3 | 4 | 5 |
| 17 | When I read about a concept in a Chemistry textbook, I think of an investigation that could do to understand it better. | 1 | 2 | 3 | 4 | 5 |
| 18 | I'm pretty good at getting down to work whenever I need to do an investigation. | 1 | 2 | 3 | 4 | 5 |
| 19 | Many of the investigations that we do make sense: they are related to the theory we do in Chemistry lessons. | 1 | 2 | 3 | 4 | 5 |
| 20 | I think about what I have to learn from each investigation to keep myself focused. | 1 | 2 | 3 | 4 | 5 |
| 21 | When I am doing a new investigation, I try to see in my own mind how all the related concepts and ideas fit together. | 1 | 2 | 3 | 4 | 5 |
| 22 | I often wonder about whether I will ever be able to cope with the investigations properly. | 1 | 2 | 3 | 4 | 5 |
| 23 | Often I find myself questioning designs and results of investigations we do or I read about. | 1 | 2 | 3 | 4 | 5 |
| 24 | I feel that I am getting on well and this helps me put more effort into investigations. | 1 | 2 | 3 | 4 | 5 |
| 25 | I concentrate on learning just those bits of information that I have to know to pass in investigations. | 1 | 2 | 3 | 4 | 5 |
| 26 | I find that learning Chemistry concepts and applying them in investigations can be quite exciting at times. | 1 | 2 | 3 | 4 | 5 |
| 27 | I am good at following up some of the readings on investigations suggested by the teacher. | 1 | 2 | 3 | 4 | 5 |
| 28 | I keep in mind how my Chemistry teacher marks our investigations and what he is likely to be looking for. | 1 | 2 | 3 | 4 | 5 |
| 29 | When doing investigations I sometimes wonder why I chose to do Advanced Level Chemistry. | 1 | 2 | 3 | 4 | 5 |
| 30 | When I am doing an investigation I stop from time to time to reflect on what I am trying to learn from it. | 1 | 2 | 3 | 4 | 5 |
| 31 | I work steadily through the term and year rather than leave it all until the last minute. | 1 | 2 | 3 | 4 | 5 |
| 32 | I am not really sure about designing investigations so I try to write down all I can think of. | 1 | 2 | 3 | 4 | 5 |
| 33 | The ideas and data generated in investigations often set me off on long chains of thought of my own. | 1 | 2 | 3 | 4 | 5 |
| 34 | Before writing down the design of an investigation, I think first about how best to tackle it. | 1 | 2 | 3 | 4 | 5 |
| 35 | I often seem to panic when I get behind with my investigations. | 1 | 2 | 3 | 4 | 5 |
| 36 | When I am assigned an investigation, I examine the details carefully to see how they fit in together. | 1 | 2 | 3 | 4 | 5 |
| 37 | I put a lot of effort in investigations because I am determined to do well. | 1 | 2 | 3 | 4 | 5 |
| 38 | I gear my preparation for the Chemistry practical test or examination to just what is required to pass. | 1 | 2 | 3 | 4 | 5 |
| 39 | Some of the ideas I come across in investigations are really gripping. | 1 | 2 | 3 | 4 | 5 |

| 1 = disagree 2 = disagree somewhat 3 = unsure 4 = agree somewhat 5 = agree | | | | | | |
|---|---|---|---|---|---|---|
| 40 | *I usually plan out my week's work in advance either on paper or in my head. | 1 | 2 | 3 | 4 | 5 |
| 41 | I keep an eye open for what my teacher thinks is important when doing investigations and concentrate on that. | 1 | 2 | 3 | 4 | 5 |
| 42 | I am not really interested in Chemistry but I have to take it for other reasons. | 1 | 2 | 3 | 4 | 5 |
| 43 | Before collecting data for an investigation, I first create mental images of what the data should look like. | 1 | 2 | 3 | 4 | 5 |
| 44 | I generally make good use of my time during our Chemistry practical sessions. | 1 | 2 | 3 | 4 | 5 |
| 45 | I often have trouble in making sense of the things I have to remember when doing investigations. | 1 | 2 | 3 | 4 | 5 |
| 46 | When designing an investigation, I like to consider all the options (possible experimental designs) even if they don't get me very far. | 1 | 2 | 3 | 4 | 5 |
| 47 | After collecting data for an investigation, I check it through to see if it really makes sense and helps me answer the question at hand. | 1 | 2 | 3 | 4 | 5 |
| 48 | Often I lie awake worrying about an investigation I think I won't be able to do. | 1 | 2 | 3 | 4 | 5 |
| 49 | It's important for me to follow the argument or to see the reason behind collecting specific types of data during investigations. | 1 | 2 | 3 | 4 | 5 |
| 50 | I don't find it difficult at all to motivate myself to do investigations. | 1 | 2 | 3 | 4 | 5 |
| 51 | I would like to be given experimental procedure when we are required to do investigations. | 1 | 2 | 3 | 4 | 5 |
| 52 | Sometimes I get hooked on Chemistry concepts and feel I should do an investigation to learn more. | 1 | 2 | 3 | 4 | 5 |

**B. Preferences for different types of teaching, resources and examination in the Chemistry practical component.**

***1 = definitely dislike 2 = dislike to some extent 3 = unsure 4 = like to some extent 5 = definitely like***

| | | | | | | |
|---|---|---|---|---|---|---|
| a | Chemistry teachers who tell us exactly what to do during investigations. | 1 | 2 | 3 | 4 | 5 |
| b | Chemistry teachers who encourage us to think for ourselves and show us how they themselves think. | 1 | 2 | 3 | 4 | 5 |
| c | Practical examinations that allow me to demonstrate my thinking capacity and apply Chemistry concepts. | 1 | 2 | 3 | 4 | 5 |
| d | Practical examinations that need only assess us on investigations described in our Chemistry textbooks and in past examination papers. | 1 | 2 | 3 | 4 | 5 |
| e | A Chemistry practical syllabus that clearly states the investigations that we will be examined on. | 1 | 2 | 3 | 4 | 5 |
| f | A Chemistry practical syllabus that encourages us to read around a lot for ourselves. | 1 | 2 | 3 | 4 | 5 |
| g | Investigations that are challenging and require us to go beyond the material learnt in class with the teacher. | 1 | 2 | 3 | 4 | 5 |
| h | Chemistry textbooks that have descriptions of investigations that can be easily learned. | 1 | 2 | 3 | 4 | 5 |

Finally, how well do you think you have been doing in your assessed work on investigations overall, so far?

***Encircle your choice in the table below***

| Rather badly | | Not so well | About average | | Quite well | | Very well | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Thank you for completing this questionnaire.**

## Appendix F Categorisation of the ASIIS statements by approach

### Deep approach

***Seeking meaning (SM = 4+17+30+43)***

| | |
|---|---|
| 4 | I usually set out to understand for myself the meaning of what we have to learn from investigations. |
| 17 | When I read about a concept in a Chemistry textbook, I think of an investigation that could do to understand it better. |
| 30 | When I am doing an investigation I stop from time to time to reflect on what I am trying to learn from it. |
| 43 | Before collecting data for an investigation, I first create mental images of what the data should look like. |

***Relating ideas (RI = 11+21+33+46)***

| | |
|---|---|
| 11 | I try to relate the investigations I do to the work I cover in the theory lessons. |
| 21 | When I am doing a new investigation I try to see in my own mind how all the related concepts and ideas fit together. |
| 33 | The ideas and data generated in investigations often set me off on long chains of thought of my own. |
| 46 | When designing an investigation, I like to consider all the options (possible experimental designs) even if they don't get me very far. |

***Use of evidence or data collected for an investigation (UE = 9+23+36+49)***

| | |
|---|---|
| 9 | I look at the results carefully and try to reach my own conclusions about the investigations I am doing. |
| 23 | Often I find myself questioning designs and results of investigations we do or I read about. |
| 36 | When I am assigned an investigation, I examine the details carefully to see how they fit in together. |
| 49 | It's important for me to follow the argument or to see the reason behind collecting specific types of data during investigations. |

***Interest in investigations (ISI = 13+26+39+52)***

| | |
|---|---|
| 13 | Regularly I find myself thinking about ideas from investigations when I am doing other things. |
| 26 | I find that learning Chemistry concepts and applying them in investigations can be quite exciting at times. |
| 39 | Some of the ideas I come across in investigations are really gripping. |
| 52 | Sometimes I get hooked on Chemistry concepts and feel I should do an investigation to learn more. |

## Strategic approach

### *Organised (O = 1+14+27+40)*

| | |
|---|---|
| 1 | I manage to find conditions for doing investigations which allow me to get on with my work easily. |
| 14 | I think I am quite systematic and organised when it comes to preparing for a practical examination. |
| 27 | I am good at following up some of the readings on investigations suggested by the teacher. |
| 40 | *I usually plan out my week's work in advance either on paper or in my head. |

### *Time management (TM = 5+18+31+44)*

| | |
|---|---|
| 5 | During practical sessions and examinations, I organise my time carefully to make the best use of it. |
| 18 | I'm pretty good at getting down to work whenever I need to do an investigation. |
| 31 | I work steadily through the term and year rather than leave it all until the last minute. |
| 44 | I generally make good use of my time during our Chemistry practical sessions. |

### *Alertness to assessment demands (AA = 2+15+28+41)*

| | |
|---|---|
| 2 | When doing an investigation, I keep in mind how best to impress the marker. |
| 15 | I look carefully at the teacher's comments on my investigations to see how to get higher marks next time. |
| 28 | I keep in mind how my Chemistry teacher marks our investigations and what he is likely to be looking for. |
| 41 | I keep an eye open for what my teacher thinks is important when doing investigations and concentrate on that. |

### *Achieving (A = 10+24+37+50)*

| | |
|---|---|
| 10 | It's important for me to feel that I am doing as well as I really can in investigations. |
| 24 | I feel that I am getting on well and this helps me put more effort into investigations. |
| 37 | I put a lot of effort in investigations because I am determined to do well. |
| 50 | I don't find it difficult at all to motivate myself to do investigations. |

### *Monitoring effectiveness (ME = 7+20+34+47)*

| | |
|---|---|
| 7 | I go over my investigation designs carefully to check the reasoning and that it makes sense. |
| 20 | I think about what I have to learn from each investigation to keep myself focused. |
| 34 | Before writing down the design of an investigation, I think first about how best to tackle it. |
| 47 | After collecting data for an investigation, I check it through to see if it really makes sense and helps me answer the question at hand. |

## Surface Approach

***Lack of purpose (LP = 3+16+29+42)***

| | |
|---|---|
| 3 | Often I wonder if the investigation I am doing is worthwhile. |
| 16 | There is not on investigations in Chemistry that I find interesting. |
| 29 | When doing investigations I sometimes wonder why I chose to do Advanced Level Chemistry. |
| 42 | I am not really interested in Chemistry but I have to take it for other reasons. |

***Unrelated memorising (UM = 6+19+32+45)***

| | |
|---|---|
| 6 | I find I have to concentrate on just memorising the procedures to practical work done before. |
| 19 | Many of the investigations that we do make sense: they are related to the theory we do in Chemistry lessons. |
| 32 | I am not really sure about designing investigations so I try to write down all I can think of. |
| 45 | I often have trouble in making sense of the things I have to remember when doing investigations. |

***Syllabus-boundness (SB = 12+25+38+51)***

| | |
|---|---|
| 12 | I tend to read very little beyond what is actually required to pass in investigations. |
| 25 | I concentrate on learning just those bits of information that I have to know to pass in investigations. |
| 38 | I gear my preparation for the Chemistry practical test or examination to just what is required to pass. |
| 51 | I would like to be given experimental procedure when we are required to do investigations. |

***Fear of failure (FF = 8+22+35+48)***

| | |
|---|---|
| 8 | Often I fear I am drowning in the shear amount of investigations we have to cope with. |
| 22 | I often wonder about whether I will ever be able to cope with the investigations properly. |
| 35 | I often seem to panic when I get behind with my investigations. |
| 48 | Often I lie awake worrying about an investigation I think I won’t be able to do. |

### 1. Preferences for different types of teaching, resources and practical examinations

**Supporting understanding** *(related to a deep approach)*

| | |
|---|---|
| b. | Chemistry teachers who encourage us to think for ourselves and show us how they themselves think. |
| c | Practical examinations which allow me to demonstrate my thinking capacity and apply Chemistry concepts. |
| f | A Chemistry practical syllabus which encourages us to read around a lot for ourselves. |
| g | Investigations which are challenging and require us to go beyond the material learnt in class with the teacher. |

**Transmitting information** *(related to a surface approach)*

| | |
|---|---|
| a | Chemistry teachers who tell us exactly what to do during investigations. |
| d | Practical examinations which need only assess us on investigations described in our Chemistry textbooks and in past examination papers. |
| e | A Chemistry practical syllabus which clearly states the investigations which we will be examined on. |
| h | Chemistry textbooks which have descriptions of investigations which can be easily learned. |

**Appendix G The designing and understanding questionnaire (DUQ)**

Thank you for agreeing to take part in this study.

This questionnaire is designed to obtain information on your understanding of investigations, their role in Advanced Level Chemistry and how you go about doing them.

1. One of the assessment areas in the Advanced Level Chemistry syllabus is 'Experimental Skills and Investigations'. Consequently, in your practical sessions (and eventually the final practical examination), you are asked to design or plan and carry out an investigation.

   I am aware that you did an investigation in your last practical session, what was it about?

   ___________________________________________________________________________________

   ___________________________________________________________________________________

   ___________________________________________________________________________________

2. Describe to me how you went about designing, planning and carrying out this investigation. Did you use any specific strategy (steps/method/procedure)?

3. Did you find yourself stuck at any moment during the investigation? If so, how did you solve the challenge, if at all?

4. How successful were you in planning and performing the investigation? Did you manage to produce the desired plan and results?

5. What did you learn from the investigation in terms of chemistry content and doing an investigation?

6. Have you done a similar investigation before? If so briefly describe what that similar investigation was about.

7. You have done many investigations since you started Advanced Level Chemistry, what do you understand by an investigation? What makes a practical activity an investigation? How is it different from other types of practical work?

8. In your opinion, what is the role of investigations in Chemistry? Why do you think investigations are part of the Advanced Level Chemistry syllabus? Why is it important for you to do investigations?

9. What is the source of the investigations that you do during your Chemistry practical sessions? (textbooks, past examination papers, teacher's own questions)

10. Do you see any relationship between the investigations that you do and the theory that you learn in the regular Chemistry lessons? If so, give an example.

11. What are your career aspirations? What do you want to study after completing Advanced Level?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

12. Do you think the ability to design, plan and carryout investigations will be useful in your future studies and professional career? Why? In what way?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

13. How well do you do in designing, planning and carrying out investigations? After doing an investigation do you get the marks that you expect?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

14. If you have any other comment to make with respect to investigations, please use the space below.

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

**Thank you for completing this questionnaire.**

**Appendix H Questionnaire on investigations for chemistry teachers**

This questionnaire seeks your views on investigations in Advanced Level Chemistry. Please answer the questions as accurately and honestly as you can. Your response is anonymous and confidential to the researcher and his supervisor.

1. You are: Female _____ Male: ______

2. For how long have you been working as a teacher? ______________________

3. For how long have you been teaching Advanced Level Chemistry?_______________

4. One of the Advanced Level Chemistry assessment areas is 'Experimental skills and Investigations'. I am aware that you have at least one Chemistry session per week dedicated for practical work. How often, in a week, do you ask your students to design, plan and carry out investigations?

   ---------------------------------------------------------------------------------------------------

5. What types of investigations did you assign to your students in your Chemistry practical sessions and end of term examinations (e.g. fair testing and comparing; classifying and identifying things; pattern seeking; exploring; making things or developing systems)

   ---------------------------------------------------------------------------------------------------

   ---------------------------------------------------------------------------------------------------

   ---------------------------------------------------------------------------------------------------

   ---------------------------------------------------------------------------------------------------

   ---------------------------------------------------------------------------------------------------

6. What is the source of the investigations you assign to (done by) your students? (e.g. Chemistry textbooks, past examination papers, I design the investigation tasks).

   ---------------------------------------------------------------------------------------------------

   ---------------------------------------------------------------------------------------------------

   ---------------------------------------------------------------------------------------------------

7. You have done many investigations with your students and you probably did investigations yourself when you were in high school or at university. What do you understand by an investigation? What makes a practical activity an investigation? How is it different from other types of practical work?

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

8. In your opinion, what is the role of investigations in chemistry education? Why do you think investigations are part of the Advanced Level Chemistry syllabus? Why is it important for students to do investigations in Advanced Level Chemistry?

-----------------------------------------------------------------------------------------------------

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9. How do you teach your students to do investigations? What skills and content do you teach them?

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------------------

10. In your opinion, how do your students approach investigations? What strategies (methods/procedures) do they use?

11. How well do your students do in designing, planning and carrying out investigations? After doing an investigation do they get the marks you expect?

12. If there is something else you would like to say about investigations in Advanced Level Chemistry that you have not been able to say so far, please write it below.

**Thank you for completing this questionnaire.**

## Appendix I Questions for the focus group discussions

Good day. Thank you for agreeing to take part in this interview.

This interview is designed to obtain information on your understanding of investigations, their role in Advanced Level Chemistry and how you go about doing them.

1. What is an investigation to you?
2. What, in your opinion, is the role of investigations in the Advanced level Chemistry curriculum?
3. You have just done an investigation, what was it about?
4. Have you done a similar investigation before? If so briefly describe what the investigation was about.
5. Describe to me how you went about designing, planning and carrying out the investigation. Did you use any specific strategy?
6. Did you find yourself stuck at any moment during the investigation? If so, how did you solve the challenge, if at all?
7. Do you think you did well in the investigation? Did you manage to produce the desired plan and perform the investigation as expected?
8. What explanation can you offer for your performance and the way you do investigations?
9. What did you learn from the investigation?
10. Do the investigations that you do relate to the theory that you learn in the regular Chemistry lessons?
11. What is the source of the investigations that you do during your Chemistry practical sessions? (textbooks, past examination papers, teacher’s own questions)
12. What are your carrier aspirations? What do you want to study after completing Advanced Level?
13. Do you think the ability to design, plan and carryout investigations will be useful in your future studies and professional career? Why/In what way?

## Appendix J Interview schedule for chemistry teachers

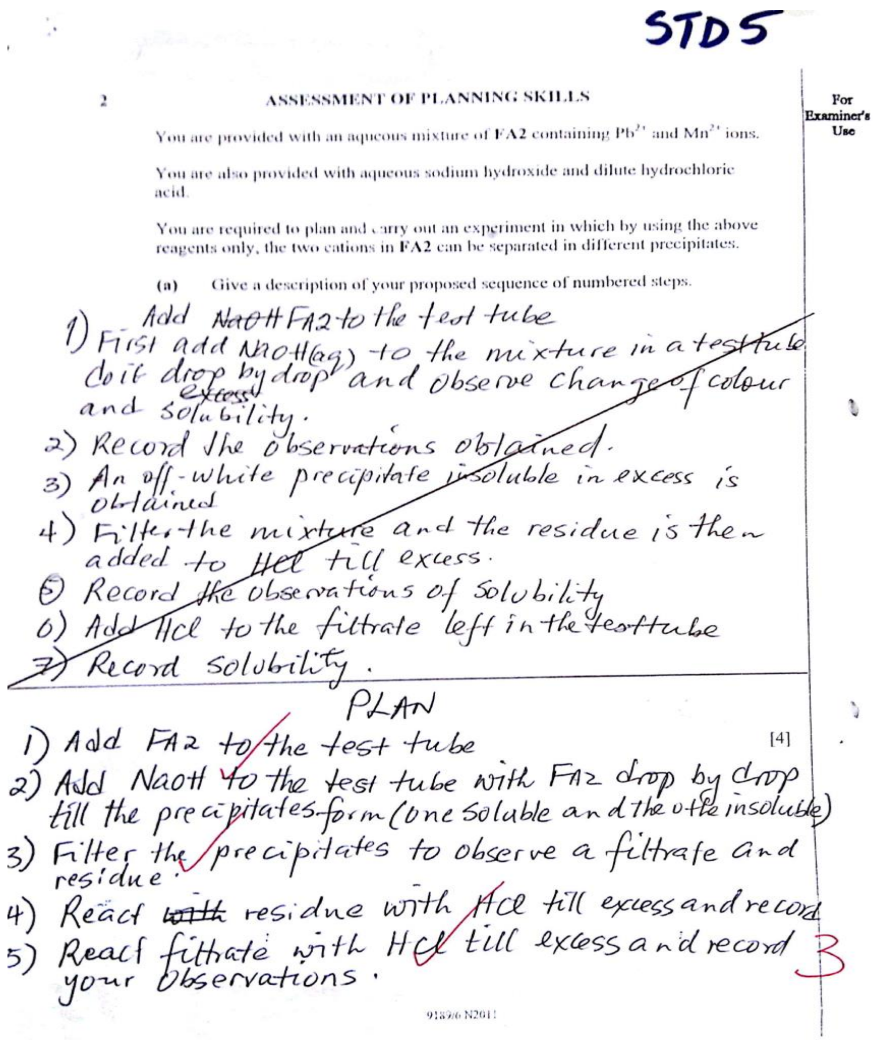
Good day. Thank you very much for agreeing to participate in this interview session. The purpose of this interview is to gather information related to the investigations done by your Advanced Level Chemistry class. The interview will last about 15 minutes.

1. Please share with me something about your background as a Chemistry teacher?
2. What types of investigations have you done with your Chemistry class?
3. What is the source of these investigation tasks?
4. What is the role of investigations in Chemistry teaching and learning?
5. What are your aims for student learning through investigations?
6. What have your students learned through investigations?
7. How do you develop the skills required by students to successfully do investigations?
8. How do your students perform in investigations?
9. What strategies do they use to design and carryout investigations? What approaches do they use?
10. How has your Advanced Level students' performance in investigations progressed since you started working with them?
11. In what way do you think your Advanced Level Chemistry students' experiences of investigations relate to their motivation to learning Chemistry? Does your Advanced Level Chemistry class enjoy doing investigations?
12. In your opinion, are your Advanced Level Chemistry students working towards excelling in investigations?

**Thank you very much for your time.**

## Appendix K Exemplar analysed scripts

### a) The iterative approach: exemplar script


STD 5

2 ASSESSMENT OF PLANNING SKILLS

For Examiner's Use

You are provided with an aqueous mixture of FA2 containing $Pb^{2+}$ and $Mn^{2+}$ ions.

You are also provided with aqueous sodium hydroxide and dilute hydrochloric acid.

You are required to plan and carry out an experiment in which by using the above reagents only, the two cations in FA2 can be separated in different precipitates.

(a) Give a description of your proposed sequence of numbered steps.

1) ~~Add NaOH~~ FA2 to the test tube
~~First add NaOH(aq) to the mixture in a test tube do it drop by drop and observe change of colour and excess solubility.~~
~~2) Record the observations obtained.~~
~~3) An off-white precipitate insoluble in excess is obtained~~
~~4) Filter the mixture and the residue is then added to HCl till excess.~~
~~5) Record the observations of solubility~~
~~6) Add HCl to the filtrate left in the test tube~~
~~7) Record solubility.~~

PLAN

1) Add FA2 to the test tube
2) Add NaOH to the test tube with FA2 drop by drop till the precipitates form (one soluble and the other insoluble)
3) Filter the precipitates to observe a filtrate and residue.
4) React ~~with~~ residue with HCl till excess and record
5) React filtrate with HCl till excess and record your observations.

[4] 3

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The planning stage:

First attempt

- *Student changes $NaOH_{(aq)}$ in favour of FA2 in step 1.*
- *Student crosses out all the seven steps and starts afresh.*

Second attempt

- *Steps 1 and 2 are different from those in first attempt. Ideas in step 1 of first attempt now presented as two separate steps.*
- *Step 3 of first attempt suggests that only one precipitate would be formed when $NaOH_{(aq)}$ is added but step 2 in second attempt shows that the student is now aware that a mixture of precipitates is obtained.*
- *Some steps in the first attempt were consolidated in the second attempt thereby reducing the number from seven to five.*
- *Evidence of good substantive and procedural knowledge.*
- *Evidence of reflective practice*
- *A good mark of 3 out of 4 reflects an improved plan.*

5

(b) Carry out your plan and record your steps and observations in **Table 1**.

For Examiner's Use

**Table 1**

| steps | observations |
|---|---|
| 1. ~~Add~~ NaOH add | Two precipitates formed off-white was insoluble whilst white precipitate was soluble. |
| 2. Filter the products | Colourless $Pb^{2+}$ filtrate and an offwhite residue ($Mn(OH)_2$) is produced. |
| 3. Add HCl to the residue. | Soluble in HCl forming no precipitate ($MnCl_2$) then? |
| 4 Add HCl to the filtrate | White precipitate insoluble in excess ($PbCl_2$). |

[8] 6

(c) From your observations, identify the stages at which each of the cations were collected as precipitates.

$Mn^{2+}$ precipitate is observed at stage of adding NaOH to FA2

$Pb^{2+}$ precipitate is observed at the stage of adding HCl after filtering, to filtrate. [2] 2

[Total: 14] 8

Implementation of the plan

- *Good marks obtained for the table of results and inferences.*
- *No evidence revisions (no crossings)*
- *Evidence of good substantive knowledge – student can link theory with practice*
- *It is possible that the student tried the first plan without recording the results on this template, did not get the expected outcomes and then came up with an improved plan in the second attempt.*

**b) The linear approach: exemplar script**

STD 2

4

2 ASSESSMENT OF PLANNING SKILLS

For Examiner's Use

You are provided with an aqueous mixture of **FA2** containing $Pb^{2+}$ and $Mn^{2+}$ ions.

You are also provided with aqueous sodium hydroxide and dilute hydrochloric acid.

You are required to plan and carry out an experiment in which by using the above reagents only, the two cations in **FA2** can be separated in different precipitates.

(a) Give a description of your proposed sequence of numbered steps.

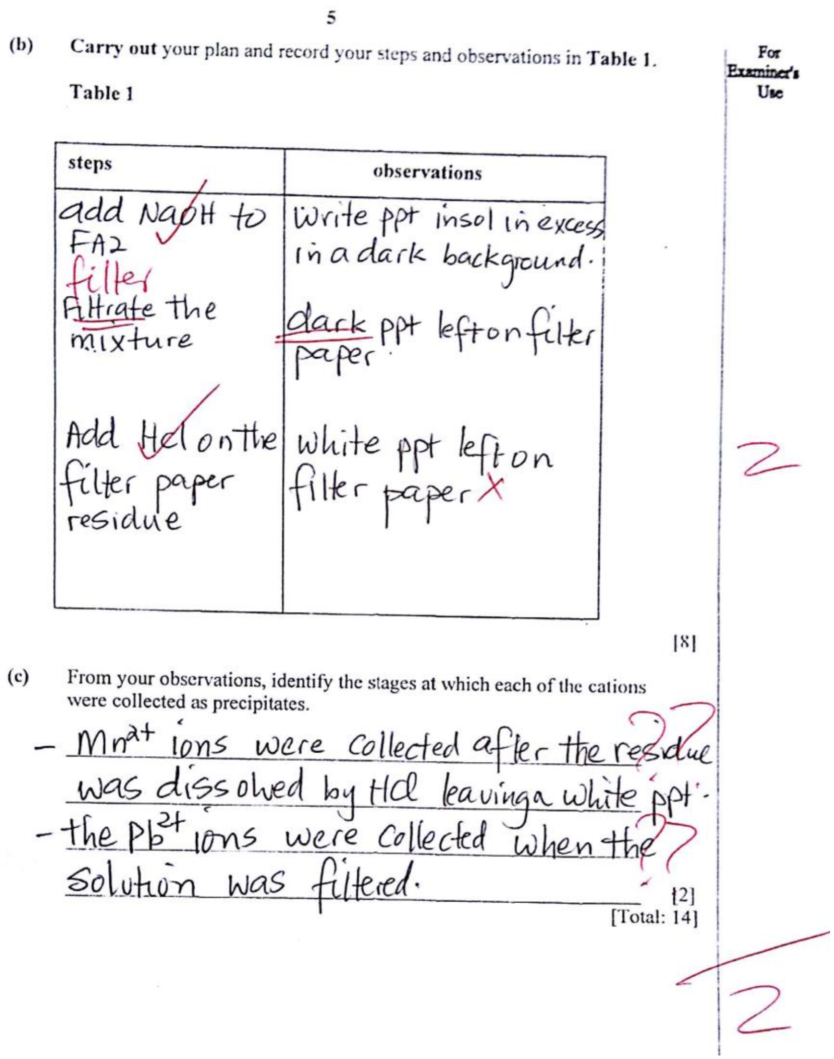
1. Add NaOH ✓ to solution FA2 in a test-tube. $Pb^{2+}$ ions form a white ppt sol. in excess and $Mn^{2+}$ will remain an insoluble white ppt.
2. ~~Filtrate~~ Filter the solution to remain with white $Mn^{2+}$ On the filter paper and the filtrate will be $Pb^{2+}$ ions
3. Dissolve ~~the residue~~ Add HCl(aq) ✓ or pierce it to obtain a solution ✓ of the residue.

3

[4]

The planning stage:

- *Student comes up with an experimental procedure.*
- *No crossings, three clean steps with no evidence of changes.*
- *Students came with one plan and settled for it although it lacked some detail.*


5

(b) Carry out your plan and record your steps and observations in **Table 1**.

For Examiner's Use

**Table 1**

| steps | observations |
|---|---|
| add NaOH to FA2 | Write ppt insol in excess in a dark background. |
| ~~Filtrate~~ filter the mixture | ~~dark~~ ppt left on filter paper. |
| Add HCl on the filter paper residue | white ppt left on filter paper ✗ |

[8]

2

(c) From your observations, identify the stages at which each of the cations were collected as precipitates.

– $Mn^{2+}$ ions were collected after the residue was dissolved by HCl leaving a white ppt.
– the $Pb^{2+}$ ions were collected when the solution was filtered.

[2]

[Total: 14]

2

Implementation of the plan:

- *Flaws in the plan evident in the incorrect observations recorded.*
- *Student did not revise plan in the wake of unexpected results or student did not realise results were incorrect.*
- *Incomplete data collection and processing.*
- *Student fails to link theory with observations to come with the expected inferences.*
- *Evidence of limited substantive knowledge.*
- *Very low mark obtained.*

**c) The divergent approach: exemplar script**

STD 25

4

2 ASSESSMENT OF PLANNING SKILLS

For Examiner's Use

You are provided with an aqueous mixture of **FA2** containing $Pb^{2+}$ and $Mn^{2+}$ ions.

You are also provided with aqueous sodium hydroxide and dilute hydrochloric acid.

You are required to plan and carry out an experiment in which by using the above reagents only, the two cations in **FA2** can be separated in different precipitates.

(a) Give a description of your proposed sequence of numbered steps.

1. Add Hcl to FA2. White ppt formed. ✗
2. Add NaOH ✓ to mixture. white ppt sol. in xs.
3. Filter to obtain colourless filtrate ^

1

The planning stage:

*Student comes up with three steps of which only one was credited.*

*No evidence of revision of plan.*

*Plan shows poor substantive and procedural knowledge*

5

(b) **Carry out** your plan and record your steps and observations in **Table 1**.

**Table 1**

| **steps** | **observations** |
|---|---|
| 1 add HCl X | white ppt |
| (R) 2 add NaOH | white ppt |
| 3 filter. | Colourless filtrate |
| | |

[8]

(c) From your observations, identify the stages at which each of the cations were collected as precipitates.

______________________________________________

______________________________________________

______________________________________________

______________________________________________ [2]

[Total: 14]

Implementation of the plan:

- *All the steps not correctly stated.*
- *Incorrect observations recorded.*
- *No evidence of revision and improvement of steps.*
- *No inferences arrived at in part (c) – student unable to link observations with theoretical understanding.*

## Appendix L Characteristics of the hybrid approaches to investigations

| Approaches | Characteristics | Encouraged by students who have/are: | Encouraged by teachers who: |
|---|---|---|---|
| Deep-iterative | • students focus on developing good substantive and procedural knowledge required to successfully do investigations<br>• students successfully apply the problem-solving Chain<br>• students construct knowledge through doing investigations<br>• students relate new and previous knowledge gained through investigations and otherwise<br>• students can link investigations to real life and the everyday work of real scientists | • a desire to do investigations driven by intrinsic curiosity<br>• sound and appropriate substantive and procedural knowledge which is required to do investigations<br>• a positive view of investigations leading to high confidence in ability to do them<br>• an ability to identify errors in designing, planning and execution of investigations | • demonstrate good understanding and personal interest in investigations<br>• relate new material to what students already know and understand as well as linking theory to investigations<br>• bring out the structure of the subject and role of investigations in Chemistry education<br>• adopt active (hands-on-minds-on) teaching and learning approaches and confront students' weaknesses in substantive and procedural knowledge<br>• use investigative problems that are thought provoking and incorporate concepts from different topics of the subject<br>• |
| Deep-linear | • students focus on developing good substantive and procedural knowledge required to successfully do investigations<br>• students apply the PSC but time constraints prevent iteration<br>• students construct knowledge through doing investigations<br>• students relate new and previous knowledge gained through investigations and otherwise<br>• students can link investigations to real life and the everyday work of real scientists | • desire to do investigations driven by intrinsic curiosity<br>• sound and appropriate substantive and procedural knowledge required to do investigations<br>• a positive view of investigations leading to high confidence in ability to design and execute them<br>• do not revise experimental procedures do to time constraints | • demonstrate good understanding and personal interest in investigations<br>• relate new material to what students already know and understand as well as linking theory to investigations<br>• bring out the structure of the subject and role of investigations in Chemistry education<br>• adopt active (hands-on-minds-on) teaching and learning approaches and confront students' weaknesses in substantive and procedural knowledge<br>• use investigative problems that are thought provoking and incorporate concepts from different topics of the subject |

| | | | |
|---|---|---|---|
| | | | • inadvertently introduce limiting factors such exam conditions in their daily practice |
| Strategic-iterative | • students create a balance between meaningful construction of knowledge and rote learning<br>• students focus on acquiring sufficient substantive and procedural knowledge to successfully do investigations<br>• effort is channelled towards achieving good marks for the investigations done especially in the final examination | • are not necessarily being driven by intrinsic motivation but the desire to pass examinations with good grades<br>• do enough to master the relevant substantive and procedural knowledge<br>• view investigations as a key component of the Chemistry practical syllabus which impacts on their overall performance | • do not necessarily demonstrate a personal interest in investigations and cover them simply as a syllabus requirement<br>• help students to see the relationship between facts and ideas while doing investigations to maximize their chances of passing practical examinations<br>• drill students on experimental procedures<br>• use past examination questions and give marking guidelines to students<br>• emphasise on the importance of linking theory to investigations to get good marks |
| Strategic-linear | • students create a balance between meaningful construction of knowledge and rote learning<br>• students focus on acquiring sufficient substantive and procedural knowledge to successfully do investigations<br>• effort is channelled towards achieving good marks for the investigations done especially in the final examination<br>• students only consider one way of doing the investigation | • are not necessarily being driven by intrinsic motivation but the desire to pass examinations with good grades.<br>• do enough to master the relevant substantive and procedural knowledge<br>• view investigations as a key component of the Chemistry practical syllabus which impacts on their overall performance<br>• See time, substantive and procedural knowledge as limiting factors | • do not necessarily demonstrate a personal interest in investigations and cover them simply as a syllabus requirement<br>• do not necessarily help students to see the relationship between facts and ideas while doing investigations to maximize their chances of passing practical examinations.<br>• drill students on experimental procedures<br>• use past examination questions and give marking guidelines to students<br>• emphasise on doing investigations under examination conditions as preparation for the final examination |

| | | | |
|---|---|---|---|
| Surface-linear | • students rely on rote learning<br>• students focus on memorisation and recalling procedures of similar investigations done before<br>• students do not recognise new material as building on previous work<br>• students see investigations only as practical work done to prepare for and pass examinations | • do investigations as a necessary evil part of the Chemistry syllabus<br>• lack the requisite substantive and procedural knowledge to successfully do investigations<br>• a cynical view of investigations believing that recall of facts and procedures is what is required<br>• one way of doing an investigation which is largely flawed | • do not demonstrate a personal interest in investigations and cover them simply as a syllabus requirement<br>• do not help students to see the relationship between facts and ideas while doing investigations to maximize their chances of passing practical examinations<br>• drill students on one scientific method<br>• use past examination questions and give marking guidelines to students but no proper guidance and feedback<br>• emphasise on doing investigations under examination conditions as preparation for the final examination |
| Surface-divergent | • students rely on rote learning<br>• students focus on procedures used before to design and execute the investigation<br>• students do not recognise new material as building on previous work<br>• students do not necessarily appreciate why they do investigations | • do investigations as a necessary evil part of the Chemistry syllabus<br>• lack the requisite substantive and procedural knowledge to successfully do investigations<br>• never come up with the correct design, experimental procedure and results<br>• may not attempt the investigations at all | • convey disinterest or a negative attitude to investigations<br>• present Chemistry content so that it is perceived as a series of unrelated facts and ideas<br>• allow students to be passive<br>• frequently use the recipe type of practical work<br>• fail to show students how to link theory to investigations<br>• do not give feedback to students after each investigation apart from returning marked scripts |

**Appendix M Versions of the DUQ**

| Pilot Questionnaire | Final draft |
| --- | --- |
| 1. In many of your practical sessions you are asked to design, plan and carry out an investigation. What is an investigation to you? | 1. One of the assessment areas in the A-Level Chemistry syllabus is 'Experimental Skills and Investigations'. Consequently, in your practical sessions and examinations, you are asked to design or plan and carry out an investigation. I am aware that you did an investigation in your last practical session. What was it about? |
| 2. What in your opinion is the role of investigations in your study of Chemistry? | 2. Describe to me how you went about designing, planning and carrying out this investigation. Did you use any specific strategy/steps/method/procedure)? |
| 3. You did an investigation in your last practical session, what was it about? | 3. Did you find yourself stuck at any moment during the investigation? If so, how did you solve the challenge, if at all? |
| 4. Have you done a similar investigation before? If so briefly describe what the investigation was about. | 4. How successful were you in planning and performing the investigation? Did you manage to produce the desired plan and results? |
| 5. Describe to me how you went about designing, planning and carrying out the investigation. Did you use any specific strategy? | 5. What did you learn from the investigation in terms of chemistry content and doing an investigation? |
| 6. Did you find yourself stuck at any moment during the investigation? If so, how did you solve the challenge, if at all? | 6. Have you done a similar investigation before? If so briefly describe what that similar investigation was about. |
| 7. Did you manage to produce the desired plan and perform the investigation as expected? | 7. You have done many investigations since you started A-Level Chemistry, what do you understanding by an investigation? What makes a practical activity an investigation? How is it different from other types of practical work? |
| 8. What did you learn from the investigation? | 8. In your opinion, what is the role of investigations in Chemistry? Why do you think investigations are part of the A-Level Chemistry syllabus? Why is it important for you to do investigations? |

| | |
|---|---|
| 9. What explanation can you offer for your performance and the way you do investigations? | 9. What is the source of the investigations that you do during your Chemistry practical sessions? (textbooks, past examination papers, teacher's own questions) |
| 10. Do you see any relationship between the investigations that you do and the theory that you learn in the regular Chemistry lessons? If so, give an example. | 10. Do you see any relationship between the investigations that you do and the theory that you learn in the regular Chemistry lessons? If so, give an example. |
| 11. What is the source of the investigations that you do during your Chemistry practical sessions? (textbooks, past examination papers, teacher's own questions) | 11. What are your career aspirations? What do you want to study after completing A-Level? |
| 12. What are your carrier aspirations? What do you want to study after completing A-Level? | 12. Do you think the ability to design, plan and carryout investigations will be useful in your future studies and professional career? Why? In what way? |
| 13. Do you think the ability to design, plan and carryout investigations will be useful in your future studies and professional career? Why/In what way?<br>14 ---- | 13. How well do you do in designing, planning and carrying out investigations? After doing an investigation do you get the marks that you expect?<br>14. If you have any other comment to make with respect to investigations, please use the space below. |

# Appendix N Node summary of students' understanding of an investigation

22/12/2016 09:41

| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|

## Node

**Nickname:** Nodes\\Inquiry

**Classification:**

**Aggregated:** Yes

| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|
| Dataset | 1 | 30 | 618 | 30 | |

**Nickname:** Nodes\\Inquiry\Designed by self

**Classification:**

**Aggregated:** No

| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|
| Dataset | 1 | 8 | 135 | 8 | |

**Nickname:** Nodes\\Inquiry\Discovery learning

**Classification:**

**Aggregated:** No

| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|
| Dataset | 1 | 10 | 177 | 10 | |

**Nickname:** Nodes\\Inquiry\How scientists work

**Classification:**

**Aggregated:** No

| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|
| Dataset | 1 | 7 | 200 | 7 | |

22/12/2016 09:41

| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|

**Nickname:** Nodes\\Inquiry\Problem solving

**Classification:**

**Aggregated:** No

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 5 | 106 | 5 | |

**Nickname:** Nodes\\Process skills

**Classification:**

**Aggregated:** Yes

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 24 | 314 | 24 | |

**Nickname:** Nodes\\Process skills\Experimenting

**Classification:**

**Aggregated:** No

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 9 | 114 | 9 | |

**Nickname:** Nodes\\Process skills\Hypothesising

**Classification:**

**Aggregated:** No

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 4 | 62 | 4 | |

**Nickname:** Nodes\\Process skills\inferring

**Classification:**

**Aggregated:** No

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 4 | 52 | 4 | |





| Source Type | Number of Sources | Number of Coding References | Number of Words Coded | Number of Paragraphs | Duration Coded |
|---|---|---|---|---|---|

**Nickname:** Nodes\\Process skills\manipulating variables

**Classification:**

**Aggregated:** No

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 2 | 24 | 2 | |

**Nickname:** Nodes\\Process skills\Observing

**Classification:**

**Aggregated:** No

| | | | | | |
|---|---|---|---|---|---|
| Dataset | 1 | 5 | 62 | 5 | |

**Appendix O   Language clearance certificate**

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**Dr Saths Govender**

6 JANUARY 2017

TO WHOM IT MAY CONCERN

## LANGUAGE CLEARANCE CERTIFICATE

This serves to inform that I have read the final version of the thesis titled:

"Exploring Students' Approaches to Investigations in Advanced Level Chemistry" by T. Chirikure.

To the best of my knowledge, all the proposed amendments have been effected and the work is free of spelling and grammatical errors. I am of the view that the quality of language used meets generally accepted academic standards.

Yours faithfully

--------------------------

DR S. GOVENDER
B Paed. (Arts), B.A. (Hons), B Ed.
Cambridge Certificate for English Medium Teachers
MPA, D Admin.

## Appendix P Turnitin Report

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| Submission date: | 10-Jan-2017 05:19PM |
| Submission ID: | 757942216 |

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Exploring Students' Approaches to Investigations in Advanced Level Chemistry

by

Tamirirofa Chirikure

A thesis submitted in fulfilment of the academic requirements for the degree of Doctor of Philosophy in the School of Education

College of Humanities

University of KwaZulu-Natal

January 2017

Exploring Students' Approaches to Investigations in Advanced Level Chemistry

ORIGINALITY REPORT

| 11% | 10% | 5% | 5% |
| --- | --- | --- | --- |
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

## Appendix Q Question paper

When sodium thiosulphate, $Na_2S_2O_3$, solution reacts with acid, sulphur is slowly precipitated according to the following reaction.

$$S_2O_3^{2-}(aq) + 2H^+(aq) \rightarrow S(s) + SO_2(g) + H_2O(l)$$

a) Design an experiment to investigate the effect of the concentration of $Na_2S_2O_3$ on the rate of the reaction

You are provided with:

- a stopwatch
- a measuring cylinder
- a 250cm$^3$ beaker
- a sheet of paper with X drawn on it
- 0,5 moldm$^{-3}$ sulphuric acid
- 0,1 moldm$^{-3}$ sodium thiosulphate

Present you plan as a sequence of numbered steps.

*Plan*

(8)

b) Using the results which you would have obtained, describe how you would determine the order of reaction with respect to $Na_2S_2O_3$.

(5)

**Total: 13**