

https://dspace.org/

Practical work in university chemistry: aims and outcomes

Gunter, Christopher E.

2014-03-17
http://hdl.handle.net10539/14176

Downloaded from a DSpace repository. https://dspace.org/

Practical work in University chemistry:

Aims and outcomes

by

Christopher E. Gunter

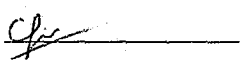
Degree of Master of Science by coursework and research:

A research report submitted to the School of Science Education, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science

Degree awarded with distinction on 23 November 2000

Declaration

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



C. E. Gunter

28th day of December 1999

Abstract

The purpose of this research was to identify and gain insight into factors that affect learning in undergraduate chemistry practical work. A case study was conducted with a 'typical' undergraduate student selected from the first year chemistry major class at the University of the Witwatersrand (WITS). A number of factors were found to affect the learning that took place and the insight gained was used to make recommendations to the WITS Chemistry Department about how to facilitate more meaningful learning in their undergraduate laboratory sessions. Many of the aims for science practical work were revised and various teaching strategies to realise the different aims were put forward. When categorising the different types of lab activities using the traditional classification system of 'verification', 'guided inquiry' and 'open inquiry', it was found that this system was insufficient. An additional type of lab activity was, thus, identified and named a 'procedural' lab session.

Acknowledgements

Many thanks to the students and staff in the WITS University Chemistry Department who made their time and other resources available for this research. Thanks also to Prof. J. D. Bradley for his valuable insight and help.

CONTENTS

DECLARATION i
ABSTRACT ii
ACKNOWLEDGEMENTS iii
LIST OF FIGURES viii
LIST OF TABLES ix

CHAPTER ONE - INTRODUCTION

1.1 Practical Work : Aims and Outcomes 1
1.2 Research Aims 1
1.3 Research Questions 2
1.4 Literature Review 2
1.4.1 Introduction 2
1.4.2 Meaningful learning defined 2
1.4.3 The changing aims and role of practical work in science education 3
1.4.4 Factors that affect learning in the laboratory 6
1.4.5 Research methodology in the laboratory and the attainment of valid, generalisable results 15
1.4.6 Research methodology in the laboratory and the usefulness of the results 17
1.4.7 Conclusion 23
1.5 An Overview of the Research Design 23
1.5.1 Quantitative vs. qualitative approach 24
1.5.2 Overall research design 25
1.5.3 Method of analysis 26
1.6 An Overview of the Research Report 26

CHAPTER TWO - DESCRIBING THE CONTEXT

2.1 Introduction 27
2.2 The Quest for the Typical 27
2.2.1 WITS university - typical ? 27
2.2.2 Choosing a 'typical' laboratory session 27
2.2.3 Choosing a 'typical' student 32
2.3 What the Student *should have* Learned Prior to Experiment A6 and the Pre-lab Test .....

2.3.1 Skills and concepts covered in previous lab sessions 36
2.3.2 Skills and concepts covered in lectures and tutorials prior to experiment A6 40
2.4 Conclusion 43

CHAPTER THREE - A DESCRIPTION OF THE STUDENT'S ACTIVITIES DURING THE LAB SESSION

3.1 Introduction 44
3.2 A Description of the Lab Session 44
3.2.1 Additional lab A6 45
3.3 Conclusion 72

CHAPTER 4 - ANALYSIS OF THE PRE- AND POST-LAB TESTS

4.1 Introduction 73
4.2 Analysis of the Pre-lab and Post-lab Tests 73
4.2.1 Introduction 73
4.2.2 Analysis of question 1(a) 73
4.2.3 Analysis of question 1(b) 79
4.2.4 Analysis of question 1(c) 84
4.2.5 Analysis of question 1(d) 86
4.2.6 Analysis of question 2(a) 87
4.2.7 Analysis of question 2(b) 89
4.2.8 Analysis of question 3(a) 90
4.2.9 Analysis of question 3(b) 91
4.2.10 Analysis of question 4(a) 93
4.2.11 Analysis of question 4(b) 95
4.2.12 Analysis of question 4(c) 97
4.2.13 Analysis of question 4(d) 99
4.2.14 Analysis of question 5 100
4.2.15 Analysis of question 6 112
4.2.16 Analysis of question 1(a) - skills test 113
4.2.17 Analysis of question 1(b) - skills test 119
4.2.18 Analysis of question 2(a) - skills test 120
4.2.19 Analysis of question 2(b) - skills test 127
4.2.20 Analysis of question 3(a) - skills test 127
4.2.21 Analysis of question 3(b) - skills test 133

4.2.22 Analysis of question 4 133

CHAPTER FIVE - FACTORS THAT AFFECT MEANINGFUL LEARNING IN THE LABORATORY : PART 1

5.1 Introduction 136
5.2 Factors that Affected Meaningful Learning in the Laboratory 136
5.2.1 The role of the demonstrator as perceived by the demonstrator..... 136
5.2.2 The assessment of the student 141
5.2.3 The amount of time available to the student to conduct the experiment..... 145
5.2.4 The aims of the experiment as perceived by the student..... 148

CHAPTER SIX - FACTORS THAT AFFECT MEANINGFUL LEARNING IN THE LABORATORY : PART 2

6.1 Introduction 150
6.2 Practical work : Aims and outcomes 150
6.2.1 Meaningful and rote learning of skills : A definition 150
6.2.2 The learning aims for laboratory work 153
6.2.3 The effect of the type of lab session on the skills learned 154
6.2.4 The effect of the context of the lab session on the skills learned 154
6.2.5 Is there a place for the 'verification laboratory' ? 157
6.2.6 A new name for an old type of lab session 166
6.2.7 Evidence from experiment A6 167
6.2.8 Recommendations 172
6.3 Prelab preparation 175
6.3.1. Interpretations 175
6.3.2. Recommendations 183
6.4 Conclusion 187

CHAPTER SEVEN - CONCLUSION

7.1 Introduction 188
7.2 Answers to the research questions 188
7.2.1. Answers to the first Research Question 188
7.2.2. Answers to the second and third Research Questions 189
7.3 Strengths and limitations of the research 194

7.3.1 Strengths 194
7.3.1 Limitations 195
7.4 Possible avenues for further research 196
7.5 Conclusion 197

REFERENCES 199

APPENDIX A 206
(1) Survey of two 'typical' students
APPENDIX B 207
(1) The chemistry department's learning aims for experiment A6
(2) The pre- and post-lab tests
APPENDIX C 212
(1) A copy of experiment A6 from the lab manual
(2) A copy of the lab manual's instructions for prelab preparation
APPENDIX D 213
(1) A copy of the student's writings in her lab manual during the lab
(2) A copy of the student's marked lab report for the experiment
APPENDIX E 215
(1) A copy of the model answers prepared by lecturer #2

LIST OF FIGURES

Figure 1: The role of practical work pre-1960 5
Figure 2: The role of practical work post-1960 5
Figure 3: Multilevel-thought triangle 11
Figure 4: A rough map of the lab 45
Figure 5: Washing the precipitate out of the beaker 59
Figure 6: Folding the filter paper 59
Figure 7: Scraping the filter paper with a spatula 107
Figure 8: Washing the filter paper 108
Figure 9: Scraping the filter paper with a glass rod 109
Figure 10: Funnel in conical flask 121
Figure 11: Folding the filter paper into a conical shape 123
Figure 12: Holding the filter paper horizontally over the funnel 122
Figure 13: Washing the precipitate out of the beaker (pre-lab test) 125
Figure 14: Washing the precipitate off the filter paper 128
Figure 15: Testing with silver nitrate 130
Figure 16: Washing the precipitate 131
Figure 17: Clamping the funnel 131
Figure 18: Possible arrangement of instructions in a manual 186

LIST OF TABLES

Table 1: Goals of laboratory activity 4
Table 2: Characteristics of three types of lab sessions 6
Table 3: Levels of discovery in the learning laboratory 7
Table 4: Common features of the first year chemistry major additional labs 8
Table 5: A summary of the skills and concepts covered in ordinary labs O1 - O3 and additional labs A1 - A2 37
Table 6: A summary of the skills and concepts covered in ordinary labs O4 - O6 and additional labs A3 - A5 38
Table 7: The aims of laboratory activity 154

Chapter 1

Introduction

1.1. Practical work : aims and outcomes

> "One of the interesting things about laboratories is that there has never been definite consensus about ... [their] purposes. Perhaps that is why they have remained popular: they can be thought to support almost any aim of teaching science" (White, 1996, p. 762).

After listing the many aims put forward for practical work in science education, White (op cit) then noted,

> "What is important is to specify how the laboratory does each of these things, because that detail should enable purposeful design and selection of specific experiments that should be more effective than an unplanned, expedient set" (p. 763).

This research has looked deeply into the aims that science educators have proposed for practical work. But it also looks at perhaps the more important question posed by White of how best to realise the different aims. There is a great potential in practical work to facilitate the meaningful learning of 'science'. Nevertheless, science educators have allowed it to lay dormant for too long. To add to this, many research projects have discovered another great potential in practical work - the potential to waste a lot of time and money. This research provides recommendations to the chemistry department of the University of the Witwatersrand (WITS) as well as to the science education community for achieving the many aims that practical work is supposed to facilitate.

1.2. Research aims

The main purpose for the study was to gain insight into the factors that affect learning in the undergraduate first year chemistry laboratory sessions at WITS. Once insight into these factors had been gained, it would be used to make recommendations to the WITS chemistry department about how they could facilitate more meaningful learning in their undergraduate laboratory sessions.

1.3. Research questions

- What factors have 'typically' been affecting learning in the WITS chemistry undergraduate laboratory sessions ?
- How have these factors 'typically' been affecting the learning that takes place in the WITS chemistry undergraduate laboratory sessions ?
- How can we manipulate these factors to facilitate more meaningful learning in the WITS chemistry undergraduate laboratory sessions ?

1.4. Literature review

1.4.1 Introduction

Potentially, chemistry practical work is an excellent opportunity for learning to occur, but it is also provides an excellent occasion to spend a lot of time and money simply getting our hands wet. In most cases, it is the latter rather than the former that has occurred. Some have even gone so far as to denounce practical work as "a costly sham" (Kahn, 1990), while still other skeptics have described it as "the long way to the sink !" (Johnstone, 1993).

This review of the literature starts off with definitions of fundamental terms used in the rest of the research report and then goes on to the changing role and aims of practical work in science education. The current literature regarding the investigation of factors that affect learning in the laboratory, as well as attempts to control them are considered. Following this, methodological challenges of educational research in the laboratory and the solutions thereof have been discussed. Finally, different types of research methodologies in the laboratory and their respective strengths and weaknesses are put forward with a view to justifying the methodology used in this research.

1.4.2. Meaningful learning defined

In order to avoid ambiguities of meaning throughout the rest of the report, it is imperative the term 'meaningful learning' be clearly defined. In recent times, there have been two main theoretical frameworks of learning which have become popular upon which to develop a research strategy. One of these is Piaget's theory of developmental stages in learning (Piaget, 1926, 1929) and the other is Ausubel's assimilation theory of learning (Ausubel, 1963, 1968). The term "meaningful learning", is derived from Ausubel's theory.

Ausubel's theory of learning is appealing "for both its simplicity in the kind and number of key concepts and its comprehensiveness in terms of the school learning events to which it is relevant. With respect to knowledge acquisition, the theory meets the criterion of parsimony; it also has significant implications for skill or motor learning and the acquisition of positive feelings or "affect." " (Novak, 1984).

Meaningful learning is contrasted by Ausubel with *rote* learning. In a nutshell, meaningful learning involves the learner consciously relating new knowledge to concepts and propositions already known. Rote learning, on the other hand, is the acquisition of new knowledge merely by verbatim memorisation, and is arbitrarily incorporated into a person's knowledge structure without interaction with what is already there (for more detail see Novak and Gowin, 1984).

1.4.3 The changing aims[1] and role of practical work in science education

Practical work has been a part of science education for a great many years. According to Hofstein (1991), since "the end of the nineteenth century, when schools began to teach science systematically, the laboratory became a distinctive feature of science education" (p. 189-190). Hofstein (op. cit.) maintains that in its early stages, practical work's main aim was to *confirm* and *illustrate* "information learned in a lecture or from a textbook" (p. 190).

After the 1960's, however, a number of new aims for practical work increasingly began to appear. These emphasised scientific inquiry skills as well as the process of science and placed stress on the importance of providing opportunities for students to make 'discoveries' during the laboratory experience (Klainin, 1991).

Ausubel (1968) maintained that practical work "gives the students appreciation of the spirit and method of science, ... promotes problem solving, analytic and generalisation ability, ... [and] provides students with some understanding of the nature of science" (p. 345).

Anderson (1976) summed up his view of what the aims for practical work in science education should be:

> "(1) to foster knowledge of the human enterprise of science so as to enhance student intellectual and aesthetic understanding;
> (2) to foster science inquiry skills that can transfer to other spheres of problem solving;
> (3) to help the student appreciate and in part emulate the role of the scientist; and

[1] In this report, the word 'aim' will be used to describe 'a desired outcome or result' of the learning experience.

(4) to help the student grow both in appreciation of the orderliness of scientific knowledge and also in understanding the tentative nature of scientific theories and models." (p. 204).

Lunetta and Hofstein (1980) organised the aims of practical work in science education into three domains (1) the cognitive domain (which involves the intellectual development of the student), (2) the practical domain (which involves the co-ordination of the brain and muscular activity) and (3) the affective domain (which involves the student's attitude to a task). Each domain has its own set of aims (see table 1, below).

Table 1 : Goals of laboratory activity (Lunetta and Hofstein, 1980).

Domain	Goal
Cognitive	Promote intellectual development
	Enhance the learning of scientific concepts
	Develop problem solving skills
	Develop creative thinking
	Increase understanding of science and scientific method
Practical	Develop skills in performing science investigations
	Develop skills in analysing investigative data
	Develop skills in communication
	Develop skills in working with others
Affective	Enhance attitudes towards science
	Promote positive perceptions of one's ability to understand and to affect one's environment

With the change in the aims of practical work, a change in its *role* in the science education process began to be proposed. Previously, central to science education was the introduction of the student to scientific concepts. These concepts could be confirmed and illustrated in the laboratory if the teacher desired. This was illustrated (figure 1) by Romey (1968).

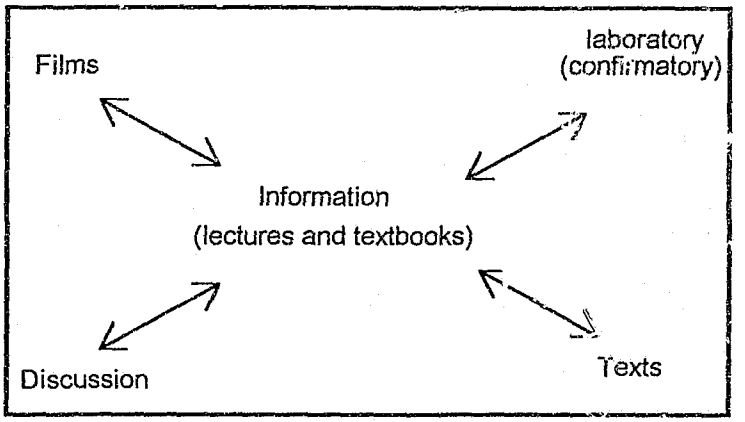


Figure 1 : The role of practical work pre-1960

The new emphasis on the *process of science*, however, meant that the laboratory could assume a central role in science education. Students were meant to conduct guided scientific 'investigations' through practical work in which they could 'discover' scientific concepts for themselves. Lectures, textbooks and other sources of information would assume a supplementary role to the investigation.

Romey (1968), once again illustrated this (figure 2).

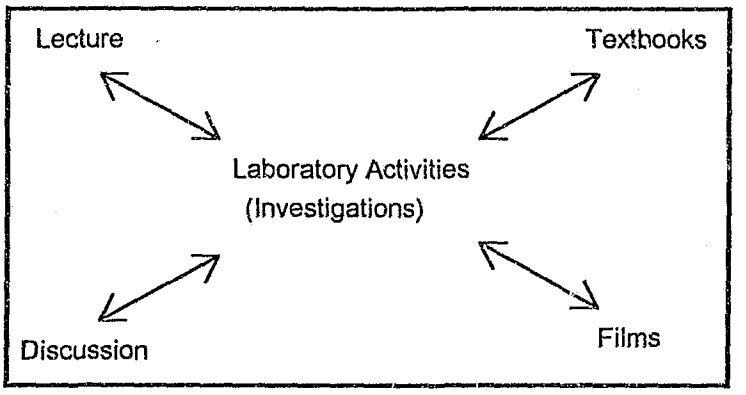


Figure 2 : The role of practical work post-1960 (Romey 1968)

However appealing this form of science education appeared in the 1960's, by "the mid-1970's science educators and researchers were questioning the value and the educational effectiveness of the science laboratory at least as it was practised in many schools and in many places in the world. This has led to a trend in which there is a retreat from student centred science activities in the laboratory" (Hofstein, op cit). Despite this observation, the extent to which the laboratory investigation is currently playing a central role in most educational institutions does not seem to

have been conclusively determined. On top of this, a number of extensive reviews of the literature covering the aims of practical work and its role in science education (viz. Hofstein, 1991; Klainin, 1991; Hofstein & Lunetta, 1982) have not been able to clearly articulate how effective it has been in realising the diverse aims put forward above. Neither were they able to make clear how *best* we can use the laboratory experience to facilitate these aims.

The question posed by Ramsey and Howe (1969) is still being asked by many today;

> "That the experience possible for many students in the laboratory situation should be an integral part of any science course has come to have a wide acceptance in science teaching. What the best kinds of experiences are, however, and how these may be blended with more conventional classwork; has not been objectively evaluated to the extent that clear direction based on research is available to teachers". (p. 75)

1.4.4. Factors that affect learning in the laboratory

A great deal of educational research has been conducted with students in the laboratory setting in order to investigate the factors that affect the learning that takes place therein. This section explores the efforts of those who have endeavoured to do so and the outcomes thereof.

1.4.4.1. The nature of practical work

"There is a touching faith among science educators that practical work is, without question, a good thing" (Johnstone, 1993, p. 118). Johnstone's insightful comment highlights a vital, yet much over-looked aspect of practical work that affects learning in the laboratory. He went on to point out that simply *doing* practical work will not automatically cause students to learn science and called for a reappraisal of the place (or role) and *nature* of practical work in school science. The attainment of the many aims outlined above, it seems, depends not only on the fact that the students *do* practical work but also on the nature (or *type*) of activity presented to them in the laboratory.

Hofstein (1991) noted that "[s]tudents' behaviours are significantly controlled by the *type* of laboratory activities provided by the laboratory handbook" (p. 203, italics added). Pavelich & Abraham (1979), in an attempt to investigate how the type of laboratory can affect learning, classified practical work into three types of laboratory sessions: verification, guided inquiry, and open inquiry (see table 2 below).

Table 2. Characteristics of three types of lab sessions [a]

	Verification	Guided Inquiry	Open Inquiry
Order	C → D	D → C	D → C
Choice of problem	T	T	S
Experiment design	T	T	S
Data Analysis	T	S	S
Data Explanation	T	S	S

[a] C : Concepts D : Data T : Teacher S : Student

They, thereupon, attempted to show that a guided inquiry type of laboratory work (as opposed to a verification type) *better* facilitated the following three aims,

(1) to acquaint the student with fundamental laboratory techniques and procedures.

(2) to give the student experience with aspects of scientific enquiry.

(3) to enhance the student's thinking ability toward more abstract thinking processes.

They maintained that;

> "in the verification laboratory the intellectual decision making exercises that characterize laboratory work are performed for the student. The teacher (or lab manual) chooses the problem, the experimental design, the method of data analysis, and (through the introductory theoretical discussion) suggests an explanation for the data" (p. 100)

Their carefully designed guided inquiry lab instructions, on the other hand, did not provide the student with a theoretical discussion or a method for analysis of the data. The students were, thus, required to produce their own analysis and explanation of the data.

In their paper, however, no formal evaluation of the attainment of the first two aims was conducted, while the extent to which the third aim was realised was ascertained by students' responses to 'Piagetian type paper and pencil tests'. It is interesting to note that their results, after subjecting their students to *two semesters* of guided inquiry, did not show any significant difference to students who were involved in traditional verification type lab sessions.

Other similar classifications of laboratory session types include that of Pella (1961), who devised a system of degrees of freedom to distinguish between lab types, as well as Herron (1971), who categorised practical work by its 'level of discovery' (table 3).

Table 3: Levels of discovery in the learning laboratory (Herron, 1971)

Level of Discovery	Problems	Ways and Means	Answers
Level 0	Given	Given	Given
Level 1	Given	Given	Open
Level 2	Given	Open	Open
Level 3	Open	Open	Open

Lunnetta and Tamir's (1979) study of laboratory manuals uncovered a great gap that generally exists between the types of activities that students perform in the laboratory and the stated aims for the laboratory teaching. Very often it seems that science educators have set practical work for their students without giving thought to whether the type of lab session provides opportunity for the students to learn meaningfully through it. Gott and Duggan (1996) commented that "the assumption that an understanding of scientific evidence will emerge as a result of doing practical work, without being specifically taught, is questionable" (p. 793). On the whole, however, not a great deal of research work seems to have been done with respect to how the *type* of practical work affects the learning in the laboratory. Most commentators on the state of science learning in the laboratory simply seem to take it for granted that student achievement of the many aims for practical work is in some way dependent on the nature of the learning experience. Very few, it seems, have actually set out to think this factor through thoroughly or investigate it at length.

1.4.4.2. Amount of pre lab preparation

> "The most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly " (Ausubel, 1968).

Most lab sessions require some sort of pre-laboratory preparation on the part of the students for meaningful learning to take place successfully. This is simply because "first time, unprepared learners are not in a position to process laboratory experiences with understanding" (Johnstone, 1997). From a study of the literature, it seems that the issue is not so much whether pre-lab preparation should take place but (1) what type of pre-lab preparations should take place and (2) how do we motivate the students to actually do them.

Johnstone (1997) suggests that merely reading through the manual and doing a few calculations before entering the laboratory is not sufficient. He proposes a more fundamental preparation involving "revision of theory, reacquaintance with skills, planning the experiment to some extent, [and] discussion with members of a team about partition of labour" (p. 267). He suggests that the aim of this would be to;
(1) convince the student that the experiment is worth doing

(2) convince the student that the results are important and informative
(3) give the student some feeling of ownership to justify the time spent
(4) give the student a feel for the procedure
(5) cause the student to explore the important variables.

He goes on to describe research where the number of 'thoughtless questions' was reduced and mean post-lab test scores were increased when students participated in pre-laboratory preparation (although he does not describe the type of preparation or how long the average student spent doing it).

Novak and Gowin (1984) report research where students were required by the teacher to draw *Vee diagrams* (a heuristic device that looks like a capital V) prior to the lab session. They relate that "[s]tudents so instructed spent 90 percent of their time in the laboratory on task related activities, whereas students not so instructed only did half as well" (p. 114).

Palladino and Figgens (1983) recount how they developed a self-paced, interactive computer program consisting of pre-laboratory exercises for students to do before they entered the laboratory. Students "who showed by their answers a greater need for additional understanding were provided with extensive branching and looping subroutines" (p. 212). They found that 71 % of students who used the program before every lab session felt that they had a good understanding of the laboratory exercises before they entered the laboratory, while only 58 % of students who did not use the program felt likewise.

In a study of undergraduate first year university students, Rollnick et. al. (1998) investigated the effect of different types of pre-lab preparation on the laboratory experience and report writing. The two types of pre-lab preparation required were;
(1) a synopsis of the experiment.
(2) pre-lab questions about underlying theory relevant to the lab session.
They found that in both cases students who did well in the pre-laboratory exercises tended to have well written reports. Their results did not reveal any distinct advantage to writing synopses over the traditional pre-lab question type exercises. They also observed that "some students will prepare thoroughly no matter what obligatory preparation is demanded".

Frequently, however, the problem is not that no pre-lab preparatory exercises exist, but that the students don't bother to do them. White (1996) speculated that this is a result of the routineness of experiments. He pointed out that "routine encourages mindlessness" (p. 771). To alleviate such problems, he suggested that students be *forced* to answer questions about the experiment before they are allowed to enter the laboratory.

Pickering (1992) compared experimental and control groups of students where the experimental group of students were not allowed to bring the manual into the laboratory, but were allowed to "prepare their lab notebooks in any way whatever". This forced the experimental group to do pre-lab preparation. His results, obtained from paper and pencil tests, disappointingly did not show any significant difference between the two groups. He suggested that the *type* of preparation could also be a factor. Some students may simply copy the lab manual into their lab notebooks.

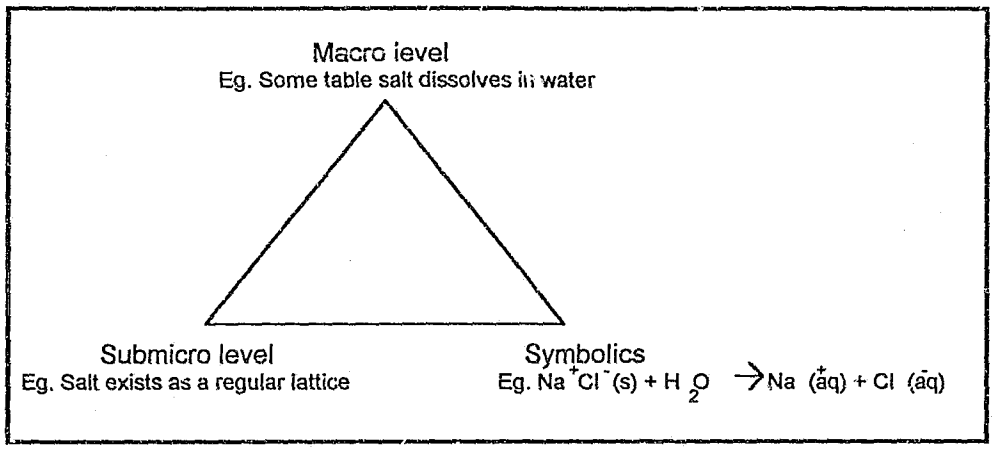
1.4.4.3. 'The noise to signal ratio'

One factor that has raised a considerable amount of attention is that of 'the noise to signal ratio' of practical work (Johnstone and Wham, 1982; Johnstone and Letton, 1988). Johnstone (1993) maintains that the student cannot tell one from the other. Often merely peripheral or preparatory aspects of the practical (ie. noise) become just as important to the student as the vital observations to be made (signal). This may result in an overload of the working memory of the student (ie. too many things to think about at once) causing him/her to be unable to systematically and intelligently work through the experiment. Often an information overload reduces students to simply following the procedure in the lab manual without actually understanding what they are doing.

Johnstone and Wham (op. cit.) give three recommendations to improve the amount of learning that takes place in the laboratory;
(1) enhance the signal by giving a clear statement of the point of the experiment
(2) suppress the 'noise' by stating clearly what is preliminary, peripheral and preparatory
(3) teach important skills for their own sake, *before* using them for some investigation. This would avoid the possible overload of trying to teach manipulative or interpretive skills at the same time as data are being sought.

1.4.4.4 'Multilevel thought'

Johnstone (op. cit.) in his paper, "*Why is science difficult ? Things are seldom what they seem*", puts forward another argument against most educational laboratory practice. He maintains that one reason why science concepts are so difficult for students to learn through practical work is because they have to deal with ideas and information on three levels - the macro, submicro and symbolics level (see figure 1).



"The macrophenomenon (tangible and visible) that salt dissolves in water is 'explained' in terms of its existing in a regular lattice, being attracted to water molecules and being towed off into solution. This is then 'shown' as $Na^+Cl^-(s) + H_2O \rightarrow Na^+(aq) + Cl^-(aq)$" (Johnstone, 1993, p. 118)

Figure 1: Multilevel thought triangle (adapted from Johnstone, 1993) :

In a normal science classroom, a teacher can jump from one corner of the triangle to another almost in one sentence, leaving the student stuck in the macro corner. This very phenomenon of multilevel thought is demanded by most practical sessions in the laboratory. Students are expected to make observations at the macro level, and then interpret them in terms of the submicro and symbolics level. This immediately throws them into the middle of the triangle above. Johnstone reckons that it "*is doubtful if the edifice would have been any less secure if the experiment had not been done at all*" (p. 119).

His suggestion for improvement of learning in the laboratory is that "there is a sense in which science should be taught at a *macrolevel only*, with 'explanation' [ie. symbolics and submicro levels] available on demand and in doses small enough to be processed" (p. 122, italics added). This suggestion, however, can only be accepted if our aims are limited to students learning practical skills and becoming familiar with certain chemical macrophenomena. Johnstone gives no counsel with regard to 'multilevel thought' when practical work is used specifically as a tool to aid the learning of symbolics and concepts that describe the submicro level of matter.

1.4.4.5 Assessment

Guskey (1994) noted that some researchers (vis. Haladyna et al, 1991; Shephard, 1990) have found that assessment systems like multiple choice tests and standardised achievement tests can

cause teachers to skew their instruction to the basic skills needed to successfully complete the test. As a result of this, the curriculum can narrow (Shephard, 1989).

For many educational institutions, written evidence, either in the form of a laboratory report or a paper and pencil test, is the sole means of assessing all the work done by students in the laboratory. This method, though i is the most economically viable and the least time consuming, can cause demonstrators and laboratory teachers to skew their teaching to the completion of a lab report. This in turn can reduce the amount of meaningful learning that takes place during practical work because 'test oriented' students will not bother to learn anything that will not be assessed - in this case manipulative skills (see Turner, 1983).

This problem can be alleviated in two ways;

(a) practical examinations

These have been used to some extent in South African universities, but, as noted by Ganiel and Hofstein (1982), they do have a number of disadvantages. Firstly, the examinations are limited only to experiments that can be done within a short period of time (eg. 2-3 hours). This limits the scope of the experiment and thus the validity of the assessment. Secondly, practical examinations are difficult to administer and thus they cannot be conducted very often. This means that there is a high probability that the results will not be reliable or valid, because many of the students may be overly anxious. Thirdly, most practical examinations are administered to large groups of students at the same time. Thus, the assessor will not have time to observe each student systematically and thus will only be able to assess their written work.

(b) continuous assessment

Hofstein (1991) observes that in such "systems of assessment, the teacher unobtrusively observes each student during normal lab activities and rates him or her on specific criteria" (p. 208). There are two disadvantages to this however:

(1) it is a very time consuming method of assessment, and only a few students at a time can be assessed.

(2) unless the student's actions are taped on video, it is difficult for anyone to *check* the validity of the assessment. For this reason it is absolutely essential that the assessor give evidence for every inference (s)he makes about the student's performance as well as be absolutely honest in his/her report of what went on.

The consequences of using continuous assessment, however, are that classes must be smaller and teachers must have an excellent system by which to record, store and report their

observations (unskilled teachers may find that they have hundreds of 'bits' of information about each student but no way in which to report it to parents, pupils or other institutions).

Novak (op. cit.) found that laboratory work (as compared to lecture or lecture demonstration instruction alone) resulted in little or no increase in students' understanding of the relevant science concepts. He speculated that part of the reason for this is that students are "preoccupied with making observations, records of observations, and ... transforming their records" (p. 611). In doing so, he noted that they do not give careful and explicit attention to the events or objects that they are observing or to the regularities they are seeking to observe.

He maintained, however, that instructing students in the nomenclature of Gowin's Vee and its use in interpreting laboratory work was found to be a useful way of alleviating the problem described above. By means of 'Vee mapping' students are forced to consider the role of theories and concepts in choosing events for observation and constructing records or transformations of data. Novak and Gowin (1984) suggest that Vee mapping can be evaluated *in addition* to a written lab report when students are required to report on an inquiry that was made in the laboratory.

1.4.4.6. The laboratory teacher's perceptions of the aims of the practical and how they should be taught

> "One of the lessons learned during the years of massive curriculum development (in the 1960's) was that the teacher plays an extremely important role in what students learn. The best curriculum materials can result in limited student growth if a teacher is insensitive to the intended goals" (Hofstein, 1991, p. 202)

Shymansky et. al. (1976) developed what is called 'SLIC (Science Laboratory Interaction Category) - teacher', an instrument whereby one can obtain information about what *kind* of teaching is occurring in the laboratory. Barnes (1967) also designed a similar instrument called the Biology Laboratory Activity Checklist (or BLAC) which measures the *type* and *amount* of biology laboratory work from the student's point of view. Some (Eggleston et al, 1976) have found that no matter what the intended aims of the experiment or actual activities that students engage themselves in, the teaching style of the teacher will greatly influence what learning takes place. "Deductive-oriented teachers teach practical work authoritatively [leaving the students with the idea that there is one correct answer sanctified by authority to the questions posed for the practical], while more inquiry-oriented teachers teach investigative methods of learning" (Hofstein, 1991, p. 203). Pavelich and Abraham (1979) also mention how "superficially-trained

inexperienced teaching assistants" (p. 103) can break down the whole process of guided-inquiry, because they can give the game away to the students by simply giving them the 'right' answer.

1.4.4.7. Student-student interactions (peer interaction and co-operation in the laboratory)

Hofstein (1991) reports two recent studies that have been conducted on this factor by Cohen (1987) and Okebukola (1986). Both showed that co-operative learning in small teams in the laboratory greatly improved the attitudes of the students towards laboratory work and the topic that they were covering in the practical. Farrell et al (1999) have also reported work where they divided their students into groups of four or five and assigned each a role within the group (viz. manager, recorder, technician, reflector and presenter). Although a full assessment of the course had not been completed by the time their paper was published, they were able to show that their group work approach significantly enhanced the attitude of students towards chemistry practical work.

1.4.4.8. The laboratory manual

Rollnick et al (1998) maintain that the "tools of language available to the student to mediate the written instructions" can affect what the student learns in the laboratory. Certainly it is possible for the reading vocabulary and sentence structure of the laboratory manual to be of too high a level for students. Not only that, but if the laboratory manual leaves too much unsaid (eg. relevant concepts are not clearly defined), it can impair the student's ability to learn meaningfully from the laboratory session. Chen (1980) found a significant improvement in students' understanding of relevant concepts as a result of a physics laboratory by (among other things) rewriting the written instructions and specifically making clear how these concepts were relevant to the experiment at hand.

1.4.4.9 The student's perception of the aims of the practical

Students can hold different ideas about the purpose of a laboratory session (Knamiller & O-saki, 1995) and this in turn can affect how they interpret the resulting data. Gunstone (1994) relates a physics experiment concerning Ohm's law (V = IR) where students were to wire a DC circuit and "explore whatever relationship there might be between V and I" (p. 143) for a light bulb resistor. All but one of the students "explicitly asserted one of the purposes of the experiment to be the verification of Ohm's Law" (p. 143) when in fact the transformed data (a plot of V vs. I) clearly shows that Ohm's Law is not verified in this case. A straight line graph of V vs. I is only obtained when resistance is constant, in this case it was not because the temperature of the light bulb increased over time and this meant that the resistance increased. Most of the students

simply drew a 'line of best fit' between the data points attributing the discrepancies to 'experimental error' or 'errors in the equipment', clearly showing that the perceived aim of the experiment influenced how the students interpreted the data and thus what they learned.

1.4.4.10. The interdependency of different factors

Potentially, every aspect of the laboratory experience can act in some measure to affect the meaningful learning that takes place, from student-teacher interactions to the broken ventilation system which could promote stale, stuffy and unhealthy working conditions to the *size* of the laboratory equipment. Not only this, but many times the factors mentioned above act interdependently to affect the amount and type of meaningful learning that takes place. For this reason McComas (1997) has suggested that the laboratory be studied as an *ecological system*. This review of the literature has considered only those factors that were *predominantly* found in the literature as well as some factors that (with hindsight) the researcher believes to be relevant to this specific project.

1.4.5. Research Methodology in the laboratory and the attainment of valid, generalisable results

The methodological challenge that arises when conducting educational research in the laboratory, is that of *valid measurement* vs. *generalisablity*.

The practical nature of laboratory work means that the measurement of *performance skills* is inevitably involved in any research that takes place around it. The challenge arises because, as noted by Parsons et al (1991), "there is a poor correlation between the marks obtained by observing and the marks obtained by inspection of the written product from the same piece of work". This confirms work done earlier by Tamir (1972).

Grobman (1970) noted that;

> "With few exceptions evaluation [of 'new' science teaching projects] has depended on written testing ... there has been little testing which requires actual performance in a real situation or in a simulated situation which approaches reality ... This is an area where testing is difficult and expensive" (p. 192-193)

Paper and pencil tests as well as written student reports are easy to administer and mark, but they are limited only to the evaluation of (1) experimental data and observations and (2) the

recognition, formulation and interpretation of the problems studied. They *cannot* validly measure the extent to which the student has acquired the relevant *practical skills* - only observation of the student involved in the performance of these can lead to their evaluation with a high degree of validity (though even this is no guarantee of valid results because different observers can see different things depending on their theoretical standpoint and what they are looking for). The validity[2] of such cases, however, can be improved by the use of a video tape which would settle any disputes with regard to what actually happened.

The reason why, as stated by Grobman (opt cit), evaluation which requires a *performance* of some sort becomes expensive and difficult is because it takes up much more time than simply getting students to submit written answers. This is because each student has to be *observed individually* as (s)he performs the tasks set for him/her. Paper and pencil tests, are much less time consuming because an infinite number of students can complete written responses simultaneously without the need for individual attention. Thus, for research involving the measurement of practical skills, sample sizes have to be greatly reduced and are therefore very likely to be 'non-representative' of the entire population.

This problem can be solved, however, by adopting an idea from Schofield (1993).

Schofield (op. cit.) maintains that if one wants to understand a single situation in the light of the findings from another, then it is crucial to have detailed, comprehensive descriptions of both instances. Analysis of the "similarities and differences then makes it possible to make a reasoned judgement about the extent to which we can use the findings from one study as a 'working hypothesis' ... about what might occur in the other situation. Of course, the generally unstated assumption underlying this view is that our knowledge of the phenomena under study is sufficient to direct attention to important rather than superficial similarities and differences. To the extent that our knowledge is flawed, important similarities or differences may inadvertently be disregarded."

It is possible, nevertheless, to design the study of a very small sample so that it will still be relevant to a substantial number of individuals within a population. Schofield (op. cit.) once again suggests that this could be done by studying *what is*. By this he means the *typical* or the *ordinary*. "If policy-makers need to decide how to change a program or whether to continue it, one very obvious and useful kind of information is information on how the program usually functions, what is usually achieved, and the like. Thus the goal of studying *what is* is one important aim for many kinds of summative evaluations" (p. 98).

---

[2]The type of validity in question here is sometimes called 'descriptive' validity and refers to the *factual accuracy* of the account made (Maxwell, 1992).

Obviously it will be impossible to find a case that is typical in all respects. (This is because even if we could find a typical student in all major relevant dimensions, typical students do not all work in an environment that is typical in every way.) Thus, we cannot take the 'studying *what is*' principle too far by implying that it represents an *entire population*. Nevertheless it is a useful concept that could guide the qualitative researcher in his/her choice of initially deciding who and what to study in order to achieve maximum relevance to other interested parties.

Studying *what is* can also be enhanced if the researcher chooses to study two or three typical cases. In this way (s)he can check whether hypotheses in one case ring true in the others. Hypotheses that don't stand up to this sort of falsification can then be adapted so as to fit all the cases studied. Obviously the more cases studied the more credibility hypotheses carry. (Care must be taken, however, to balance the number of cases chosen with the amount of detailed description, which if inadequate, can result in individual case studies losing their ability to act as a 'working hypothesis' in other similar situations.)

1.4.6. Research methodology in the laboratory and the usefulness of the results

Much educational research into the factors that affect learning in the laboratory has been of the quantitative type in which a researcher, prior to the field work, postulates a factor that could affect meaningful learning in the laboratory. (S)he then sets about (1) selecting a sufficiently representative sample of students, (2) splitting it up into equivalent control and experimental groups, (3) exposing the experimental group to a new teaching program and the control group to the conventional one, and (4) comparing the respective changes in the responses of the two groups from a pretest to a post-test in order to determine the extent to which the new teaching program has affected the learning that took place (See Pavelich & Abraham (1979), Palladino & Figgens (1983), Pickering (1992), Johnstone (1997), Rollnick et. al. (1998)).

This type of research has one serious limitation, however. As noted by Hofstein and Lunetta (1982) when commenting on past research of this sort, if "differences in learning did occur between students [in an experimental and a control group] ... those differences were probably masked by confounding variables, by insensitive instruments, or by poor experimental design. Indeed ... the variables that have been controlled and measured often have been only a subset of *important dependent and independent variables*" (p. 212). This observation highlights the fact that quantitative research of this sort is often not able to explain *why* a certain change (or lack of it) occurred. It can only tell us the probability of another member of the population attaining a

certain change in the pre- and post-test result from the same test in the same setting[3]. This is because the reasons for the change from a pre- and post-test result are not actively explored and systematically described by the quantitative researcher. They are *presupposed* before either test is ever written. Thus, by postulating a factor that will affect learning in the laboratory at the outset, quantitative researchers *presuppose* a relationship between a certain type of behaviour and it's meaning. This process of presupposition is rendered invalid when one realises that different students (or groups of students) can exhibit the same response for a multiple choice test question, but for entirely *different reasons*. Thus, the relationship between the response and the meaning attached to it is presupposed by the person who designed the answer to the test.

In order for a researcher to determine with greater confidence *why* a certain response was exhibited by a member of the sample, (s)he would have to make a systematic description of the context of the response. In quantitative research such systematic descriptions are not usually done. This is because in order for sample sizes to be sufficiently representative, they have to have a relatively large number of individuals in them. Thus, it becomes very costly and time consuming to look at each individual member of the sample and systematically describe the context of each of his/her responses in order to determine *why* (s)he exhibited certain actions.

Quantitative researchers often try to counter this criticism of their method by trying to control every possible factor that could cause a change in the students' responses other than the predetermined factor. In this way, they attempt to ensure that the change undergone by the students is *only* a result of the special treatment and not of some extraneous factor. This too, however, is not a fail-safe remedy. Often *unforeseen* extraneous factors can creep into the learning process during the time of the programme[4]. If this happens (and it usually does), there is little that the quantitative researcher can do except (1) start the research again, this time trying to control this factor, (2) ignore it and assume that the factor did not have any significant effect on the results obtained or (3) report the results making educated guesses about the extent to which the factor affected the results obtained. It is the last course of action that usually occurs in quantitative research and this usually leads to results with an unsatisfactory level of validity.

For this reason, Hofstein and Lunetta (1982) commenting on the shortcomings of past quantitative research noted that, "Seldom has attention been given to the characteristics of the student sample or even to describing the nature of the laboratory instruction. ... Research into

---

[3]Note: This type of research cannot tell us the probability of another member attaining a certain change in the pre- and post-test result *for a certain reason* either.

[4]Parlett and Hamilton (1972) report a case where unforeseen factors rendered the results of the research invalid - "After criticism that it had not controlled for the Hawthorne effect, the i.t.a. experiment was *restarted* after two years." (Parlett & Hamilton, 1972, p. 9, italics added)

the effectiveness of science laboratory experiences should use valid methods to monitor dependent and independent variables more carefully than in the past" (p. 213).

This problem was experienced specifically by Pickering (op. cit.) in his account of a new type of pre-laboratory preparation. The results of the post-test (which, by the way, was paper and pencil only) showed a non-significant statistical difference between the experimental and control groups. In order for him to explain why these results were attained, he had to try to think of factors that might have caused a non-significant difference (eg. rather than actively summarising the lab-manual, students *may* have merely copied it out into their lab books *perhaps* resulting in minimal differences between the two groups). His lack of substantial proof resulted from his lack of description of the context of the entire learning experience. If he had described how each individual student had set about their pre-lab work, as well as how this affected their subsequent learning in the laboratory, he then might have been able to give valid reasons for the observed test results. But even if his class had consisted of only ten students he would not have been able to *systematically* describe each one's learning processes *by himself* (he would have needed a team of researchers - perhaps one for each student). As a result, the post-test scores could only tell the reader the probability of another member of the population attaining a certain result in the same setting. They could not, however, indicate the probability of another member of the population displaying a certain response in the same test under the same conditions *for the same reasons*.

Pavelich & Abraham (op. cit.) also experienced similar problems with the results that they obtained. They found that their experimental group did not display greater abstract thinking abilities (based on Piagetian-type tests) than their control group after exposing them to an inquiry-format laboratory program. In their attempt to explain these results (based on educated guess-work rather than systematic observations) they concluded that it *might* have been because (1) the demonstrators were "inexperienced" and "superficially trained" or (2) because the chemistry portion of the freshman's academic experience was not enough to effect measurable change in the growth of the students' intellectual development.

As noted by Roychoudhury & Roth (1996), "research ... conducted in the process-product paradigm ... usually has not *described* the student-student or student-teacher interaction in detail" (p. 424, italics added). As a result of this, it cannot tell us with a high degree of validity *why* a certain result was achieved. Thus, even if Pickering (op cit) had observed marked differences between the control and experimental groups, unless he had provided a systematic, detailed description of the learning process in his published paper, he would not have been able to assert with a high degree of certainty that the change was a result of the pre-lab preparation. The differences could have been due to some 'extraneous' factor (eg. the Hawthorne effect or

the experimental group received more attention from the teacher than the control group). Again these might not have occurred, but since no detailed description of the learning process was reported to have been made, his results would not be able to refute these accusations in any sort of valid way.

The proposed solution is twofold.
(1) The researcher should actively observe the students while they are engaged in the learning experience in order to describe factors that are affecting the learning that is taking place. This will enable him to increase the validity[5] of the inferences made about *why* a presupposed relationship was or was not confirmed. This sort of observation, however, has frequently been labelled as 'subjective' because of the fact that multiple observers of the same events can interpret what actually goes on in totally different ways. This difficulty is countered by a process of 'triangulation' (Wolcott, 1988) where inferences made about the student's behaviour are based on at least three sources of information (eg. observed behaviour, responses to oral questions posed during the learning experience and written data like lab reports and rough work).

As Maxwell (1992) observes, "[a]ccounts of participants' meanings are never a matter of direct access, but are always *constructed* by the researcher(s) on the basis of participants' accounts and other evidence" (p. 290). Thus the need for triangulation is vital if one is to accurately understand the meanings of the students' actions in the laboratory and make valid descriptions of the factors that affect their learning. One cannot haphazardly observe students between the pre- and post-tests and make educated guesses about what may have caused the results. There has to be some sort of *systematic inquiry* into what went on in the laboratory in order to make a valid description of the context of the learning. Once this is achieved, evidence for each postulated factor that affected learning must be provided.

This, however, leads us back to the challenge that we faced before - the fact that when making observations, only a small sample at a time can be investigated with a high degree of validity and often at the cost of decreasing the generalisablity. Thus, the researcher should go to great lengths to choose a sample that is 'typical' of the population (see section 1.4.6. above).

Roychoudhury and Roth (1996) used this method to great effect in order to investigate the interactions between students working in a group while they were conducting open inquiry

---

[5]This type of validity is different to 'descriptive' validity mentioned in the previous section, which is primarily concerned with the factual accuracy of the events that occurred. This type of 'interpretive' validity (Maxwell, 1992) is primarily concerned with the soundness of the inferences "from the words and actions of the participants in the situations studied" (p. 290).

experiments. They obtained data from three sources (1) videoing the students as they were conducting the experiments, (2) getting the students and the teacher to write reflective essays on the whole process, and (3) observation of the students' laboratory reports. This enabled them to validate their results by triangulation. They discovered three types of interactions that occurred between their students while working in groups on open inquiry experiments. Their 'thick', detailed descriptions of the context of the setting, however, allow the reader to make a reasoned judgement about the extent to which (s)he could use the findings as a 'working hypothesis' about what might occur in his/her own setting. Other research of this sort was reported by Olsen et al (1996) who conducted case studies of three high school science teachers' approach to using experiments to help them teach Newton's second law.

(2) The student's responses in the pre- and post-tests should also be obtained by a method that enables the researcher to validate the responses. This ensures that no presupposition of the meaning of the student's actions on the part of the researcher can invalidate the inferences drawn from the students answers to the tests. This is commonly done by using the interview method (Posner and Gertzog, 1982), where the student may be asked questions like, 'why do you say that ?' in order to clarify the answers that (s)he gives while responding to the set questions. This, again, is a very time consuming method of gathering data and therefore must be solved by the careful selection of 'typical' students as outlined in section 1.4.6. above.

Although the qualitative approach to research does offer some solutions to the challenges faced in quantitative research, it is not the educational researcher's methodological panacea. One of its drawbacks can be understood by drawing a parallel with Heisenberg's Uncertainty Principle. Heisenberg asserted that it is impossible to simultaneously know the exact location and momentum of a quantum particle. This is because if one tries to measure its exact location, the *actual act of observation disturbs its motion in an uncontrollable and unpredictable way.* Similarly, if one tries to measure its motion, its location is disturbed in a like manner. The very means of observation, disturbs the system in an indeterminate way (Halliday and Resnick, 1988).

In the same way, the very presence of an observer (in this case the researcher) can cause the actions of the student to be affected in an uncontrollable, unpredictable way (especially if the researcher is always asking questions, taking notes and making the student very conspicuous to the rest of the group). (S)he may try to impress the researcher and may even suppress behaviour that (s)he believes will cause the researcher to see him/her in a bad way. The extent to which this occurs is the extent to which the results of a qualitative study can be invalid (because it does not accurately portray the *normal state* of the student(s) under investigation). Hammersley and Akinson (1983), in their book 'Ethnography : Principles in Practice' note a number of factors

under the heading of 'field relations' that can cause the validity of an ethnographic account to decrease. Those being researched will often "try to gauge how far he or she [ie. the researcher] can be trusted, what he or she might be able to offer as an acquaintance or friend, and perhaps how easily he or she could be manipulated or exploited" (p. 78).

There are, however, a number of steps that qualitative researchers can take to improve the validity of their investigations.
(1) The researcher can try to hide him/herself from the student (either by a hidden camera/tape recorder or by a suitable disguise). This, however, brings us to the issue of human rights (Do the researched have a right to know that we are studying their actions ? How important is it to gain the permission of a person (or group of persons) before one conducts research with them ?).
(2) The researcher, through the detailed descriptions, can make reasoned judgements about the extent to which the change of behaviour has occurred (see Miller (1952) who encountered such problems).
(3) The researcher can take steps to make the student feel comfortable in his/her presence; this ensures that (s)he will not significantly alter his/her behaviour. This can be done by;

- making him/her aware that the study is anonymous.
- being sensitive to the temperament of the student and making him/her feel at home in the presence of the researcher.

In this research, the latter two solutions have been employed to maximise the 'interpretive' validity of the results.

1.4.7. Conclusion

A great number of people have endeavoured to investigate the factors that affect the realisation of the many aims set forth for practical work. Some of these factors include, the nature of practical work, the amount of pre-lab preparation, the 'signal to noise ratio' (Johnstone and Wham, 1982), 'multilevel thought' in practical work (Johnstone, 1993), the assessment of practical work, the laboratory teacher's perceptions of the aims of the practical session, student-student interactions in the laboratory, the laboratory manual as well as the student's perception of the aims of the practical.

Educational research in the laboratory, however, presents us with a challenge in its methodology. This is because the measurement of learning therein inevitably involves practical skills which cannot be observed on a large scale in a short time. Results obtained from samples of a manageable size, however, are not usually generalisable. Nonetheless, this difficulty can be

overcome to a certain extent by choosing a sample that may be considered 'typical' of the population (Schofield, 1993).

The quantitative approach to educational research in the laboratory is useful to the degree that it allows us to determine the probability of obtaining a certain result under specific, fixed conditions. Its limitations appear, however, when one attempts to use it to determine *why* these results were obtained. This is because in general no systematic description of the context is made and thus any inferences relating to reasons for responses are not necessarily valid.

Qualitative research, on the other hand, allows the researcher the opportunity to actively make detailed descriptions of the context of the learning experience as well as obtain the actors' perspectives of the meanings of their actions. Detailed descriptions of context allow the reader to use the research under scrutiny as a 'working hypothesis' about what would happen in his/her situation, while obtaining the actors' perspectives ensures that inferences made about their behaviour and its meaning hold a greater degree of validity. This in turn ensures that the researcher's hypotheses about the factors that affected learning are more valid.

1.5. An overview of the research design

1.5.1 Quantitative vs. Qualitative approach

In this research, a qualitative/descriptive approach was favoured over the process-product/ quantitative approach. This was because the research questions necessitated the unearthing of *reasons* for students' responses. A qualitative approach meant that a greater degree of validity could be attained in the results, while the thoughtful selection of a 'typical' student under 'typical' circumstances with the provision of a context, meant that the research would still be of great value to interested parties from other settings.

1.5.2 Overall Research design

At first, it was decided to select three 'typical' students from the 1st, 2nd and 3rd year chemistry mainstream classes at the University of the Witwatersrand (from now on referred to as WITS). The researcher would then describe the learning process as it occurred in one 'typical' laboratory session for each student in order to identify and gain insight into the factors that affected his/her learning. Once all three descriptions had been completed, they would be systematically compared in order to determine which factors were specific to each setting, and which were common to all the students. After gathering data from the first year student only, however, it was decided that gathering and analysing data in a similar way for *three* students

would not be within the time constraints for the research. This study, therefore, only includes data collected for one 'typical' student chosen from the first year class.

A 'typical' lab session was selected from the first year practical course and pre- and post-lab tests were then designed. These were used to gauge how much learning had taken place as a result of the student's activities in the laboratory. It was decided to proceed in this manner even though the student might learn something during the practical that was not included in the tests. The reason for this was that the researcher was not interested in gaining insight into the factors that affected the learning of *unexpected* learning outcomes. Rather this study investigated the factors that affected the learning of outcomes specifically desired by the WITS Chemistry Department (these were gained by an interview with the lecturer in charge of the first year lab course - from now on referred to as lecturer #2), as well as those proposed in the current literature (see section 1.4.4.). In doing this, it was thought that the results would be more interesting to more people involved in the design and facilitation of practical work.

The validity of the tests was improved by the use of (1) the interview method which enabled the researcher to ask the student questions about *why* she answered in the way that she did for the conceptual questions and (2) a video camera which enabled the researcher to improve the factual accuracy of the assessment of manipulative skills as well as ask the student questions pertaining to the motives for her actions[6].

A description of student 1's activities during the lab session was also made by observing her and asking her questions. Observations and interviews were made at various stages in the learning process.

(i) An interview was conducted with the student after the pre-lab preparation but before she went into the laboratory. This was done in order to determine the extent to which she had prepared beforehand and if there were any areas of the pre-lab preparation that were problematic. It was also to determine whether or not there were any other extraneous factors[7] that might have influenced the amount of meaningful learning that went on during the lab session.

(ii) Observations and the answers to questions posed to her while she was conducting the lab activities were collected. This was done by the researcher writing down as much of her activity during the time in the laboratory as possible and taping her answers given on a portable tape recorder. (This enabled the researcher to eliminate much presupposition of meaning from the

---

[6]The student chosen was a 'she' and will be referred to as 'student 1' in subsequent sections.

[7]Extraneous factors would be factors that are peculiar to this particular student or lab session (eg. work not covered in class, student sick etc.). These types of factors will be taken into account when making inferences about the final test results.

observations made). It was decided not to use the video camera to observe the student during the laboratory time because it would make the researcher's activities too conspicuous to the other students and could greatly affect the results.
(iii) A photocopy was made of the student's writings in her lab manual as well as the lab report that she had to hand in at the end of the session.
(iv) An interview was also conducted one day after the lab session to clarify any factors or issues that the researcher thought needed further investigation.

Information was also obtained from other relevant persons involved in the learning process (eg. the student's demonstrator and the lab manager - a lecturer assigned to ensure the overall safety and smooth running of the lab activities) by interview. This was done to increase the validity of any inferences made about their actions during the lab session. The class lecturer was also interviewed (from now on referred to as lecturer #1) and was, at the time of the lab session chosen, giving the first year class a course in organic chemistry. This was to establish what the students should have learned as a result of the lectures and the tutorials.

All this information was then used to isolate and scrutinise factors that affected the student's learning during the practical session. In the light of these factors, recommendations were put forward about how to improve the laboratory learning experience.

1.5.3 Method of analysis

The results of the pre- and post-lab tests were compared to one another and the results of the post-test were explained by using the description of the lab session, the interviews and the other sources of data outlined in section 1.5.2.

The interpretation of the student's pre- and post-lab test responses, in conjunction with all the other sources of information, were then used to identify and gain insight into factors that affected the amount of learning that occurred as a result of the lab session.

1.6. An overview of the rest of this research report

The next chapter deals with the *context* of the research. It describes the WITS first year setting, outlining what the student should have covered in the lectures and tutorials before her involvement in the research. Chapter 2 also describes how the first year major practical courses are run at WITS and how the researcher went about choosing a typical student. Chapter 3 then furnishes the results obtained from the description of the student's activities in the laboratory. Whilst chapter 4 is an analysis of the data gained from the pre- and post-lab tests. Chapters 5

and 6 build on these results by discussing factors that affected the learning of the student in the laboratory. Finally, chapter 7 provides the conclusion, with a summary of the answers to the research questions, a discussion of the strengths and limitations of this research and directions for further investigations.

Chapter 2

Describing the context

2.1. Introduction

This chapter provides a context for the research in terms of;
(1) how the first year laboratory course at WITS is run,
(2) an introduction to the experiment chosen and
(3) the concepts and skills that should have been covered by the student in lectures, tutorials and lab work prior to the chosen experiment.
In doing so, the reader is able to ascertain the extent to which (s)he is able to use the results as a working hypothesis about what might occur in his/her own particular setting.

At the same time, this chapter makes clear the extent to which the student and the lab session chosen may be deemed 'typical'. This once again enables the reader to determine the extent to which the results are applicable to the cases familiar to him/her.

2.2. The quest for the 'typical'

The information for this section came primarily from two sources;
(1) field notes taken during selection of the student and the lab session,
(2) the researcher's memory of what happened some time after the student had been selected.

2.2.1. WITS university - typical ?

The decision to conduct this research project at WITS university, as opposed to any other South African university, was purely one of convenience. No claim about the 'typicality' of WITS university is made. Nevertheless, the context provided in this report is such that it does allow readers from other universities to make inferences about the applicability of the recommendations to his/her particular setting.

2.2.2. Choosing a 'typical' laboratory session

Before a typical student was chosen, a lab session that could be considered typical of the chemistry major first year lab course was selected. As far as possible, it was desired that the lab session chosen was fairly typical of the types of sessions the 2nd and 3rd year undergraduate students were experiencing. This would make the research applicable to more groups of people.

The Chemistry major laboratory sessions are split up into two types - what the department calls 'additional labs' and 'ordinary labs'. The students conduct 'additional labs' one week and 'ordinary labs' every alternate week.

Upon inspection of the lab manuals for the 'ordinary labs' and 'additional labs', one observes that 'ordinary labs' generally have a focus question (see the use of Gowin's Vee - Novak and Gowin, 1984) for the students to answer. All of them also have pre-lab questions that the student is required to do before entry into the laboratory is permitted. Ordinary lab sessions also make explicit to the student what is expected from him/her with regard to the lab report (ie. the types of table that should be drawn up, how much space to leave for comments, exactly what to comment on in the report, is all included in the lab manual). The demonstrators all have solutions for these lab manuals in which ideal results are given with prescribed mark allocations for each lab as well as recommended teaching strategies for the demonstrators to follow. The students are required to hand in their lab reports on the day that the lab session is completed.

Additional labs, on the other hand, generally do not have exercises to do before entry to the laboratory is allowed. They also do not make explicit what is required of the student with regard to the lab report except for 2-4 questions at the end of the report. The demonstrators are given solutions for these questions as well as a guide as to marking the lab report. They are not, however, given learning aims for all but three of the additional labs. They also were not given any recommended teaching strategies for the lab session. The 'additional labs' are also mostly longer than the ordinary labs, and generally require a full three hours to complete. The students are also not required to complete a lab report during the lab session but may hand in a report 5 days after the completion of the practical session.

In order to obtain maximum relevance to other interested parties, it was decided that the lab session chosen should have some similarities to those conducted in the 2nd and 3rd years. A review of their main features has, therefore, been provided below.

(1) In the majority of the 2nd and 3rd year lab sessions the students work individually, but in *all* the sessions the students are encouraged to interact with their peers in order to learn more (although it is not mandatory).
(2) Approximately 1/4 of all the 2nd and 3rd year lab sessions are done with the students working in pairs, sharing results but writing reports separately (or they are supposed to).
(3) The vast majority of the lab sessions involve equipment that the students are able to handle (ie. atypical equipment would be equipment that the lecturer/demonstrator would have to

use on behalf of the student and obtain data for him/her because the equipment is too complicated or expensive for students to use).

(4) The vast majority of the lab sessions do not involve chemicals that are so dangerous that students have to take unusual safety precautions.

(5) The majority of the labs are related to the lectures in some way.

(6) All of the lab sessions require students to follow a given 'recipe' in a lab manual that does not contain too many pictures. These manuals generally consist of text with a few diagrams.

(7) The vast majority of the lab sessions require students to (i) read through the lab manual before they come into the lab, (ii) follow the recipe outlined therein, (iii) collect data as a result of this, (iv) answer the questions provided at the end, (v) write up a lab report at home (no guidance is usually provided), and (vi) hand it in ± 1 week later. Thus, they may be considered to be verification type laboratory sessions.

Both the ordinary and additional labs are similar to these labs in that they include features (1), (3), (4), (5) and (6). The additional labs, however, more closely resemble the 2nd and 3rd year lab sessions with regard to feature (7.v. & vi.) Thus, it was decided to choose an additional lab as being *more* typical. Table 4 indicates their common features.

Table 4: Features of the first year chemistry major additional labs

Feature	Additional lab number											
	1	2	3	4	5	6	7	8	9	10	11	12
Qualitative lab* activity		✓			✓	✓						✓
Quantitative lab activity	✓	✓	✓	✓	✓	✓				✓	✓	✓
Dry lab† activity							✓	✓	✓			
Verification	✓	✓	✓	✓	✓	✓				✓	✓	✓
Guided inquiry												
Open inquiry												
pre-lab Questions												
Work in Pairs		✓										
Microscale										✓	✓	✓
Calculations & concepts:												
% yield	✓										✓	
% recovery	✓			✓						✓		
% by mass			✓			✓					✓	
% purity			✓			✓				✓		
Titration			✓									
Spectroscopy							✓	✓	✓			
Conductance					✓							
TLC (r_f value)		✓								✓	✓	✓
Melting point												✓
Learning aims										✓	✓	✓

*In cases where both qualitative and quantitative labs are indicated, it implies that the lab session involves both types of activities.

†All three dry lab sessions are what may be considered tutorials. They consist of exercises on spectroscopy where spectra are given and students are required to interpret them. The students are not required to collect data as a result of following a procedure. They are simply given the data and told to interpret it. The extent to which a verification lab session may be considered as an extended tutorial, is the extent to which these 'dry labs' may be classified under the verification type lab session.

As can be seen above, all the lab sessions, except the three dry tutorial type lab sessions on spectroscopy, include some sort of quantitative aspect, while four lab sessions include both qualitative and quantitative aspects. All the lab sessions are of the verification type. Most labs include the calculation of a percentage 'something', the most common being the percentage by mass, percentage purity and percentage recovery. Four labs require the student to reflect on the concept of thin lay chromatography in some way. Learning aims are included in the lab manual

for only three out of the twelve lab sessions (these are outlined at the beginning of the experiment). These same three sessions are also the only three that are conducted using microscale glassware.

Additional lab session A6 includes the calculation of a percentage by mass and a percentage purity, while it also has qualitative aspects in it. It is of the verification type, and no direct learning aims are provided for it in the lab manual. The only aspect of it that was not fairly typical was that it did not involve thin layer chromatography.

A6 also proved to be a useful choice because of time constraints. The additional labs in the third term consisted of three atypical dry labs (unsuitable choices for this research). If, therefore, a lab session *after* the second term was chosen, the collection of the data would only have been done in the *fourth* term. Since it was already the beginning of the 2nd term at that stage of the research, the idea of waiting that amount of time before any data was collected was undesirable. The choice was confined effectively, therefore, only to the lab sessions that occurred in the second term (A4-A6 conveniently).

Below is a short description of each of these lab sessions;
A4 *Purification of ammonium ferrous sulphate (AFS)* - (scheduled for 10/5/99)
Crude AFS is dissolved in a hot mixture of water and sulphuric acid. The mixture is then cooled and the pure AFS is excepted to precipitate out. The mixture and any impurities contained in the AFS are separated from the pure AFS by means of filtration with a Hirsch funnel. Students are required to calculate the percentage recovery of the purified AFS.

The researcher's past experience with experiment as a demonstrator suggested that it would be extremely short and easy for most students. The majority of the students had finished well within the time allocated and were able to calculate the percentage recovery with relative ease. Thus, it was not considered as typical of the additional lab sessions.

A5 *Qualitative investigations of the nature of ammonium ferrous sulphate* - (scheduled for 24/5/99)
The following tests are applied to a sample of AFS

- test for sulphate ions
- test for ferrous ions
- test for ammonium ions
- test for water molecules

The conductance of different solutions and mixtures are then compared to that of AFS. Students are expected to give explanations for the differences and similarities that are observed. They are

also required to draw a graph (should be straight line) of conductance vs. concentration for KCl solutions of varying concentrations.

A5 seemed fairly typical. It consisted of both qualitative and quantitative aspects but it didn't require the calculation of a percentage 'something'. Also, from personal experience, the researcher knew that the demonstrators in previous years made their students work in pairs for the qualitative testings to save time. If this occurred again this year, the experiment would definitely be atypical.

A6 *Determination of the percentage by mass of sulphate in the sample of ammonium ferrous sulphate by gravimetric analysis* - (scheduled for 7/6/99)
AFS is dissolved in a mixture of water and HCl, barium chloride is added and the sulphate in AFS is precipitated as barium sulphate and collected in ashless filter paper which is vapourised in a preweighed porcelain crucible and lid. The students are required to calculate the percentage by mass of sulphate in AFS and then use their answer to calculate the percentage purity of the AFS used. At various stages in the experiment, qualitative tests are done to check for the presence of impurities.

With both qualitative and quantitative aspects and the calculation of a percentage 'something', A6 seemed the most typical of the additional lab sessions in the second term. It also appeared to be fairly typical of 2nd and 3rd year lab sessions in that no instructions for writing the report were supplied, the students would not be working in pairs, and no pre-lab questions were given.

Thus, on the basis outlined above, A6 was chosen as the typical lab session (see appendix D for a photocopy of the procedure from the lab manual).

2.2.3. Choosing a 'typical' student

The first year major class was split up into 3 groups with 15, 16 and 18 students in each group at the beginning of the year. Each group was then assigned a demonstrator who was to demonstrate to the group for the rest of the year. Thus, in order to choose a typical student, it was important to ensure that the demonstrator was fairly typical. An abnormal demonstrator would not make for typical results.

In order to choose a typical demonstrator, the researcher attended lab session A4 on a Monday afternoon to become familiar the people involved. It was then discovered that one of the groups had its lab sessions on a Thursday afternoon. All three of the demonstrators were honours

students. Since the researcher was demonstrating himself on a Thursday afternoon, he was forced to select one of the groups on a Monday.

During A4, both demonstrators called their groups to gather around a chalk board and gave them a pre-lab talk. D1's talk, however, was longer than the other's and she also stressed to the students what she thought would be the most important part of the lab session. Both demonstrators wrote down how to do the calculations for the practical. Neither of the demonstrators demonstrated the techniques to be used that day. It was also observed that demonstrator one (D1) had 16 students while demonstrator two (D2) had 18.

D1 appeared to be more prepared and clued up about what was going on. Her students asked her many more questions than D2's. It seemed that if they had *anything* that they were unsure of they asked her. D2, however, appeared to be friendlier and even had tea with her students and chatted to them in a very good-natured way. Once the experiment got underway, both demonstrators moved around from bench to bench checking that everything was going all right with their students. D2 started to do this much sooner than D1, however, because D1 had to deal with a great many questions from her students all at once. Nevertheless, once the flurry of questions to D1 had ceased, both demonstrators seemed to handle the task of wandering from bench to bench in a very similar manner. D1's students, however, seemed to work quicker than D2's and they finished a lot sooner than D2's. As a result of this, D1 was able to leave the lab about 1/2 an hour before D2. This could be because D1 was more organised than D2 and thus her students were able to work faster, but (from the observations made) this appears to be only part of the answer (- see subsequent comments on the differences between the two *groups* of students).

Just before the start of A4, each demonstrator was interviewed in order to gain more personal information about them. In each case, they were asked simple questions for which their responses were written down by the researcher. These were;

	D1	D2
Is this the first year that you are demonstrating to students ?	☑	☑
Have you done any education courses ? [8]	☒	☒
Is WITS the only university you have ever attended courses ?	☑	☑
What marks did you get last year ?[9]		

[8] Demonstrator 1 did mention that she was considering going into education at some stage in her life (ie. she may want to become a lecturer at a university), but that she had never done any courses in line with that career choice.

[9] Both demonstrators had obtained the same marks the previous year and won the 3rd year gold medal jointly for coming first in their class. Demonstrator 1, however, obtained the gold medal for lab work.

Along with the choice of a typical demonstrator, it was also important to ensure that the demonstrator chosen had a fairly typical *group of students*. A class list with the student's lab marks, was then obtained in order to observe any differences between the two groups. Upon doing this, two striking features were noticed;
(1) D1's group had an average of 64 % for the laboratory sessions that they had already done, while D2's group had an average of 46 %.
(2) D1's group consisted mainly of students who had registered for the first time in 1999, while only about half of D2's group consisted of such students.

An informal interview conducted with D2 revealed that at the beginning of the year, all the students wrote some sort of test. The ones who didn't do so well, were put into her group while those in D1's group were those who did better. This test was a *written* general chemistry test which didn't include lab work. Thus it did not necessarily imply that the students in D2's group would obtain lower marks for the subsequent lab sessions. According to Parsons et al (1991), marks obtained through written tests show only a small correlation to the marks obtained through demonstrations (ie. actually 'doing' a task). D2 may also have been a stricter marker than D1. Nevertheless, the difference in lab marks was remarkable, and it added somewhat to the final decision.

After some deliberation, it was decided to focus on D1's group. The reason for this was because repeat and mature students could be regarded as atypical, and even if a student from D2's group were chosen, the probability that (s)he would be working next to a repeat student or a mature student would be extremely high. (A repeat student would be abnormally familiar with the work, and may give the student extra assistance - especially if they work together). The differences between the two demonstrator's teaching styles, however, appeared to be minimal and thus the choice of *demonstrator* did not look as if it would be a variable that would affect the results in any great way.

Once the group had been chosen, the following students were eliminated as being atypical;

- Repeats and mature students.
- Those with the highest and lowest lab marks. This was done by calculating D1's group average so far and then eliminating those who were much higher or lower than it. Since the average was 64 %, anyone with an average of 80 - 100% or 40-0% was excluded. This eliminated 4 out of 15 students.
- Students who finish very early or late. These students were eliminated by making a note of the early and late finishers in A4. The times taken ranged from 1 hr 40 mins (the fastest person) to 2 hrs 11 mins (the slowest person). Thus, it was decided to eliminate anyone who

finished after 2 hrs and 5 mins or before 1 hr 55 mins. As a result of this, seven more students out of the 15 in D1's group were eliminated. D1 was also asked to point out who she thought was an extremely fast or slow person. She mentioned two students who she thought were fast, one of these had already been noted above, and this meant that one more person could be eliminated. She also pointed out three students who she thought were particularly slow. Two of these students had not been eliminated yet.

- Students who create accidents. No specific note was made of this aspect when in A4. Nevertheless, the interview with the demonstrator revealed a student who was "good" (no definition of 'good' was supplied) and another who she said was slow, but knew what was going on. The latter had not been eliminated yet. And so one more student was dismissed.
- Foreign students. Of the students surveyed (see later for the details of the survey), all of them went to South African schools and all of them claimed that their home language was a recognised South African language. Thus, no students were eliminated because they were foreign.

This left two students out of a possible 15 that had not been eliminated yet. A survey was designed to determine more personal atypical information from them. The students were asked to provide the following (See appendix A for the actual survey with the two students responses);

- The school that they had attended.
- Their age.
- The number of years they had been out of school.
- What they had been doing if this was not their first year out of school.
- If this was the first tertiary institution that they had attended.
- The name of the University or tertiary institution that they had attended.
- If this was their first year of *chemistry* at university
- If they had completed any additional lab courses[10].
- What their first language was.
- If they had done any special lab courses or extra laboratory work.
- If they had won any science prizes at school.

One of the two students surveyed, had attended Potchefstroom Girls High School and was 19 years old. This was her first year in a university but not her first year out of school. For one year she had played sport overseas. Her first language was English and she indicated that she had done no special or additional lab courses or work, neither had she won any science prizes.

---

[10]This question is ambiguous, however. The researcher meant for the students to indicate whether they had done any extra lab courses apart from university. What is ambiguous about it is that the students were involved in the first year 'additional lab course' at WITS at that time.

The other had attended Mama High School, and was 17 years old. This was his first year out of school and his first year in university. He had never done any special courses in lab work, but he had facilitated during the year of Science and Technology Exhibition and obtained a facilitation certificate as a result of this. He also indicated that he had done some additional lab courses (although he did not specify what). His first language was Xhosa.

At this point, however, it should be noted that the concept of a 'typical' South African university student should not be taken too far in the light of the diversity of backgrounds of the population of our country (especially taking into consideration the gross differences in education experienced by people from different races, cultures and language groups in the past). Not only that, but these two students were of different gender. While females are well represented in the chemistry (I) major class[11], the question remains whether results obtained from a female student may be regarded as 'typical' for students of the opposite gender ?

As was noted in 1.4.6, studying *what is* should not be extended to mean that the results of one student could be applicable to an entire population. Nevertheless, the provision of (1) a context for the selection process and the learning experience, as well as (2) certain characteristics of the student chosen, enable the reader to make reasoned judgements about the extent to which the results of this study are applicable to his/her own particular setting.

In the end, the first student mentioned above was selected. Eventually a decision *had* to be made in favour of one or the other student and the fact the first one indicated that she had never been involved in any sort of science related activities (apart from her regular education) made it more likely that she would not be familiar with any of the concepts and skills in A6 prior to the experiment.

2.3. What the student *should have* learned prior to A6 and the pre-lab test.

To further characterise the typical student, the skills and concepts that (theoretically) should have been learned in previous lab sessions as well as the lectures and tutorials were identified.

2.3.1. Skills and concepts covered in previous lab sessions

[11] Out of the 57 students registered for the chem (I) major course in 1999, 25 were females and 32 were males.

The skills and concepts covered in previous *lab sessions* were determined by inspecting the student's lab manuals for the ordinary and additional labs. The result of this has been summarised in table 5 & 6 below.

Table 5: A summary of the skills and concepts covered in ordinary labs O1 - O3 and additional labs A1 - A2.

lab	title	skills applied	concepts applied
O1	An introduction to mass and volume measurements	(A) using (1) a burette, (2) a pipette, (3) the rough and (4) accurate electronic balances (B) weighing liquids (C) measuring the volume of liquids (D) identifying all the apparatus in their locker	(1) sig. figs. (2) accuracy (3) precision (4) density/mass/volume calculations
A1	Synthesis of Aspirin and AFS	(A) using (1) a measuring cylinder (2) a dropper (3) a Bunsen burner (4) a tripod and gauze (5) a Hirsch funnel (6) the rough and (7) accurate electronic balances (8) evaporating dish (B) weighing solids (C) dissolving solids (D) cooling hot solns with ice or in air (E) separating a solid from a liquid by means of vacuum filtration. (F) drying wet products	(1) line drawings (2) molecular weights (3) percentage yield (4) limiting reagents (5) the action of sulphuric acid in synthesis of aspirin (6) standardisation of potassium dichromate with AFS (7) significant figures
O2	Estimation of the HCl concentration in gastric juice	(A) using (1) a burette, (2) a pipette, (3) a conical flask (B) conducting a titration	(1) sig. figs. (2) indicators (3) strong acid-strong base titration
A2	Purification of aspirin by recrystallisation	(A) preparing mixtures (B) using (1) a measuring cylinder (2) a Bunsen burner (3) a tripod and wire gauze (4) a Hirsch funnel (5) the rough and (6) accurate electronic balances (C) dissolving solids in liquids (D) drying wet products (E) observing and inferring about solubility of aspirin in different solvents	(1) calculation of % mass (2) solubility (3) reactions of different substances with AFS (4) sig. figs.
O3	Standard solutions, dilution and spectrophotometery	(A) using (1) the rough and accurate balances (2) a volumetric flask (3) a pipette (4) a spectrophotometer (understanding it too) (B) measuring absorbance (C) making up standard solutions (D) drawing a graph by; (1) selecting the appropriate scale for the readings (2) deciding which unit will be the horizontal and which will be the vertical axis (E) the process of; (1) guided exploration in groups, (2) a semi controlled discussion in order to determine the results of the exploration and form a hypothesis (3) testing the hypothesis (F) working co-operatively (G) diluting solutions (H) reading off graphs (I) drawing a calibration curve.	(1) absorbtivity (Beer's law) (2) concentration (3) sig. figs.

Table 6: A summary of the skills and concepts covered in ordinary labs O4 - O6 and additional labs A3 - A5

lab	title	skills applied	concepts applied
A3	Determination of composition by mass of carboxylic acid group in aspirin	(A) using (1) a burette, (2) a pipette, (3) the rough and (4) accurate electronic balances (B) the procedure of accurately weighing out 1.5-1.8 g (C) conducting a titration (D) *making up a standard solution*	(1) precision (2) accuracy (3) percentage by mass of carboxylic acid in aspirin (4) percentage purity (5) sig. figs (6) organic reactions
O4	Bonding and molecular shapes	(1) building models of molecules	(1) Lewis diagrams (2) VSEPR theory (3) macro and microscopic descriptions of matter (4) atom, *molecule*, compound
A4	Purification of AFS	(A) using (1) a measuring cylinder (2) Hirsch funnel (C) determination of approximate solubility (B) warming a solution over a Bunsen burner with a tripod and wire gauze (D) filtering with a normal filter funnel and paper (if their sample had impurities in it).	(1) sig. figs. (2) The relationship between solubility and temperature (3) percentage recovery
O5	What is the formula of hydrated barium chloride ? a gravimetric analysis	(A) using (1) a crucible and lid (2) a pair of tong (3) a desiccator (4) pipeclay triangle (5) accurate and rough balances	(1) the concept of hydrated salts (2) the meaning of a gravimetric analysis (3) spluttering (4) *accuracy and precision*
A5	Qualitative investigations of the nature of AFS	(A) using (1) a conductivity cell (B) qualitative observing (C) plotting graphs of conductivity for singly charged ions	(1) the test for, sulphate ions, iron(II) ions, ammonium ions, and water in AFS. (2) conductivity
O6	Group relationships of the elements	(A) qualitative observations	(1) reactivities of group 1 and 2 elements in water (2) the reactivity of Ca, Mg, Na and Al towards hydrochloric acid (3) the relative acidic and basic properties of the oxides or the hydroxides of the elements of the third period.

2.3.2. Skills and concepts covered in lectures and tutorials prior to A6

In order to determine what the students had already covered in lectures, the 'learning goals' laid out by the chemistry department for the first year major course were inspected. These were listed in the student manual supplied to the students at the beginning of the year. Their stated purpose was "to provide you [the student] with a set of objectives that you should be able to do on completion of each section of the course. ... some of the learning goals will be covered ONLY in the Tutorials and not in the lectures at all" (Chem. 101, Chemistry Department Student Manual : First term, p. 7). The tutorial questions that should have been done by the student were also noted. This exercise indicated (1) what type of question the student should have been familiar with prior to the lab session as well as (2) what concepts the student could be expected to know as a result of the tutorials and lectures. Since the researcher was a tutor for the chem (I) major class in 1998, the tutorial questions were very familiar to him.

Hence, given below is;
(1) a list of all the sections of the chem (I) major course that should have been covered in the lectures prior to the pre-lab test[12], including the learning goals (L.G.) in each section relevant to the concepts pertaining to experiment A6.
(3) a list of the tutorial questions that should have already been done by all the chem (I) major class[13].

(0) Introduction: Units, measurement, force, energy

- L.G. (0.1) - Distinguish between qualitative and quantitative descriptions of substances
- L.G. (0.5) - Explain what is meant by precision and accuracy when referring to measurements

(1) Atoms and molecules : The building blocks of substances

- L.G. (1.2) - Distinguish amongst elements, compounds, atoms, molecules and ions.
- L.G. (1.6) - Describe how mixtures are separated by filtration, distillation and chromatography
- L.G. (1.13) - Explain what is meant by the atomic weight (relative atomic mass) of an element and calculate molecular weights (relative molecular masses) of pure substances.

---

[12]It was determined, after an interview with lecturer #1 (the current lecturer to the chem (I) major class), that the students were going through "Carbon and Hydrocarbons" in the lectures (section 8 in their syllabus) by the time of additional lab A6. This meant that they had already covered sections 0-7.
[13]According to the student manual, tutorial 12 was held in the same week as the pretest (it was on the Monday while the pretest was on the Friday). The lab session A6 was held on the following Monday and the post-test on the Tuesday.

- L.G. (1.17) - Define the molar mass of a pure substance and use molar masses for interconversions between amount and mass.

(2) The atmosphere : Gases and gas laws

(3) The periodic table and chemical bonds

- L.G. (3.14) - Give the valencies of the elements in groups I-VIII
- LG. (3.16) - Use valency to write empirical formulae of binary compounds formed by representative elements and deduce valencies of elements from empirical formulae.
- L.G. (3.17) - Give the formulae, charges and names of the ions specified on page 16 of this Student Manual (includes Fe^{2+}, Fe^{3+}, Cl^-, SO_4^{2-}, Ba^{2+}, Ag^+, NO_3^-).
- L.G. (3.18) Use trivial and systematic (Stock) nomenclature to name simple inorganic compounds whose formulae are given, and *vice versa.*
- L.G.(3.23) - Explain what is meant by ion, cation, anion, and describe the formation of an ionic bond.

(4) Chemical reactions and the halogens

- L.G. (4.4) - Give equations to represent the following types of reactions: synthesis, decomposition, oxidation-reduction (redox), acid-base, and precipitation.
- L.G. (4.6) - Define oxidation, reduction, oxidant (oxidising agent), reductant (reducing agent), and redox reaction in terms of electron transfer.
- **L.G. (4.13) - Explain what is meant by a precipitation reaction and describe the use of such reactions in gravimetric analysis.**
- L.G. (4.1.4) - Describe general trends in the solubilities of some common salts and hydroxides.

(5) Stoichiometry

- L.G. (5.2) - Calculate the amount and the mass of a substance in a chemical reaction
- L.G. (5.3) - Define a limiting reactant and identify a limiting reactant by calculation
- **L.G. (5.4) - Explain what is meant by theoretical yield and percentage yield and calculate the percentage yield of a reaction.**
- **L.G. (5.5) - Calculate the percentage composition of a compound from its molecular formula.**

(6) The electronic structure of atoms and molecules

(7) Sulphur, phosphorus and chlorine: Period 3 Non-metals

- L.G. (7.4) - Define what is meant by an oxidation number and deduce the oxidation number of an atom in a give molecule
- L.G. (7.5) - Use oxidation numbers to establish which species in a redox reaction has been oxidised and which has been reduced.

(8) Carbon and hydrocarbons[14]

---

[14]According to the interview with lecturer #1, the students had 10 more learning goals (out of 24) of this section to cover at the time of A6.

Tut 1: Units, measurement, force, energy

- Q1 - covers L.G. (0.1), Q6 - covers L.G. (0.5)

Tut 2: Atoms and molecules : The building blocks of substances

Q10.c. i. - covers L.G. (1.17)

Tut 3: The atmosphere : Gases and gas laws

- No relevant questions

Tut 4: The periodic table and chemical bonds

- Q7 - covers L.G. (3.18)

Tut 5: The periodic table and chemical bonds

- No relevant questions

Tut 6: The periodic table and chemical bonds

- No relevant questions

Tut 7: Chemical reactions and the halogens

- Q4 - covers L.G. (4.6),
- Q7 - covers L.G. (4.14)

Tut 8: Stoichiometry

- Q1 - covers L.G. (4.13),

In this question, students are given the mass of an impure sample of magnesium chloride. They are told that all the magnesium chloride is reacted with excess sodium phosphate in water and they are also given the mass of the resulting magnesium phosphate precipitate. They are then required to;

(1) explain the meaning of 'precipitate' and 'gravimetric analysis'

(2) Calculate the mass and the amount of magnesium chloride in the impure sample

(3) Calculate the mass of the impurities in the sample

(4) explain the assumption made when using this method of analysis (Answer: The assumption is that all the magnesium chloride dissolves in the water and reacts with sodium phosphate).

- Q3 - covers L.G. (5.3),
- Q4 - covers L.G. (5.5)

In this question, students are given the molecular formula for a compound ($C_{14}H_{16}N_2O_5$) and told to calculate the mass percentage of the carbon contained therein.

Tut 9: Stoichiometry

- Q5 - covers L.G. (5.3)

Tut 10: The electronic structure of atoms and molecules

- No relevant questions

Tut 11: The electronic structure of atoms and molecules & Sulphur, phosphorus and chlorine: Period 3 Non-metals

- Q4 - covers L.G. (7.4), Q5 - covers L.G. (7.5)

Tut 12: Carbon and hydrocarbons

- No relevant questions

Tut 13: Carbon and hydrocarbons

- No relevant questions

2.4. Conclusion

This chapter has provided a context for the research by outlining;
(1) justifications for the lab session chosen as typical,
(2) justifications for the 'typical' student chosen and
(3) a summary of what the student might be expected to have learned prior to the experiment A6 conducted during the lab session.
In doing this, the reader is able to make reasoned judgements about the extent to which the case studied is able to provide a working hypothesis to use in his/her own particular setting.

The chapter 3 provides a 'thick' description (Schofield, 1993) of the learning process and the student's activities during the lab session while chapter 4 is an analysis of the data gathered from the pre- and post-lab tests.

Chapter 3

A description of the student's activities during the lab session

3.1. Introduction

Once a lab session and a student had been chosen, the data collected came from 5 sources;
(1) the interviews with the demonstrator.
(2) the interview with the student just before she went into the lab, but after she had prepared for the lab (from now on referred to as the 'pre-lab interview').
(3) the description of the students activities in the lab (this includes a copy of the lab report that she handed in (appendix D) as well as a copy of her writings in her lab manual as she conducted the lab (appendix D)).
(4) the pre-lab test (conducted before the student had looked at the lab manual) and post-lab tests (conducted after the student had handed in the report).
(5) the interview with the student after the post-lab test to clarify any questions about the activities in the lab (from now on referred to as the 'post-lab interview').

Sources (1) & (5) are not directly included in this report to save space. Exerpts from these interviews, however, have been included in the text when they were required to establish a point. This chapter deals mainly with the description of the student's activities in the laboratory. This was used to interpret the student's responses in the post-lab test as well as identify and gain insight into factors that affected her learning as she conducted the experiment.

3.2. A description of the student's activities during the lab session

This description of the student's activities was produced from the field notes made in the lab, as well as the transcribed interviews conducted with the student at various stages in the lab session. It should be noted, however, that when making a description of a learning process there will obviously be some observations that will be irrelevant to the overall purpose of the research (eg. the colour of the demonstrator's shirt or the length of the piece of chalk that the demonstrator used are unlikely to be factors that affect the students learning). On the other hand there will be other observations that are vital to gaining an understanding of what and how the student learned (eg. what the demonstrator said in the pre-lab talk). There are also some observations that one cannot be sure, until *after* the data has been analysed, whether it was useful to record them. Nevertheless, as much detail as possible must be included in a description of this sort

because any one of these observations could prove to be useful when, at a later stage, the researcher is attempting to put forward a hypothesis about what the student learned.

The researcher thus went to great lengths to try and describe every action of the student in the laboratory and as a result of this, the first draft of this description was extremely long and detailed, containing many trivial observations. Many of these, therefore, were omitted to reduce the reading load of the report. A copy of the first draft of the description, however, is available on request from the author.

A copy of the procedure given for experiment A6 has been placed in appendix C.

3.2.1. Additional Lab A6 (Scheduled for 2-5 pm, 07/06/1999)

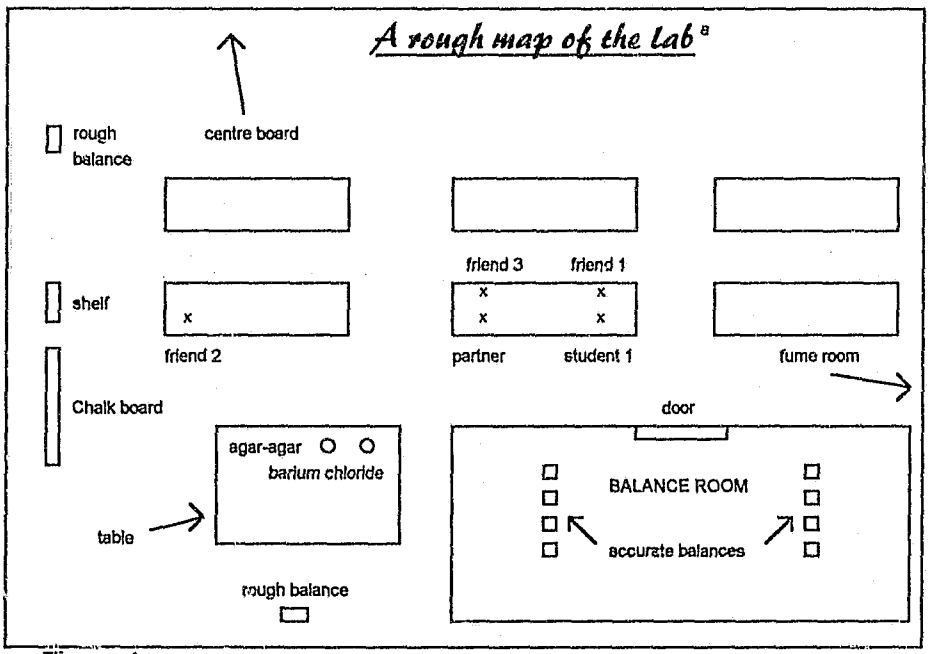


Figure 4:

[a]This sketch is only of about 1/5 of the entire first year laboratory, Nevertheless, the student never left the area shown above (except when she went to get the spare key for her locker, and to the fume room).

The researcher arrived in the lab at 1:40 pm. No-one was around, and the following observations were made of the state of the lab at the time;

None of the rough balances were switched on, but a diagrammatic outline of the procedure for accurately weighing a substance, was stuck to the wall above each one[15]. On a shelf near the chalk board, the following were provided for the students; gloves, wooden splints, plastic droppers and labels. Inorganic and organic waste bottles and emergency tissue paper were also provided by the department, while each desk had four Bunsen burners on it (one for each student). In the balance room, all the accurate weighing balances were switched on and ready for use except one - which was not set to zero.

The following was written on the bottom half of the centre board;

"Determination of the percentage by mass of sulphate in the sample of AFS by gravimetric analysis. Take from your demonstrator 5 % barium chloride, agar-agar, 1 % ammonium thiocyanate, 0.10 ortho-phenanthroline[16] and silver nitrate, 11 M HCl (conc.) is in the west fume room, desiccators are in the lockers next to yours, discard Na in the sodium waste beaker, discard your waste in the inorganic waste bottles provided".

Demonstrator 1 then arrived. She filled some marks in the register at the centre bench (just below the centre board) and then approached the area delineated in the map above. The researcher then asked her if he could interview her (the purpose was to determine what she intended to tell the students in her pre-lab talk). By this time, however, the other demonstrators were just about to let the students into the laboratory and she asked if it could be put until later because she had to get ready[17].

At 1:57 p.m. the students began to filter in. Student 1 entered at 1:58 p.m.. When she got to her desk, she began to scrabble through her bag. It appeared that she had left her locker key at home and had decided to use the unlocked locker next to hers. The only problem was that it did not have all the equipment necessary for the experiment in it. She then told her partner that she might need to take some of the stuff out of the locker next to his (since that one also had no lock on it). At this stage the demonstrator called everyone to gather around at the chalk board for the pre-lab discussion.

As everyone was making their way to the chalk board the lab technician made an announcement over the loud speakers asking the majors (the group of which student 1 was a part) not to talk if

---

[15]The students were instructed to (1) place a sample vial on the rough balance, (2) fill it up until the approximate weight needed was obtained, (3) place the full vial on the accurate balance, (4) empty the contents of the vial into the necessary container, (4) reweigh the empty vial on the accurate balance, (5) subtract the mass obtained in (3) from that obtained in (4) to get the exact mass of substance.

[16]No units for the concentration were noted.

[17]This interview was thus held after the lab session.

possible because a practical exam in another part of the laboratory would be in progress at the same time as this experiment. This announcement was largely ignored by the students, however, and the lab activity appeared to proceed in a similar manner to that in A4.

Once most of the students had assembled around the board, the demonstrator then commenced her talk.

DEMONSTRATOR: (The researcher was standing a distance from the demonstrator and this resulted in the poor sound quality of the recording. A blank space indicated by dots ..... implies a gap where the recording is unclear. Where the gap is not too lengthy, however, the reader is given some idea of what was said in the footnotes).
.....[18] the procedure quickly, what I want you to do, is when it says "treat the hot solution with agar-agar solution" ok. Ok are you at that point, where it says leave the mixture to stand .....[19] while you are waiting for it to cool down for those 10 to 15 mins start this part where it says your um prepare your, por ... your porcelain crucible ok because you have to heat your porcelain crucible for at least 10 to 20 minutes ok and you are going to do that while you are waiting for that instead of waste time. Ok so while you are waiting doing nothing for those ten minutes look on then page 32 its the third paragraph ok I want you to start there. Ok so now you'll get to the page numbers. Ok we are talking about question 2 ok. Do you understand again what they are talking about .....[20] ... I would do ..... what they also want you to do is get the mass of barium sulphate ions ok so basically what you would do is you just ..... work out the number of moles on top of that ..... the mass, mass of the sulphate ok and then you also know how much sulphate you had in ammonium ferrous sulphate because you've got the formula ok so you know what mass you are expecting of the sulphate ok so you know that you know what your original mass of the ammonium ferrous sulphate is ok so you get number of mole over mole so you know what your original mass of ammonium ferrous sulphate is and then you can work out your moles of $BaSO_4$ ..... that over your sulphate ..... ok do you understand. There are other ways of doing it but that's just to see if you get your the right mass of sulphate or ..... ok are you all fine with that ok. If you have any problems to ask me during the lab. Please try not to talk very much during this lab ok. Is there anything that you weren't sure too of, or is it pretty straight forward. It is a long lab you'll work quickly but you use ..... ok. Ok there's just some more I would like to ask you - it says um accurately weigh the crucible etc. reheat for 15 minutes 'cause you want to make sure that the mass is constant there might

---

[18] It sounded like she said "Ok, turn to the procedure quickly"
[19] At this point the lab manager made a short announcement over the loud speaker while the demonstrator continued to speak. This drowned the voice of the demonstrator off the tape. However, she could have said "for 10 to 15 minutes".
[20] The lab manager made another announcement that drowned out the sound of the demonstrator who continued to speak.

still be some carbon in there ok and you want to make sure that you have burnt it all off so you reheat it for 15 minutes um weigh it again and if it is changed by more than 0.05 ..... then you've got to reheat it again and weigh it again until you get a constant .....[21] ok.
(A student asked a faint question)
DEMONSTRATOR: Yes report what is going on to three decimal places Ok. ok.
(Another student asked a question while most of the others began to disperse to their desks).

(While the demonstrator was explaining question 2 in the lab manual to the group, student 1 was laughing with her friends and not really listening).

The demonstrator wrote the following on the board as she was giving the pre-lab talk[22];

no. moles $BaSO_4$ => mass SO_4

Original mass AFS.
no. moles SO_4 in $\frac{\text{Mass } SO_4 \text{ exper.}}{\text{Theoretical mass } SO_4}$

$$\%\ SO_4\ sample = \frac{mass\ SO_4}{mass\ AFS} * 100$$

$$Expt.\ \%\ SO_4 = \frac{theoretical\ SO_4\ mass}{exp.\ m\ AFS} * 100$$

$$\%\ purity = \frac{observed\ mass\ SO_4}{expected\ mass\ SO_4} * 100$$

At this stage, student 1 and friend #2 were talking to one another. The researcher approached student 1 to find out what they had been discussing;

RESEARCHER: What was your friend telling you over there ?
STUDENT 1: (laughs) oh no

---

[21] sounds like "for that temperature"
[22] The writings in italics were not copied directly from the board into the field notes. This was because at the time of the pre-lab talk, the researcher had three tasks to do, (1) hold the mic to record what the demonstrator was saying, (2) observe student 1 to record the extent to which she was listening, and (3) write down what was on the board. It was extremely difficult to do all three simultaneously and still remain reasonably inconspicuous to the entire group. Thus, after copying down the first bit of writing, the researcher decided to do (1) and (2) rather than (3). As a result of this, the writings on the board were taken from a student at the end of the lab session who, supposedly, had copied the demonstrator's writings word for word.

RESEARCHER: Anything about the lab or nothing ....
STUDENT 1: Ja no, just about you have to reheat, I was just making sure to clarify that it is actually after the experiment.
RESEARCHER: What ?
STUDENT 1: Um after you calculate your mass you've got to reheat make sure that the mass doesn't differ.

RESEARCHER: ... Did you understand everything in the pre-lab talk ?
STUDENT 1: Ja

Student 1 then returned to her locker. She took a 200 ml beaker out of the locker next to hers but then went and asked the demonstrator where she could get the spare key for her locker because there was hardly anything in the one she was using. The demonstrator pointed out the lab technician's office (on the other side of the laboratory) and she headed off there. After signing for the key she returned back to her locker. Upon opening it she removed the crucible and lid, a 400 ml beaker, the tripod and gauze as well as the asbestos tile and placed it all on her bench.

Taking a piece of filter paper she approached the balance room (note: there are only accurate balances in the balance room). It was packed out. Not one accurate balance was free (no such rush for the rough balances was observed at anytime). After waiting for a short while, a balance became available and she placed the piece of filter paper on it. It read 0.780 g.

Upon returning to her desk, she wrote "0.780 g" [1] in her lab manual in pencil (appendix D contains a copy of all her writings during the lab session). Underneath it she wrote "+ 0.3 g" [2] and finally underneath this "1.080 g" [3][23]. She then took her spatula and returned to the balance room with the piece of filter paper. First she tared the balance and then placed the filter paper on it - it read 0.780 g. She then added ammonium ferrous sulphate onto the filter paper (on the balance) and the reading went up to 1.027 g[24].

---

[23]The researcher did not directly observe the student write the last two of these numbers down (ie. 0.3 g and 1.080 g), nevertheless, after consideration of all the evidence it made sense that she would have written them down at this point.
[24]It should be noted that this reading indicates a weight of 0.2470 g for the AFS, while in her lab report and later on the dialogue recorded she indicated that her weight of the AFS was 0.3115 g ! The difference here could have resulted for two possible reasons;
(1) the researcher did not record the correct mass from the balance in the field notes, or
(2) because the student did not record the weight immediately into her report or lab manual and she somehow was not using the correct weight of sulphate.
Whatever the reason, the student used the second weight in her calculations.

Not long after this, the demonstrator came and told her that the concentrated HCl that she needed was in the fume room. She then rinsed her 400 ml beaker, dissolved the ammonium ferrous sulphate in a sufficient amount of water in it and went to the fume room.

When she got there, she asked someone where the 11 M HCl was. Another person asked her if they had to add 5 or 0.5 ml HCl to their beaker. She told them 5 ml[25]. When a bottle of HCl was available to her, she did her best (using a plastic dropper) to get exactly 5 ml HCl. She then went back to her desk.

RESEARCHER: Let me ask you, you weighed out ... you measured out exactly five ml's or didn't you ? Why did you weigh ... measure out exactly 5 ml's ? Is there any specific reason ?
STUDENT 1: No.
RESEARCHER: Just because the lab manual says so.
STUDENT 1: Ja, its wrong I think.
RESEARCHER: You just did it wrong ?
STUDENT 1: Um, no I'm not sure what I've done, I'm gonna go ask.
(Getting up to go to the demonstrator).
RESEARCHER: Ok let me come with you.

Student 1 (approaching demonstrator 1): If you add like way too much hydrochloric acid is it gonna destroy the whole thing now ?
DEMONSTRATOR: How much did you add ? Ok.
STUDENT 1: I think I just put in 5. I'm not sure because um with those droppers ...
DEMONSTRATOR: Ja.
STUDENT 1: ... I put it on two ...
DEMONSTRATOR: Ok.
STUDENT 1: ... and I did two and two and one.
DEMONSTRATOR: Oh ok.
STUDENT 1: So that's why I'm wrong.
DEMONSTRATOR: That is five ml's. I don't know whether it's gonna affect your results or not. Do you know (looking at me) ? You don't know ! I'm not sure I ...
STUDENT 1: Must I do it again ?
(Demonstrator laughed and looked at me).
RESEARCHER: I'm a fly on the wall hey don't look at me.
DEMONSTRATOR: It's probably easier for you to start again. I don't ... that it will affect your results, ... HCl ... its whatever you are doing. (Paused to think).

---

[25]The lab manual instructs students to add 0.5 ml HCl.

RESEARCHER: Listen don't adjust your behaviour because I'm here hey. Just if you ... if you gonna tell her to go and it messes up and just take somebody else's results go for it.
DEMONSTRATOR: Ha ha ha
RESEARCHER: I don't mind.
DEMONSTRATOR: No, I'll just tell her to start again ha ha ha. I think it should be fine, because you need a ...
STUDENT 1: I'm gonna be diluting it.
DEMONSTRATOR: Ja you are gonna be diluting it anyway. Its just to help it break up in solution, I don't know.
STUDENT 1: Ok the ... do we have to put 200 mls in or what ? Another ...
DEMONSTRATOR: An extra 200 mls ja, how much have you put in already ?
Student 1 (no audible reply)
DEMONSTRATOR: You'll soon see whether its working or not.
STUDENT 1: Ja.

After returning to her desk student 1 took a 200 ml beaker and her wash bottle out of her locker. One of her friends asked to borrow her measuring cylinder and she gave it to them. She then proceeded to use her wash bottle to fill up the 200 ml beaker to exactly the 200 ml mark. She then added it to the 400 ml beaker with water + HCl + ammonium ferrous sulphate mixture in it.

RESEARCHER: I just want to ask you, you, you measured out exactly 200 mls there. Is there any particular reason why you got exactly 200 mls or ...
STUDENT 1: No, again its just because ...
RESEARCHER: ... because the lab manual says so ?
STUDENT 1: It makes me feel better if I do exactly what it says
RESEARCHER: Say that again.
STUDENT 1: It makes me feel better
RESEARCHER: Why ? Because you ... ?
STUDENT 1: Because then you've got more chance of it becoming right.
RESEARCHER: Oh, ok thanks.

After this she went looking for matches, upon finding some she lit her Bunsen burner (note: oxygen inlet at the bottom of the burner was open when she did this). Upon doing this, she asked her friend, "do you add this much water ?" (No reply was recorded in the field notes or the tape recordings, however). She then put the beaker containing the AFS + water + HCl solution over the lit Bunsen burner by means of a wire gauze and tripod stand. She then took a

piece of tissue paper and wiped the 200 ml beaker[26]. At this stage the Bunsen burner went out. As she was lighting it again, she held the match directly over the metal gas outlet. Demonstrator 1 then arrived on the scene and took her desiccator out of her locker for her.

Student 1 then took a measuring cylinder and went to get some barium chloride solution with a plastic dropper. While waiting 1-2 mins for someone else to finish measuring out exactly 10 ml, she indicated to one of her friends that they were supposed to measure out 10 ml of barium chloride solution. Once the bottle was available, she made quite sure that she had exactly 10 ml (bending down to ensure that the meniscus was exactly on the 10 ml line).

RESEARCHER: Can ... I saw you measured out exactly 10 mls of barium chloride, is there any specific reason why ?
STUDENT 1: No, again the same reason.
RESEARCHER: Is because ...
STUDENT 1: It just makes me feel better, ja.
RESEARCHER: Just because the lab manual says so.
STUDENT 1: Ja.

She then began to read through the lab manual and tinker with the desiccator lid. She also checked one more time that she had exactly 10 ml barium chloride solution by looking at the graduation marks on the measuring cylinder.

At 2:33 pm. she took a wooden peg, a pair of tongs and a pipeclay triangle out of her locker. She checked the solution which was nearly boiling and increased the heat. Not long after this, however, she decreased the heat.

RESEARCHER: Why did you increase the heat and then decrease it again ?
STUDENT 1: First of all I increased it so that ... um ... it will just speed up, but then I'm decreasing it so that when I add it in its ... I prefer that otherwise I am uncomfortable with my hands because it is too hot.
RESEARCHER: Oh, you don't want to burn yourself as you hold it over ...
STUDENT 1: Ja.
RESEARCHER: So you expect to have the flame on while you are adding that ...
STUDENT 1: Ja
RESEARCHER: ... in the, in the measuring cylinder.
STUDENT 1: You have to keep the flame on.

---

[26]The observations in the field notes state "takes tissue paper and cleans" . It was not noted what she was cleaning. Most likely as indicated in the text she was wiping her 200 ml beaker.

RESEARCHER: Ok.

She waited for a while, and then began to add the barium chloride solution to the beaker with a dropper while stirring constantly. While doing this, she asked one of her friends if the heat should be on while adding the barium chloride. The friend replied that she didn't know. Student 1 decreased the flame some more. She continued to add barium chloride and stir the solution, but after a while she began to have difficulties getting the barium chloride out of the measuring cylinder because her dropper was too small to reach to the bottom of the big measuring cylinder. She kept on stirring the solution though. Placing the beaker on an asbestos pad, she went to get some more barium chloride from the bottle on a table nearby. One of her friends helped her to get it out by holding up the bottle.

RESEARCHER: Why didn't you really measure out exactly the amount of barium chloride this time ?
STUDENT 1: Ok because ah the book says, just add a few more drops so that would be as much as you prefer.
RESEARCHER: Ok, so it is not important.
STUDENT 1: No.

After this she began to read through the lab manual and then added the excess barium chloride while stirring.

RESEARCHER: Something seems to be puzzling, what seems ... what is going on in your mind ?
STUDENT 1: Hey, no, ok well one thing I wasn't sure of, she said that we must add some more ... few more drops to see if the precipitate would change and it is not very clear to see if more precipitate has formed because it is the same colour as the bottom. So you can't really see.
RESEARCHER: Oh, I see so what are you ...
STUDENT 1: I was just trying to make sure if there was any precipitate forming or not.
RESEARCHER: So what do you plan to do now ?
STUDENT 1: Ok well, there isn't any more so I'm just gonna continue.

She then went to get some agar-agar solution. She added exactly 10 ml to the measuring cylinder and put the lid back on the solution bottle. After this, she went to ask the demonstrator what to do with the barium chloride that she had left over. She was told to throw it in the inorganic waste bottle. She then began to clean the measuring cylinder she used for the barium chloride solution.

RESEARCHER: So what did your demonstrator tell you there ?
STUDENT 1: That we can start with the heating of the crucible before we actually put the agar in because there you only have to wait between ten and fifteen minutes, but you have to heat the crucible between 15 and 20. So it works out that if you add the agar after you start with the crucible, it is quicker.

After this, she took out her tripod and pipeclay triangle and began to set it up to heat the crucible and lid. She then cleaned her crucible and lid with a test tube brush (no soap) and dried both with a paper towel. Upon doing this, she placed the crucible and lid on the pipeclay triangle in the correct manner, and began to read through the manual again. She obtained some matches from her partner, lit the bunsen burner and checked her watch. She then underlined the phrase "15 - 20 mins" [4] in her lab manual. Having done this, she began to converse with her partner, the researcher interviewed her to find out what they had been talking about;

STUDENT 1: Uh, when you took the crucible you have to use everything that's um ... there must at least be, there must be no moisture on everything. So one of the suggestions is to heat the crucible tongs for a little bit so that it also loses some of the moisture of ... because we handled it which brings sweat and (sounds like moles) onto it.
RESEARCHER: mm
STUDENT 1: So if you just heat it a little bit, it sort of breaks down the water.
RESEARCHER: So is that what you were telling your partner ?
STUDENT 1: Ja
RESEARCHER: Where did you find this out ?
STUDENT 1: (pause) I don't know ? ...
RESEARCHER: You just figured it out yourself ? ...
STUDENT 1: An observation.

While waiting for her crucible and lid to heat, the researcher interviewed her once again.

RESEARCHER: Tell me, while we are waiting ... ok uh ...
STUDENT 1: I'm gonna ... I've decided I'm gonna wait for five minutes so that I can start with the agar solution in after five minutes and then stop both at the same time. Because you ...
RESEARCHER: Start what at the same time ?
STUDENT 1: Because for this one you have to work between ten and fifteen and this one you've got to heat between fifteen and twenty minutes. So if I wait five minutes and then I add the agar solution then I can work to fifteen minutes and then it balances each other out.
RESEARCHER: Oh I see ok that's clever. But but no what I actually meant to say was - *while* we are waiting, I want to ...

STUDENT 1: Oh.
RESEARCHER: ... ask you a question, but thanks for the information anyway.
STUDENT 1: Ok
RESEARCHER: Um it says in the manual there that you must heat just to boiling.
STUDENT 1: Ja.
RESEARCHER: Now how did you know when that had occurred ?
STUDENT 1: Well when you see the bubbles from the bottom coming up and starting to boil it means the oxygen is boil ... ja oxygen is being used.
RESEARCHER: Oxygen !!
STUDENT 1: Or something - ja
RESEARCHER: (trying to hold back a laugh but unable to)
STUDENT 1: Water is coming out ... steam is coming out.
RESEARCHER: Sorry, I'm not supposed to laugh (laughs some more). No its its steam ah but its not really ...
STUDENT 1: Water
RESEARCHER: Ja ja.
STUDENT 1: Water ... Its gotta actually bubble on the surface. ...
RESEARCHER: Ok then - because I didn't see yours have big bubbles and then ...
STUDENT 1: No no no but ...
RESEARCHER: But what ?
STUDENT 1: Those bubbles stayed there for a while so I thought that was ... because the temperature of the bunsen burner is not gonna get much hotter, so I reckoned that was its boiling ... was boiling.

After this, she began to read through the lab manual again (time: 2:48). She then asked friend 2, "do we stir when we add in the agar ?" to which friend 2 replied "I don't think so - no, we want a precipitate to form". She began to add in the agar-agar dropwise with a dropper. She held her hand very high above the beaker (± 15 cm) and allowed large drops to plop into the solution.

She added the first portion of agar-agar in a dropper over a 20 s period. The second portion was added as the first, but the third dropper-full, she added much more slowly. As the demonstrator came around, she asked her whether she should stir the solution while adding the agar-agar. The demonstrator explained to her the meaning of the word 'coagulate' - "to make it all come together". During this interchange, the demonstrator told her to go to a spare bench and heat up some water as she would be needing it later on. Student 1 determined to put water in a beaker and place her wash bottle in it and heat the water in the beaker. Since the students were already using the one bunsen burner available for each person on their own desks, they needed to go to a desk where no-one was working to heat up the water. (This meant that when student 1

wanted to use the water in the wash bottle, she had to move it - in the beaker - from the spare bench to where they were working). Student 1 asked friend 1 for a spare beaker, but friend 1 told her that she could share the water that she had already begun to heat. Student 1 agreed to this. She then went and got some ashless filter paper for herself and her partner, telling him that it was 'special filter paper'. She then went back to friend 2 who asked about washing the precipitate. Student 1 suggested washing the precipitate off the filter paper (as she did in the pre-lab test, see section 4.2.18) but friend 2 told her not to do that. Friend 2 then showed her how to fold the filter paper so that it wouldn't pop out of the funnel. After they had spent some time attempting to decipher what the lab manual meant and what procedure to follow, it was clear that student 1 was not sure of what procedure to follow. Student 1 was interviewed in order to determine the extent of her misunderstandings;

RESEARCHER: So there, what you and your friend were talking about did you really understand what you were saying or didn't ... ?
STUDENT 1: No, neither of us know what we were huh
RESEARCHER: Ok so ...
STUDENT 1: I think we actually got it wrong to start with ... because when you, when you supposed to ... I think actually that's supposed to mean 'separates' in a way.
RESEARCHER: What, to decant ...
STUDENT 1: Ja
RESEARCHER: ... means to separate
STUDENT 1: I think ... because it says take it through the filter paper retaining the precipitate in the beaker, in other words leaving it in the beaker. So I would ... its got something to do with like separating it from the precipitate - I think.
RESEARCHER: Ok
STUDENT 1: So ...
RESEARCHER: And then the other part with the washing that she was talking about ?
STUDENT 1: Ok ja, then you have to wash the precipitate into the bottom of the filter cone using hot distilled water (pause) I don't ...
RESEARCHER: So how are you gonna find out what to do ?
STUDENT 1: I'll ask [demonstrator's name]

At that, she then went to the demonstrator to ask what was going on. After some discussion with her, student 1 was interviewed again in order to determine whether she had learned anything.

RESEARCHER: Let me just ask you - so did you understand what the demonstrator is talking about now ?

STUDENT 1: Ja now I understand it
RESEARCHER: So what are you about to do ?
STUDENT 1: Ok well I'm just ...
RESEARCHER: You can work while you ... while you are talking.
STUDENT 1: Ok well, I'm just gonna filter this completely until um the precipitate is left and then when you wash, you wash it into the filtrate and then you test what's in here for silver nitrate and if there is a precipitate then you've got to keep washing it with water.
RESEARCHER: Ah !
STUDENT 1: Now I understand !

She then began to decant the solution. Approaching friend 2, while waiting for the filtrate to pass through the filter paper, she commented that it was taking too long to pour the filtrate through. Friend 2 replied that it goes faster if you keep pouring through continuously. She returned to her desk and said to her partner "are you only there !" (he was not decanting yet).

She then took the crucible and lid off the tripod and placed it on a tile to cool. After she had put them in a desiccator, she commented to friend 1 that "this paper takes extra long [to filter]". Student 1's amount of precipitate at this stage, was very little compared to friend 2's.

Student 1 continued to decant the liquid (time 3:20). By this time, the demonstrator had wandered around and asked "is it going all right [student 1] ?"

Student 1 then checked friend 1's warm water in a wash bottle (this she had transported in a beaker of warm water to her desk) and said to her "is it still warm ? It is probably going to be cold when you are finished". This caused her to get her wire gauze out of her locker in order to heat another beaker of water that she could place the wash bottle in.

While waiting for the solution to pass through the filter paper, she began to read through the lab manual again. She asked one of her friends if they had to check their name off on the register and the friend replied that they were not taking the register.

Student 1 then informed her partner that he could use her water and that he wouldn't have to heat any up. She also told him that he should heat up the water in the wash bottle (he was heating some water in a beaker and simply using the water in the beaker to wash the precipitate). Her partner replied that he would add the water to the wash bottle when finished. Student 1 said "same thing".

At 3:30 p.m., she was still decanting the liquid. She did not allow the level of the liquid to rise over the top of the filter paper. She then took the crucible and lid out of the desiccator and placed it on a white tile using her tongs. Her friend asked how she would know when it (the crucible) was cold. Student 1 replied "when you touch it and it doesn't burn". She then took the crucible and lid to the balance room, and using the tongs weighed on an accurate balance - it read 29.724 g. She returned to her desk and wrote this quantity into her lab manual (see appendix D for a photocopy of her markings in the lab manual - number [4]). She then approached the demonstrator in order to determine whether she should put the crucible and lid back in the desiccator when she had weighed it. The demonstrator told her not to because she would be heating it.

She then continued decanting. While waiting, she went to check on the previous week's lab report. Friend 2 came to talk to her and they discussed their marks (friend 2 was washing the residue at this stage). Student 1 then began to speak to her partner.

RESEARCHER: What were you talking to your partner about ?
STUDENT 1: Well um the end of my filter funnel is in the water, so that should slow down ... slow it down .
RESEARCHER: Slow what down ?
STUDENT 1: um the dripping, or the filtration. So, but I have to keep all of the same solution in one beaker so I can't take it out.
RESEARCHER: in ... you mean in one conical flask
STUDENT 1: I mean ... ja
RESEARCHER: ja - that thing ja.
STUDENT 1: conical flask
RESEARCHER: I've just got to ... because I've got to annotate this so I must know what you mean. So so now you just gonna hold it now ?
STUDENT 1: Ja because I'm nearly finished anyway so I'm not going to change to another beaker.

She then proceeded to hold the funnel over the conical flask with her hand instead of letting it rest on the rim of the conical flask.

(Time, 3:40 p.m.). The demonstrator came around and student 1 asked if she had to continue hold it up, and whether it would make a difference if she didn't.

Student 1 [to demonstrator]: No it's just because its going to take forever
DEMONSTRATOR: Maybe just clamp it over here so that you ... (very soft)

STUDENT 1: Oh ja.
DEMONSTRATOR: So you clamp it above so that the water can just drip in
STUDENT 1: Ja, because its ...
DEMONSTRATOR: Because it might hamper it I don't know.
STUDENT 1: Its taking much longer

She clamped it in a very unstable way, with the clamp at the apex of the funnel and then began to wash the precipitate out of the beaker with the warm water. First she poured a whole lot of water into the beaker and then poured it into the funnel. Friend 1 came and asked her how much precipitate she had collected. Student 1 said "not much". Friend 1 came to stand next to her, while friend 2 began to tell her what she was going to do now.

Student 1 then began to wash the precipitate out of the beaker while simultaneously allowing the water to pour into the funnel (see figure 5).

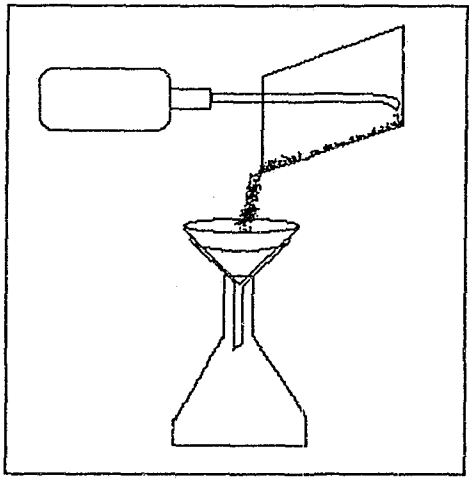


Figure 5: Washing the precipitate out of the beaker

She then began to read through the lab manual and then washed her beaker. She asked the demonstrator how she was supposed to fold the filter paper in order to put it into the crucible. The demonstrator told her to fold it from the top down (see figure 6), and then it wouldn't really matter how you fold it because it works really well, and then put it in the crucible.



Figure 6: Folding the filter paper

Another friend came (not friend 2) and asked student 1 what the bottles were for (meaning the silver nitrate bottles). Student 1 explained that they were to *test* for silver nitrate.

Student 1 placed a few drops of silver nitrate into the filtrate from the filtration. (Obviously it formed a silver chloride precipitate because it still had the original AFS + acid solution in it). As she was doing this, she spilled some silver nitrate onto her finger and she went to wash it off. She then said to her friend, you've got to do it again if it does that (ie. forms a precipitate). She then raised the clamp holding the funnel, removed the flask and put a clean beaker under her funnel. She then proceeded to pack the equipment lying around on her desk back into her locker.

RESEARCHER: Just let me ask you, why do you think that you have to test ah what's inside that um that conical flask with silver nitrate ?
STUDENT 1: Well if you still have chloride ions left, then um in your precipitate then its also ... how can I say ... that would be an extra mass which you don't want. You just want the sulphates left. And if the chlorides are in may be ... ja there is extra mass. If you keep washing the chlorides out you'll get the accurate mass of the ba .. ah sulphate ions.

She then tested the filtrate after washing, and it gave a precipitate. She washed it again with another clean beaker under the funnel and quickly washed the first beaker that she used. Student 1 then went to talk to friend 2.

RESEARCHER: Tell me, what did you, what did you ask your friend, I missed that ?
STUDENT 1: Ja, I was just making sure that the first precipitate ... or the first filtrate that we got that we can get rid of it.
RESEARCHER: Ok, so you just said ja
STUDENT 1: Ja

She then went and asked her friend if she was heating hers already (time 3:59). Going back to her desk, she added silver nitrate to the filtrate. It yielded precipitate once again. Friend 2 came and student 1 explained to her that it was taking so long to wash because she added too much HCl.

Not long after this, the demonstrator arrived on the scene again and told student 1 not to test with silver nitrate too long or she wouldn't finish (meaning that it wasn't important that she ensure that fresh filtrate did not yield a silver chloride precipitate). Friend 2 added the silver nitrate for student 1 one more time, but no precipitate resulted. Working together, student 1 and

friend 2 began to discuss the questions in the lab manual, referring to the board when they got stuck, all the while writing in their lab reports.

STUDENT 1: Ok (laughs) right, take ... you weigh your mass of the sulphate and you take .. you put it over the mass of ... the original mass you had which was 0.3 g ...
FRIEND 2: This is this out of this bottle type thing (referring to the small bottle of AFS that was used).
STUDENT 1: Ja.
FRIEND 2: Ok.
STUDENT 1: And then your theoretical sulphate would then be ... because you work out the amount of moles.
FRIEND 2: Ja
STUDENT 1: So if you get the actual formula SO_4 is like in brackets and there's a 2 with it so there's one mole of the whole thing then there should be like two moles of whatever that is.
FRIEND 2: Oooookay
STUDENT 1: And then you put the theore ... you work out the theoretical then you put the experimental one over the theoretical one.
FRIEND 2: All right.
STUDENT 1: And that's your answer.
FRIEND 2: What is our theoretical one ? No, its theoretical over ...
STUDENT 1: Ye .. No experimental over theoretical which means um...
FRIEND 2: Oh right the third part.
STUDENT 1: Oh that's the third part

They checked the board where the calculations from the pre-lab talk were still displayed.

FRIEND 2: Observed over expected ja
STUDENT 1: Experiment over theoretical
FRIEND 2: Ok ja.
STUDENT 1: And the second one [appears to be referring to the second calculation required] I'm not too sure what the the moles are of the sulphate and what is expected, but I think its ... if you have the ...
FRIEND 2: It has to be the same ... you know because if you ...

They checked the board again.

STUDENT 1: This over that ... see there is a fourth one too there so - that's ammonium ferrous sulphate so if there's two of that in the whole solution, there's one of the whole solution.

FRIEND 2: So its one SO_4
STUDENT 1: So no there's got to be two ... I think just ...
FRIEND 2: Make sure.
STUDENT 1: that's just the one ... then you've got to work the ....

They checked the board again

Student 1 then took her wet filter paper in hand and placed it in the crucible. She lit the bunsen burner in the same way as before while friend 1 adjusted the flame so that it was very low. She and friend 2 then sat down (at student 1's desk) to work out question 2 - friend 2 was writing the results into her report sheet. Student 1 then also obtained her report sheet and, sitting down next to friend 2, began to write in it (time 4:09 p.m.). Periodically as they were working, student 1 checked the filter paper in her crucible.

FRIEND 2: Mass of SO_4 is the mass we calculated hey ?
STUDENT 1: Hey ?
FRIEND 2: Times the mass of ammonium ferrous sulphate
STUDENT 1: ja ... (writing) Crucible + lid. I had to be ... (looking in lab manual) ...
FRIEND 2: The mass of the ammonium ferrous sulphate was point three grams hey ?
STUDENT 1: ja well which ever you ... yours came to be.
FRIEND 2: Aw shucks ... No, what do you mean ?
STUDENT 1: Like you didn't have to weigh exactly ... well, I didn't ... mine wasn't exactly.
FRIEND 2: No mine was exactly. When I'm good, I'm good.
STUDENT 1: Oh its starting (At this point it seems that she spotted vapours coming out of the crucible).

Student 1 approached the demonstrator to ask a question.

DEMONSTRATOR: (seeing me and laughing) Ah ha ha
STUDENT 1: Ok um the mass of the sulphate is ... if you work out ... if you weigh now what we get in the crucible - that's our barium sulphate - and because one mole equals one mole, whatever the moles is of the barium sulphate would be the moles of the sulphate. But to work out its mass would you use just the sulphate's molar mass ? Ok.
DEMONSTRATOR: Ja
STUDENT 1: And then um expected percentage ... does the ...
DEMONSTRATOR: Yes
STUDENT 1: ... theoretical sulphate ....
DEMONSTRATOR: Yes

STUDENT 1: Ok that I don't ... where do we get that value from ?
DEMONSTRATOR: Ok so you said ... cause this is what you've actually weighed the sulphate out.
STUDENT 1: Ja
DEMONSTRATOR: Now if this was pure ammonium sulphate that you were using ...
STUDENT 1: Ok, ja.
DEMONSTRATOR: Ok you wouldn't necessarily get ... you'd probably, you might get more, ok you'd probably get more than what you've actually got.
STUDENT 1: Ja
DEMONSTRATOR: Ok, so if you taking your original um ammonium ferrous sulphate mass, ok and you say ok how much sulph... What should the mass of the sulphate be in this case, if the ammonium ferrous sulphate is pure, there's no impurities ?
STUDENT 1: Ok, ...
DEMONSTRATOR: So it is .300 grams of pure ammonium ferrous sulphate then you should have, ok you can work out theoretically the mass of your sulphate. You should have a certain mass of sulphate in there.
STUDENT 1: Oh, ja ok
DEMONSTRATOR: Because if you remember what the formula looks like ...
STUDENT 1: Ja, I'm working out.
DEMONSTRATOR: So you actually need to look with the formula ...
STUDENT 1: So do I cover this now (referring to crucible) ?
DEMONSTRATOR: No you must leave it open, because that is just your carbon coming off.
STUDENT 1: Ok that very long ...
DEMONSTRATOR: Ja
STUDENT 1: ... equation (looking through her lab manual where the formula for AFS is given in A1)
DEMONSTRATOR: (Looking at me and laughing again) Ok you look at this one here that's fine that's what you want. Ok so ... Ok you see that here you have two moles ...
STUDENT 1: Ja
DEMONSTRATOR: ... of sulphate for every one mole of ammonium ferrous sulphate. Ok can you see that, so when you dissolve it in water whatever, if you had one mole of ammonium ferrous sulphate you are gonna have two moles of sulphate and water. So if you had pure ammonium ferrous sulphate ok no impurities present ... you would expect. Ok, so you would have to first of all work out the moles of ammonium ferrous sulphate that you have.
STUDENT 1: I got three ... can you use three grams. Ok
DEMONSTRATOR: Ok does that make sense
STUDENT 1: Ja

DEMONSTRATOR: Ok. Because you need to use your mass exactly like if it is .300 then it needs to be .300. Ok then from the number of moles of ammonium ferrous sulphate you can work out the number of moles of sulphate - theoretical.
STUDENT 1: Ja you just ... ja because if that is certain moles, you just times it by two.
DEMONSTRATOR: Ja and then you can work out the theoretical mass.
STUDENT 1: Mass, ok.
DEMONSTRATOR: Ok. But in this case here what you are doing is you are actually weighing the actual mass of sulphate do you know what I mean ?
STUDENT 1: Ja
DEMONSTRATOR: As in you are weighing the barium sulphate so you are getting the actual mass of sulphate that you have, so if you had impurities, you'd have a lower mass of sulphate than you expected.
STUDENT 1: Ok
DEMONSTRATOR: Does that make sense ?
STUDENT 1: Ja
DEMONSTRATOR: So do you know what that theoretical sulphate is ?
STUDENT 1: Ja no I know what it is ok
DEMONSTRATOR: Ok (to friend 2) is that all right ?
FRIEND 2: Ja I'll get it from her.
DEMONSTRATOR: (laughs) and this (referring to the crucible) when this has stopped the ... when this has stopped these vapours they are talking about .. when they have stopped coming off, you can increase the temperature ok.
STUDENT 1: Ok then can I cover it ?
DEMONSTRATOR: No you always leave it open cause otherwise you can't get any of the carbon or any of the coming off.
STUDENT 1: Ok ja because it will stay in. oh ok ja.

Friend 2 then went to talk to the demonstrator, while student 1 copied her lab report (Friend 2's lab report is exceptionally neat while student 1's is rather untidy).

Upon friend 2's return;

STUDENT 1: Ja, but here it says "Compare the observed ... Hence deduce the percentage by mass of..."
FRIEND 2: Which you have done here.
STUDENT 1: All right ok ... then ... "Compare the observed results with that expected for ammonium ferrous sulphate and express the comparison as a percentage purity".
FRIEND 2: Ja, what ...

STUDENT 1: (inaudible)
FRIEND 2: Ok and then what do we do then ?
STUDENT 1: I think it is just wording.

At 4:23, 4:24, 4:25 p.m. she checked the crucible and lid (she could have been doing this because she saw the researcher making a note of it every time she did so). She then asked friend 2 when she could turn the flame up. Friend 2 turned it up for her and said that it would start smoking again. They then returned to the discussion of the questions.

STUDENT 1: For that second part, where it says expected ...
FRIEND 2: Ja.
STUDENT 1: ... you take the theoretical amount of that ... followed by the mass of water
FRIEND 2: Where do we get the theoretical mass ?
STUDENT 1: Oooooh ok. (Pause) Ok this is what you have to do - theoretical. So now we are supposed to work out expected, expected percentage with this ...
FRIEND 2: Expected is what you would expect.
STUDENT 1: What you *think* it will be.
FRIEND 2: Ja that's theoretical.
STUDENT 1: Ja.

STUDENT 1: Ok you take ... you have um one mole of ammonium ferrous sulphate two moles of sulphate.
FRIEND 2: Ok.
STUDENT 1: So with the mass that you have of the ammonium .. ammonium ferrous sulphate you work out the mole. And then you just times it by two and you get your theoretical.

Friend 1 asked what the molar mass of ammonium ferrous sulphate was.

STUDENT 1: Molar mass of ammonium ferrous sulphate - 233.37 no I lie, I'm lying that's barium sulphate.

Finally student 1 gave the correct molar mass.

The demonstrator came past student 1's bench again.

DEMONSTRATOR: ... and then you can s... you still have to answer this question, what kind of error arose. So you can do that in the mean time.
FRIEND 2: Ok how do you do that ?

DEMONSTRATOR: Ha, you just have to think about it.
FRIEND 2: (laughs sarcastically)
DEMONSTRATOR: What happens if the iron precipitates out with it ? What's gonna happen to your results ?
STUDENT 1: Oh right. Ok.
DEMONSTRATOR: Will it give you too high or too low a figure ? And then explain why you get that answer.
FRIEND 2: Ok.
DEMONSTRATOR: Ok So you can do that now while you are waiting otherwise you are just wasting time.
STUDENT 1: Ok for the um when you write the molar mass of ammonium ferrous sulphate do we include the water at the end, the six waters ?
DEMONSTRATOR: Because your waters have actually ... water is attached to the ammonium ferrous sulphate molecule.
STUDENT 1: Even though we have heated it, we still include it ?
DEMONSTRATOR: But this is before you've heated it.
STUDENT 1: Oh ja.

At 4:30 p.m., she checked on the filter paper and shifted the bunsen burner slightly so that it was not in the same position as before.

They then began on question 3.
STUDENT 1: What did your qualitative tests indicate about the presence of iron in your $BaSO_4$?
FRIEND 2: Ja.
STUDENT 1: You know we keep, keep having to wash it ?
FRIEND 2: Ja, so with the washing up ...
STUDENT 1: So if we didn't wash it, it still would have had ions in.
FRIEND 2: Ok
STUDENT 1: ... and that would have been ... um ...
FRIEND 2: That's why we kept this.
STUDENT 1: ... extra masses. But to indicate that the ions did leave it we used silver nitrate ...
FRIEND 2: ... to check the precipitate.
STUDENT 1: Ja so it would react with the ions.
FRIEND 2: So ...
STUDENT 1: So. Ja so ? (laughs)
FRIEND 2: Ok.

STUDENT 1: Ok. What did your qualitative tests indicate about the presence of iron in your $BaSO_4$? (long pause while writing) um

After this, she went to talk to her partner and explain it to him. She noticed the lid had fallen off her crucible and she put it back on. At 4:37 p.m. she checked once again how the filter paper was doing. Looked into the crucible she exclaimed 'burn !'. She then shared her 50 ml measuring cylinder with one of her friends and then she and friend 2 began to work on the calculation of the percentage purity. (In her lab report, she called it "Theoretical" under the heading of "Comparison").

STUDENT 1: Observed ... You've put the mass in the wrong place there. Ag molar mass.
FRIEND 2: Me ?
STUDENT 1: Ja.
FRIEND 2: Why, it's the mass of that ?
STUDENT 1: Ja but you have to ... um ... ja but you see ok the mass ... what you have is three grams.
FRIEND 2: Oh right. Oh.
STUDENT 1: So what we, what we did was. Ok, what we did, we took ...
FRIEND 2: Observed over ... Oh *!#@ I'm having a good day.
STUDENT 1: What you do is, ok that's the molar mass right ?
FRIEND 2: Ja.
STUDENT 1: #@!* ok so my mass is 0.335 that was my mass. So you've got the ...
FRIEND 2: So this is over here.
STUDENT 1: Ja, ja, ja quite correct, 0.335 g over and then you work out the theoretical. So now if you have that much, you work out the moles, which is .335 divided by 392.1 that's moles that you worked out. Times that by two, that's moles.
FRIEND 2: Ja, I've got that.
STUDENT 1: Ok that's your moles. And then this moles that you get is a ... ok.
FRIEND 2: That's a mass.
STUDENT 1: Oh no that's the moles. Now what is the molar mass of sulphate itself ?
FRIEND 2: SO_4 ?
STUDENT 1: Ja.
FRIEND 2: 97.
STUDENT 1: No that's, that's barium sulphate.
FRIEND 2: Oh no.
STUDENT 1: Ok, ja.
FRIEND 2: 96.07
STUDENT 1: That's our expected mass.

FRIEND 2: Ok so that's 1.64 ... 0.164.
STUDENT 1: 0.1 no you ... but you had a different mass than me hey !
FRIEND 2: 0.3.
STUDENT 1: Ja, let me work it out. .3 divided by 392.17 times 2 times 96.07.
FRIEND 2: Ja 1.4
STUDENT 1: 0.14 ..
FRIEND 2: 0.147, yes.
STUDENT 1: Ja, mines one, 164. Mine's quite a bit different.
FRIEND 2: What was mine ? .147
STUDENT 1: Ja, um.
FRIEND 2: Don't we have to ... isn't expected percentage multiplied by a hundred ?
STUDENT 1: Ja.
FRIEND 2: Ok so that's 48, 96 % which will give you ... I'm gonna go for the sulphate. Hey 49 %

STUDENT 1: Ok so that would be, then you put that at the bottom.
FRIEND 2: What ? What we just calculated ?
STUDENT 1: Ja, forty ...
FRIEND 2: Forty nine.
STUDENT 1: I don't remember ... ok the thing is, if you have three and three, you divided you still have three right (referring to significant figures) ?
FRIEND 2: Ja.
STUDENT 1: To three, to three.
FRIEND 2: I'm not really worried about the significant figures at this stage of my life. So I'm gonna go weigh now.
STUDENT 1: Let's see (referring to the bunsen burner).
FRIEND 2: Ok, close and lets turn it up full blast.
STUDENT 1: It is full blast.
FRIEND 2: Level, now it is full blast, now you just leave for like an hour and then ...
STUDENT 1: Can I close this filt (not quite sure what she said) like this ?
FRIEND 2: No ! It musn't close. YOU MUST NOT CLOSE IT ! Ok listen I'm just quickly going to go weigh mine.
STUDENT 1: Sure.

The time at this stage was 4:42 p.m.. She then asked the demonstrator about significant figures.

STUDENT 1: Ok that's the mass that we had for the mass of ammonium ferrous sulphate. And the theoretical mass, if you had that you work out your moles of what it is, you times that moles by two.
DEMONSTRATOR: Yes.
STUDENT 1: ... and then that moles you work out, molar mass over your ... well from your molar mass you work out the sulphate ions.
DEMONSTRATOR: Yes.
STUDENT 1: I get 48 % is that ... correct ?
DEMONSTRATOR: Ouch, I'm not actually sure (laughs) but that ... Your your principle behind it is correct.
STUDENT 1: Ok if I um have three significant figures there and three there ...
DEMONSTRATOR: Yes.
STUDENT 1: ... and I have that and there is a nine there.
DEMONSTRATOR: Ok.
STUDENT 1: Do I make it 49 comma one nought or two noughts ? Because it is only supposed to be three.
DEMONSTRATOR: Ok well you make it 49.0
STUDENT 1: Ja, so it is one nought
DEMONSTRATOR: One nought ja
STUDENT 1: So then you, that would be at the bottom, and what we weighed will go on the top, well by percentage.
DEMONSTRATOR: Percentage ja, so you are gonna work out ... so its this percentage over here that you are working out.
STUDENT 1: Ja
DEMONSTRATOR: And you are gonna put that percentage on top of that one.
STUDENT 1: Ja.
DEMONSTRATOR: Do you understand why ?
STUDENT 1: Ja.
DEMONSTRATOR: Its exactly the same process as if you had taken the theoretical mass of sulphate ... I mean the expected ... the observed mass of sulphate ...
STUDENT 1: Ja.
DEMONSTRATOR: ... and divided it by the theoretical mass of sulphate
STUDENT 1: What if it is more than what we have ?
DEMONSTRATOR: then ...
STUDENT 1: then I expect ...
DEMONSTRATOR: Ok, well then you've got more than a hundred percent purity so it obviously means that maybe if there was still some carbon present some paper present. Maybe you had impurities present I don't know that like barium chloride or something like that.

STUDENT 1: Ok.
DEMONSTRATOR: Ok.
STUDENT 1: Ok.
DEMONSTRATOR: Hopefully it won't be though.

Friend 2 then returned, and they continued to work on their reports.

STUDENT 1: Ok that's the mass of barium sulphate.
FRIEND 2: Oh ok 0.345
STUDENT 1: No you've got to put it over here.
FRIEND 2: Why ? Divided by ?
STUDENT 1: 233.37
FRIEND 2: Equals ?
STUDENT 1: Ok that's your moles, ok now you take that number, times it by 96.07
FRIEND 2: Times 96.07, equals 142
STUDENT 1: Ok so that's yours.
FRIEND 2: Its less than 147
STUDENT 1: Ok now lets see what percentage of... .142 divided by point three, yours is point three, hey ?
FRIEND 2: Ja.
STUDENT 1: Ok that gives you 47 % wow, it almost gives you a hundred percent. Ok and you have 49 percent right. 47, lets make it 47 divided by 48 that times 100 - check your percentage purity.
FRIEND 2: Ooooh I'm good. Ye. But I'm just gonna reweigh it when I test it. I should actually time it now, give myself till 5 o'clock then I'm gonna go reweigh it. ... Is that the mass that I got of barium sulphate ? How do you say, that minus that, minus that, minus that, hey ?
STUDENT 1: Ja, your bigger minus your smaller.
FRIEND 2: Divided by 39.270 is equal to 1.009 no wait, 1.009 .... (very faint).

She then went and checked on the filter paper and again and said "Come on burn !!!". The time was now 4:47 p.m.. Friend 1 then came to check out student 1's report. She left not long after arriving and student 1 was content just to wait for the paper to burn. But she soon began to wash her beaker and funnel. The demonstrator then arrived on the scene once again to check her crucible. She (the demonstrator) lifted the lid with a pair of tongs and looked inside. She told student 1 "you will see that the paper is gone when you see like a white ...". Student 1 then asked if she could weigh it when she saw that. (No reply noted). She then walked over to her partner's set-up and told him that his was nearly ready.

At 4:53 p.m. she checked her burner again and said "oh, it has started".

RESEARCHER: Ok, what are you worried about ?
STUDENT 1: Ok, the two things we are supposed to add um.
RESEARCHER: Ja, those two chemicals, I know what you are talking ...
STUDENT 1: Ja, you are supposed to add them to the filtration, the liquid that we had to test for the presence of ions.
FRIEND 1: (overhearing our conversation from the other side of the desk) No, weren't we supposed to add them ... (very faint) ... in the crucible
STUDENT 1: Is it, well then that's ...
FRIEND 1: That's what I'm gonna do.
STUDENT 1: Oh ok ja. Well if that's the case, then we just add it to that. [Friend 1's name] you are supposed add it to ...

As a result of this conversation, student 1 realised that she had to add ammonium thiocyanate and ortho-phenathroline to the precipitate, and not to the filtrate. At 5:55 p.m., the demonstrator came and took the lid off her crucible - a spark came out, and the demonstrator commented, "when you take the lid off, it ignites". The demonstrator also mentioned that this was a long lab.

At 4:57 p.m. student 1 checked her crucible and lid again. (Friend 2 was far ahead of everyone else at this stage). She was about to add the ammonium thiocyanate and ortho-phenathroline solutions already (although she still thought that they had to be added to the filtrate, and she had thrown the filtrate away). The demonstrator came once again and checked student 1's crucible by lifting the lid. (The later it got the more the demonstrator seemed to be around.) By this time, student 1 was doing part (c) of question three (see the lab report).

STUDENT 1: Ok, would it be too high, or too low ?
FRIEND 2: Ok that is (c).
STUDENT 1: (writing) the percentage of sulphate ions in the sample would be ...
FRIEND 2: What ?
STUDENT 1: That's fine right ?
FRIEND 2: Just go weigh it ... (long pause while both were writing in their lab reports) percentage of percentage ...
STUDENT 1: (continuing to write) ... percentage of sulphate ions in the sample would be much larger, much larger and this too large value will affect the overall percentage purity of the, of the observed ...

At 5:04 p.m. she checked her burner again. She asked friend 2 if she thought it was 'all right'. Friend 2 advised her that it was. Upon looking inside the crucible, the researcher noticed that there was a little black powder in the it. Friend 2 then advised student 1 to "put it (the crucible and lid) in your crucible (she meant desiccator)". Student 1 then placed her crucible and lid in her desiccator.

Student 1 listened as someone told the demonstrator that they got more than 100 %[27].

Student 1 then checked the desiccator (didn't note how) and put her pipeclay triangle and tripod away. She also put the bunsen burner on the shelf neatly. After this she placed the back of her little finger on the crucible and said "I reckon its ok". At that she took the crucible and lid out of the desiccator, put them on a white tile and took them to the balance room.

Approaching one of the accurate balances (it read 0.002 g), she placed the crucible and lid on it without taring it - and it read 30.129 g. She then went back to her desk and filled the mass into her report sheet (time 5:14 pm).

At 5:20 p.m., student 1 handed her report in and left the lab with her desk tidy and clean and with the desiccator on top of it.

As far as was observed, the lecturer in charge of the lab had sat behind the centre bench and did nothing but read (and look up now and then) for the whole session. During experiment A4 he had told the researcher that the first year lab sessions bored him because they had nothing to do with the work that he was lecturing on in class, and he didn't have any interest to see how they were proceeding (ie. if they were problematic etc.).

3.3. Conclusion

In order to make inferences about the reasons about this student's response in the post-lab test with a greater degree of validity, a description of the laboratory learning process needs to be made. This chapter has included just that. This in turn will be used to interpret the student's responses in the post-lab test which is presented in the next chapter. It will also be used to discover factors that affected the student's learning in the lab, the discussion of which has been included in chapters 5 and 6.

---

[27]It was at this point that the researcher overheard demonstrator 2 telling demonstrator 1 that she had told her students to only weigh the crucible and lid once and to leave the reheating and reweighing. She also made her students hand in their reports the next day. Thus they had finished earlier than most of D1's students.

Chapter 4

Analysis of the pre- and post-lab tests

4.1. Introduction

Rather than simply presenting the interview transcripts of pre- and post-lab tests with the student, an analysis of them has been provided. This analysis was carried out in the light of the description of the student's activities in the lab. In the *next* chapter the analysis presented here as well as all the other data gathered have been *interpreted* in order to identify and gain insight into the factors that affected the student's learning.

4.2. Analysis of the pre-lab test and post-lab tests

4.2.1. Introduction

For each question, the following have been provided;
(1) a copy of the question posed to the student
(2) a model answer (or performance) for the question.
(3) the student's response in the pre-lab test.
(4) the student's response in the post-lab test.
(5) an analysis of what the student learned as a result of the lab session.

Note:

- A copy of the learning aims of the chemistry department for experiment A6 has been included in appendix D. These were used as a guide to decide what and what not to include in the test. This ensured that the results would be of maximum interest to the chemistry department.
- A copy of the student's *writings* in the pre- and post-lab tests have been included in appendix B - the numbers in square brackets correlate her writing to the interview transcript.

4.2.2. Analysis of question 1(a)

The question

(1) A chemist took an amount of ammonium ferrous sulphate (MW[28] = 392.17g/mole) and dissolved it in water. She then added (excess)[29] $BaCl_2$ to the solution and collected all the barium sulphate (MW = 208.2 g/mol) precipitate that formed ($BaSO_4$).

$$BaCl_2 + SO_4^{2-} \rightarrow BaSO_4\downarrow + 2Cl^-$$

(a) calculate what she found to be the percentage by mass of sulphate in ammonium ferrous sulphate by using the following information;

Mass of ammonium ferrous sulphate = 0.3000 g

Mass of $BaSO_4$ obtained = 0.2603 g

The model answer

$m(BaSO_4) / M(BaSO_4) = n(BaSO_4)$

$n(BaSO_4) = n(SO_4)$

$n(SO_4) * M(SO_4) = m(SO_4)$

$\therefore$ % by mass (SO_4) in AFS = $m(SO_4) / m(AFS)$

The student's response in the pre-lab test

(See lines 16 - 59 of the pre-lab test interview)

..... one has to - okay, what you would do is you would work out the moles formed. (pause) Okay, well what I would do is I would take - do I have to write it out ?

RESEARCHER: Oh ja, if you think that it would help you, fine.

STUDENT 1: Okay. Um. It should be the mass you obtain, over the mass you had - um originally (writes "Mass obtain/Mass origin") [1] - you originally had ... because you have one mole of each so if this is balanced (pointing to the balanced chemical equation in the question), which it should be, then you have 1 mole of barium .. ammonium ferrous sulphate so SO_4^{2-} (writes "= 1 B SO_4^{2-}") [2] over still the 1 mole of barium sulphate (writes "1 $BaSO_4$" underneath the SO_4^{2-}) [3] which is also, also 1 mole so we just do mass over mass. Which is 0,1002 ... 3 (writes "0,1002/0,3) [4] which is - can I use a calculator ... 3 ... it is

---

[28] MW stands for molecular weight. It is, however, is incorrect to equate it with a figure of units g/mole. Thus, the question rather should have read, MM (ie. molar mass) = 392.17g/mole.

[29] The word excess was not in the test. Afterwards it was realised that it should have been included.

33,4% (writes " = 33,4 %") [3] sulphate ions - percentage by mass. Okay, then we take 100 grams (writes "100 g and underlines it") [6] of the substance so that would be 33,4 grams (writes "= 33,4 g") [7] - no, no, no, no - ja - of 100 grams of it (writes "of 100g of sulphate") [8].

RESEARCHER: Don't worry if you make a mistake, that is fine.

STUDENT 1: Ja.

RESEARCHER: Just relax. So you said you don't have a clue. Why did you take 100 grams? Just ...

STUDENT 1: Well it is easier to take 100 grams so that you can work out ... your percentage you work out can automatically be a mass.

The student's response in the post-lab test

(See lines 15 - 52 of the post lab test interview)

....Okay, well first of all we know that 1 mole barium sulphate, 1 mole sulphate ions (writes "1 mole $BaSO_4$ → 1 mole SO_4^{2-}") [1] - you're gonna have 1 mole barium sulphate is 233,37 grams per mole (writes "1 mol - 233,37 g/mol") [2] so 1 mole sulphate (writes "→ 1 mol SO_4") [3] is um (reads the question again) - No, I need to have the correct ...

RESEARCHER: What do you need the mass of?

STUDENT 1: Sulphate ion.

RESEARCHER: Sulphate, I have got barium sulphate - oh I didn't put in the mass of the sulphate ion.

(... the researcher told the student that the molar mass of sulphur is 32,04 while that of oxygen is 16.)

STUDENT 1: Okay so if the molar mass of barium sulphate is 233,37 so from the mass that you use, you can work out the moles which is .0013 grams - ag, moles - barium sulphate, which means that there is also .0013 moles sulphate ions (writes "→ 0,0013 mol SO_4) [5]. And the molar mass of sulphate ions is (writes "(32,07)(16x4) = 96,07") [6] 96,07 so to work out its mass. (Works on calculator and writes "0.00043") [7] Then to work out the sulphate ions we take its moles which is - mole equals mass over molar mass (writes "n = m/M") [8] - and

then the mass is mole times molar mass (writes "m = nM") [9] which is comma nought nought nought four three times ninety six comma O seven (writes "= 0,00043 * 96,07") [10] which equals (pauses to work on the calculator and writes "0,0412 g") [11] ... 1 2 grams. Now from there, we would take the mass by percentage of what you have which is 0,0412 over ammonium ferrous sulphate (writes "0.0142/0.3) [12] which gives you ... um ... (writes "= 14 %") [13] ... 14% .

What the student learned as a result of the lab session

- The student meaningfully learned how to calculate the percentage by mass of sulphate in AFS by using (1) a given mass for the AFS used and (2) a given mass of barium sulphate obtained after reacting the AFS with excess barium chloride.

The *pre-lab test* appears to indicate that she had some problems with regard to the concept of 'amount' prior to her learning experience in the lab. This is because she wrote;

$$\frac{\text{Mass obtained}}{\text{Mass origin}} = \frac{1\ SO_4^{2-}}{1\ BaSO_4}$$

$$= \frac{0.1002}{0.3}$$

In doing this, she equated the ratios of the *amounts* with the ratios of the *masses*. This could mean that she is associating the 'mole', not with a fixed number of particles, but with a *weight* (Cervellati et al, (1982).

Looking closely at (1) her written answer in the pre-lab test and (2) her actions described in the previous chapter, however, it appears that there may be another reason for the nonsensical answer that she provided. Her response may have resulted, not from her misconceptions, but rather an information overload which caused her to be 'overwhelmed' by the question (see Johnstone, 1993, p. 122). Someone with a fairly tentative understanding of these concepts would be easily derailed by a very complicated problem.

When one reads through the description, it is clear that the student worked competently with the elementary concepts involved during the lab *before* she asked the demonstrator questions about the calculations involved in determining the percentage by mass. For example the following interchange occurred *before* the demonstrator was approached;

STUDENT 1: Ok (laughs) right, take ... you weigh your mass of the sulphate and you take .. you put it over the mass of ... the original mass you had which was 0.3 g ...

FRIEND 2: This is this out of this bottle type thing (referring to the small bottle of AFS that was used).

STUDENT 1: Ja.

FRIEND 2: Ok.

STUDENT 1: And then your theoretical sulphate would then be ... because you work out the amount of moles.

FRIEND 2: Ja

STUDENT 1: So if you get the actual formula SO_4 is like in brackets and there's a 2 with it so there's one mole of the whole thing then there should be like two moles of whatever that is.

FRIEND 2: Oooookay

STUDENT 1: And then you put the theore ... you work out the theoretical then you put the experimental one over the theoretical one.

(This extract was taken from the description)

The interaction above shows that the student did know, prior to the demonstrator's intervention;
(1) how to calculate the experimental percentage by mass.
(2) the stoichiometric ratios of amounts of substances.

It does not appear to be possible for the student to have learned these fundamental concepts during the demonstrator's pre-lab talk or the writings made on the chalk board. Upon closer inspection of what the demonstrator actually said and wrote, it is clear that a person with little or no understanding of the concept of amount would not be able to follow the reasoning[30].

Only one time did she ask the demonstrator about elementary calculations involving the mole. The question that she asked, however, confirmed the suspicions expressed above, because it indicated that she already had a reasonable understanding of the underlying concepts of this calculation.

---

[30]The demonstrator failed to define the words 'theoretical' and 'experimental' in her explanation. This makes her writings on the board rather vague. She also appears to use these words interchangeably with the words 'expected' and 'observed' which are also undefined. In addition to this, the transcript of her dialogue in the pre-lab talk is indicates that her monologue was rather incoherent and thus the student probably wouldn't have picked up much from it.

STUDENT 1: Ok, um the mass of the sulphate is ... if you work out ... if you weigh now what we get in the crucible, that's our barium sulphate, because one mole equals one mole, whatever the moles is of the barium sulphate would be the moles of the sulphate. But to work out its mass would you use just the sulphate's molar mass ?

DEMONSTRATOR: Ja

The student is unlikely to have sorted out the apparent serious misconceptions concerning the concept of amount between the pretest and the time of the lab session by means of the class lectures. This is because the pre-lab test was taken on a Friday (no chemistry lectures are given to the Chem 1 major students on a Friday), while the lab session was held the next Monday afternoon[31]. The Chem (1) major class have a double period on a Monday but they were going through organic chemistry in the lectures at the time of experiment A6 - nothing to do with the concepts tested here. For student 1 have to understood the concept of amount by the time she started the lab session, she must have spent time studying at home over the weekend. This was not the case because the student was asked in the pre-lab interview whether she had started studying chemistry for the exams (the study break was just about to start at that time). She replied that she had not. She also indicated in the pre-lab interview that she only spent about half an hour preparing for the lab and that this was normal for her (1/2 an hour hardly seems sufficient for her to have been able to do the normal pre-lab preparation required as well as put in some extra study of fundamental concepts). Thus, she couldn't have spent time sorting out her misconceptions while *preparing* for the lab. The assertion that she held serious misconceptions prior to the lab session, but sorted them out to the extent that she could get a question like this totally correct in the post-lab test, unaided, really seems unlikely. It appears to be more plausible that she did understand the concept of amount, but an information overload of the working memory caused her to get mixed up. Her practice with and reflection on these concepts during the lengthy lab session most likely caused her to become more confident with the concepts that underlie the percentage by mass calculation required here.

Question 1(a) necessitates that the student make many links all at once, and at different stages the student is expected to shift between macro and micro levels of thought (see Johnstone, 1993, & Ben-Zvi et al, 1988). These are two factors that just beg for an information overload. Thus, the student may well have been able to do *isolated* parts of this question in the pre-lab test if she had been presented with them[32]. But, this problem was specifically designed to see if

---

[31] This information was gained by interviewing lecturer 1, the class lecturer at the time. A copy of this interview transcript may be obtained from the author.

[32] Since the learning goal "Calculate the amount and the mass of a substance in a chemical reaction" as well as a

the student understood how to calculate a percentage by mass from experimental data. Her failure to do this in the pre-lab test, no matter what the cause, made her success in the post-lab test quite surprising.

4.2.3. Analysis of question 1(b)

The question

> (b) Using your answer to (a) calculate the percentage purity of ammonium ferrous sulphate.

The model answers[33]

Method 1

% purity = Experimental % by mass * 100 / Theoretical % by mass
Where;

- Theoretical % by mass = $M(SO_4)$*2*100 / M(AFS)
- Experimental % by mass = m(SO_4) obtained by experiment / m(AFS) used initially

∴

Method 2

% purity = Experimental % by mass * 100 / Theoretical % by mass
Where;

- Theoretical % by mass
  = m(SO_4) expected from the AFS used initially * 100 / m(AFS) used initially
  m(SO_4) expected = n(SO_4) expected / M(SO_4)
  n(SO_4) expected = m(AFS) used initially * 2 / M(AFS)
- Experimental % by mass = m(SO_4) obtained by experiment / m(AFS) used initially

Method 3

% purity = m(AFS) theoretical * 100 / Actual m(AFS)

---

whole tutorial session on this work should already have been covered by the student, she theoretically shouldn't have had such serious misconceptions. Note: tutorial sessions for the Chem (I) major class are an opportunity for them to ask questions and clear up any misconceptions that they may have.

[33]The second method was what the student was taught in the lab session by the demonstrator, and the method she used to complete the lab report.

Where;

- Actual m(AFS) = mass of the AFS used initially
- m(AFS) theoretical = n(AFS) theoretical*M(AFS)
  n(AFS) theoretical = n(SO_4) obtained from the $BaSO_4$ / 2
  n(SO_4) obtained from the $BaSO_4$ = n($BaSO_4$) obtained by experiment =
  m($BaSO_4$) obtained by experiment / M($BaSO_4$)

Method 4

% purity = m(AFS) theoretical * 100 / Actual m(AFS)
Where;

- Actual m(AFS) = mass of the AFS used initially
- m(AFS) theoretical = n(AFS) theoretical*M(AFS)
  n(AFS) theoretical = n($BaSO_4$) obtained by experiment / 2 = m($BaSO_4$) obtained by experiment / M($BaSO_4$)

Method 5

% purity = n(SO_4) theoretical * 100 / Actual n(SO_4)
Where;

- Actual n(SO_4) = m($BaSO_4$) obtained by experiment / M($BaSO_4$)
- n(SO_4) theoretical = m(AFS) used initially * 2 / M(AFS)

The student's response to this question in the pretest;

(See lines 61 - 75 of the pre-lab test interview).

61		.....Okay, there you would take your (pause) - I would
62		say you would take the molar mass that you have, which is
63		392,17 (writes "M = 392,17") [9] and the mass which you use -
64		um which is 0,3 (writes "m = 0,3") [10] - no. No, I don't know.
65	RESEARCHER:	You don't know?
66	STUDENT 1:	No.
67	RESEARCHER:	Okay. Where did you go wrong? Where are you stuck?
68	STUDENT 1:	Which is my mass for the experiment ?
69	RESEARCHER:	Okay. That is fine. .... let's do (c).

The student's response to this question in the post-lab test

..... Okay, so you would take 1 mole of ammonium
57 ferrous sulphate, (writes " 1 mol A.F.S. -> 392.17 ") [14]
58 ammonium ferrous sulphate - gives you 392,17 (writes "=> 2
59 mol SO_4 s") [15] that gives you 2 moles of sulphate ions so -
60 okay - we have 3 grams - okay - so 3 gram divided by 392 ...
61 7 (uses the calculator) - that times that by 2 to give you
62 moles of the sulphate (writes "0.00153") [16] so from there
63 you can work out - mole equals mass over molar mass (writes
64 "n = m/M") [17] - (mumbles to herself while writing "m = nM"
65 [18] then works on the calculator typing in 0.00153*96.02)
66 equals 0,147 (writes "= 0,147") [19] which is say (writes "=
67 14,7 %") [20] 14,7%. Then you would take observed over
68 expected (writes "observed/expected") [21] equals 14 over
69 14,7 (writes "= 14/14,7") [22] which is (uses the calculator)
70 95,2% purity (writes "= 95.2 % purity").

What the student learned as a result of the lab session

The answer to the previous question is used in this one. Thus, her answer in the pre-lab test further supports the assertion made in the previous question - ie. that the student experienced an information overload.

In the post-lab test, the student began to use the method that she was taught in the lab session (ie. method 2)[34]. It appears that she knew that she had to calculate the theoretical percentage by mass of sulphate and then to divide the experimental percentage by mass calculated in question 1(a) by the theoretical percentage by mass. Where she went wrong was in the calculation of the theoretical percentage by mass. She correctly calculated the amount of AFS used initially and then correctly calculated the amount of sulphate ion for this amount of AFS (ie. $n(SO_4)$ expected). From the amount of sulphate ions calculated above, student 1 calculated the *mass* of these sulphate ions. What she should have then done was divide this theoretical mass of sulphate by the mass of the AFS used initially (only then should she divide this answer by the percentage by mass obtained in question 1(a)). Instead she went on to divide *the mass of the sulphate ions in AFS* that she just calculated by the percentage mass obtained in question 1, multiplying it all by 100. This she called the "observed over expected" as well as "the percentage purity" (lines 67-70).

---

[34]It may be useful to look through the student's written answers to understand more clearly the point being made here.

This indicates that she did not have a clear understanding of how to calculate the theoretical percentage by mass of sulphate. She thought the calculated theoretical number of moles of sulphate was the theoretical percentage by mass of sulphate. The dialogue between student 1 and friend 2 in the lab session (referred to in the previous question), showed that the student did know that to calculate the *percentage purity* (one has to divide the experimental percentage by mass by the theoretical). The description reveals that she did have trouble understanding how to calculate the theoretical percentage by mass during the lab session. The following interchange occurred between the student and the demonstrator;

STUDENT 1: And then um expected percentage ... does the ...
DEMONSTRATOR: Yes
STUDENT 1: ... theoretical sulphate ....
DEMONSTRATOR: Yes
STUDENT 1: Ok that I don't ... where do we get that value from ?
DEMONSTRATOR: Ok so you said ... cause this is what you've actually weighed the sulphate out.
STUDENT 1: Ja
DEMONSTRATOR: Now if this was pure ammonium sulphate that you were using ...
STUDENT 1: Ok, ja.
DEMONSTRATOR: Ok you wouldn't necessarily get ... you'd probably, you might get more, ok you'd probably get more than what you've actually got.
STUDENT 1: Ja
DEMONSTRATOR: Ok, so if you taking your original um ammonium ferrous sulphate mass, ok and you say ok how much sulph... What should the mass of the sulphate be in this case, if the ammonium ferrous sulphate is pure, there's no impurities ?
STUDENT 1: Ok, ja.
DEMONSTRATOR: So it is .300 grams of pure ammonium ferrous sulphate then you should have, ok you can work out theoretically the mass of your sulphate. You should have a certain mass of sulphate in there.
STUDENT 1: Oh, ja ok
DEMONSTRATOR: Because if you remember what the formula looks like ... Ok so ... Ok you see that here you have two moles ...
STUDENT 1: Ja
DEMONSTRATOR: ... of sulphate for every one mole of ammonium ferrous sulphate. ... So if you had pure ammonium ferrous sulphate ok no impurities

present ... you would expect. Ok, so you would have to first of all work out the moles of ammonium ferrous sulphate that you have.

STUDENT 1: I got three ... can you use three grams. Ok

DEMONSTRATOR: Ok does that make sense

STUDENT 1: Ja

DEMONSTRATOR: Ok. Because you need to use your mass exactly like if it is .300 then it needs to be .300. Ok then from the number of moles of ammonium ferrous sulphate you can work out the number of moles of sulphate - theoretical.

STUDENT 1: Ja you just ... ja because if that is certain moles, you just times it by two.

DEMONSTRATOR: Ja and then you can work out the theoretical mass.

STUDENT 1: Mass, ok.

This reveals that the student did indeed have problems with the concept, sufficient enough to ask the demonstrator what to do. The demonstrator simply explained it to her, rather than leading her to the answer by giving her 'clues' (the explanation, however, does appear to be rather incoherent). Nevertheless, it is quite possible that the student was able to do the calculation in the lab session with the solution given on the chalk board and with the information given by the demonstrator still fresh in her mind. One day later in the post-lab test, however, she could not remember all of it and thus she would not have known how to do this calculation. Later on in the lab session, the following dialogue occurred;

DEMONSTRATOR: And you are gonna put that percentage on top of that one.

STUDENT 1: Ja

DEMONSTRATOR: Do you understand why ?

STUDENT 1: Ja

DEMONSTRATOR: It's exactly the same process as if you had taken the theoretical mass of sulphate ... I mean the expected ... the observed mass of sulphate ...

STUDENT 1: Ja

DEMONSTRATOR: ... and divided it by the theoretical mass of sulphate

The student simply affirmed that she understood what D1 was talking about. However, the demonstrator's explanation is extremely information dense, and it is quite possible that the student thought she understood when in fact she did not. Nevertheless, it is possible that the student did learn that to calculate a percentage purity one divides the experimental percentage

by mass by the theoretical, while she did not learn why this is done or how to calculate the theoretical percentage mass of sulphate in the way outlined by the demonstrator.

4.2.4. Analysis of question 1(c)

The question

> (c) The reaction of barium chloride and sulphate ions mentioned above is specifically chosen in this experiment because it is a reaction that goes to completion. Why is this fact so important if we want to get accurate results ?

The model answer

If the reaction doesn't go to completion, not all the sulphate will come out of solution
This means that our mass of $BaSO_4$ will be lower than what it should be if we got a 100% yield. This will mean that the percentage by mass of sulphate in AFS will appear to be lower that what it really is and consequently the calculated percentage purity will be less than what it really is.

The student's response to this question in the pre-lab test

(See lines 80 - 90 of the pre-lab test)

80		...because then we know that what you put in, your product - no
81		- your reactant that you put in becomes your product so
82		nothing is left over so everything will be formed that you know
83		you can use the mass of what you originally put in instead of
84		trying to work out what is left and what is limiting.
85	RESEARCHER:	Use the mass for what?
86	STUDENT 1:	um Well if you want to work out the percentage purity or
87		anything like that ...
88	RESEARCHER:	M'm.
89	STUDENT 1:	You can use what was originally in instead of trying to figure
90		out what was left. .....

The student's response to this question in the post-lab test

(See lines 76 - 84 of the post-lab test)

76 Okay well it is important to - it is important that we know that it
77 goes to completion otherwise we would have to first calculate
78 which ions are left and which aren't. So if there were ions left,
79 we would have to use a lesser amount of sulphate ions, or a
80 different blank (bank ??? - difficult to decide what she said) to
81 calculate the percentage purity. So its important to know if it
82 goes to completion you know you can use a complete blank
83 (bank ??? - difficult to decide what she said) - you don't have
84 to work out what is left and what has been used.

What the student did / did not learn as a result of the lab session

- The student's answers show some confusion. In both the pre-lab and post-lab tests, her reason for choosing a reaction that goes to completion was so that we would not have to *calculate* 'what is left and what is used' after the chemicals had been added. This could be because she had mixed up the idea of a reaction going to *completion* with a set up where the reagents are in *exact stoichiometric amounts* (and thus when the reaction is finished nothing will be left). In such a case no calculation would be required to calculate what is left and what is used. It appears that she thought that using amounts of reagent that weren't exactly stoichiometric would cause problems because then one of the reagents would be 'left' while the other 'used up'. The chemist would thus have to do a calculation to determine which one was left and which one used before (s)he could use the initial amounts in a calculation of the percentage purity for example. The calculation of how much of each reagent to add, however, should be done *before* one actually adds them to each other even if some of one reagent will be 'left over' (the chemist's job is to ensure that it is the right one that is 'left over'). Thus, it appears that student 1 did not understand the use of the term 'goes to completion' as a result of the lab session. In the interview held her (see appendix B), lecturer #2 indicated that she expected the student to learn why the reaction should go to completion.

- The student also did *not* learn that to get all the sulphate ions to react we should add excess *barium* ions. The student's comment in the post-lab test, "if there were ions left, we would have to use a lesser amount of sulphate ions", highlights her confusion. Lowering the amount of sulphate ions (which come from the AFS) will have nothing to do with increasing the accuracy of the percentage by mass, since the amount of sulphate ions will be lowered in proportion to the amount of AFS molecules. Rather, if there are ions left, increasing the amount of *barium ions* will increase the accuracy of the percentage by mass because then we can be sure that all the sulphate ions will react. This is unlikely to be a

'slip' (she could have meant 'barium ions' but said 'sulphate ions'), because in question 1(d) she mentions *twice* that the *sulphate* ions are the chemicals that should be in excess.

4.2.5. Analysis of question 1(d)

The question

> (d) The chemist mentioned above wanted to make sure that she got ***all*** the sulphate in the solution to react with the $BaCl_2$ that she added. What steps could she have taken to ensure this ?

The model answer

(1) Ensure that the barium chloride is in excess.
(2) This is done by (i) adding a few more drops of barium chloride after she already added 10 ml's (ii) observing if more barium sulphate does form. If it does, the barium chloride is not in excess and a few more drops should be added until it is.

The student's response to this question in the pre-lab test

(See lines 97 - 101 of the pre-lab test)

97 ... she would find out which of the
98 two, by using the balanced equation, would be the limiting
99 reagent. And if - if barium chloride was to be the limiting
100 reagent they would have to put more of the other one in so
101 that it would react with all of the barium chloride

The student's response to this question in the post-lab test

90 Okay, she could have um found out which one was limiting
91 again and make sure that there was more of the - an excess
92 of the sulphate ions so that all of them could react with the
93 barium chloride to make sure that it was limiting. Um again
94 you could ...
95
96 RESEARCHER: So, which one is the limiting reagent ?
97 STUDENT 1: uh barium chloride - make that limiting ah the limiting reagent.
98 Um also ... - ja.

What the student did / did not learn as a result of the lab session

- The student did not learn that it is not the balanced equation that determines which reagent is limiting and which is in excess, but rather it is the *chemist* who decides. The balanced equation helps him/her decide how much of the reagent in excess to add[35]. Her failure is shown by (1) her suggestion in the pre-lab test to *find out* by means of a balanced equation which reagent is limiting and which one is in excess and (2) a parallel suggestion in the post-lab test of "she could have *found out* which one was limiting again". This thinking however is not uncommon. Bradley & Gerrans (1990), by means of mcq tests, found that many South African teachers as well as student teachers held this same misconception as did Hackling & Garnett (1985) who conducted research with Australian students).

- The student did not learn that we want the barium chloride to be in excess in this case.

- The student did not learn that the reagent in *excess* is the one that will *not* be completely used up. Her statement in the post-lab test - "make sure that there was ... an excess of the sulphate ions *so that all of them could react* with the barium chloride to make sure that it was limiting", clearly reveals this. If the sulphate ions are in excess then it is impossible that all of them could react. Clearly the student has problems with the concept of 'limiting reagent' which were not cleared up by this lab session. This, however, is not surprising taking into consideration that she wasn't required to reflect on it at all during her activities in the laboratory.

4.2.6. Analysis of question 2(a)

The question

(2) Our chemist tested two small portions of the final dry product by placing them in a test tube each and adding a few drops of ammonium thiocyanate (1%) solution to one and ortho-phenanthroline (1%) to the other. In both cases the sample turned red.

(a) What does this mean ?

---

[35]One doesn't have to work out from the balanced equation which reagent is limiting and which is in excess, it is known at the start that the sulphate must be limiting since it is desired that all of it to come out of solution. The student has, however, only done questions in the tutorials where she had determine which out of masses for two or three reagents was the limiting reagent for a particular reaction (see section 2.3.2. - tutorial 8, Q3 and tutorial 9, Q5).

Model answers

It means that;
(i) ferrous ions (Fe^{2+}) were in the portion of final dry product to which ammonium thiocyanate (1%) was added.
(ii) ferric ions (Fe^{3+}) were in the portion of final dry product to which ortho-phenanthroline (1%) was added.

The student's response for the pre-lab test;

108 It's acidic as far I know.
109 RESEARCHER: Its, it is acidic?
110 STUDENT 1: Ja.
111 RESEARCHER: Okay. Would you just write this there?
112 STUDENT 1: Oh Okay. Product (writes "the product has acidic prop.") [11].

The student's response for the post-lab test

100 ... There was - okay um - the
104 presence - this indicates the presence of the sulphate ions I
105 think ...
106 RESEARCHER: Is that it ?
107 STUDENT 1: Ja, ok that's it. When it turns red it indicates - Ja, because
108 the two of them would react with sulphate ions.

What the student did/did not learn as a result of the lab

- The student's answer to this question in her *lab report* (handed in the day before the post-lab test), indicates that the student knew that these chemicals tested for Fe ions. The lab manual, however, provides a direct explanation for the appearance of a red colour, and so her lab report may have simply reflected the manual rather than her own knowledge. It is quite plausible, therefore, that in the post-lab test, that she was not able to remember their use (ie. because she did not have the answers right in front of her, she simply *forgot* that these reagents indicated the presence of Fe ions).

- From the student's answer to the post-lab test, we can see that she had forgotten that ammonium thiocyanate (1%) and ortho-phenanthroline (1%) were testing for *two different*

ions. This is because she said, "this indicates the presence of the sulphate ions ... the two of them would react with sulphate ions".

4.2.7. Analysis of question 2(b)

The question

(b) What does this tell you about her answers to 1 (a) and (b) above ?[36]

Model answers

- If the iron ions are incorporated into the precipitate;

(i) the calculated percentage by mass of sulphate will be lower than it should be.
(ii) the calculated percentage purity will be lower than it should be.
This is because the Fe^{2+} ion can take the place of a Ba^{2+} ion and iron has a lower molecular weight than barium[37].

- If the iron ions are clinging to the precipitate (like the chloride ions presumably do);

(i) the calculated percentage by mass of sulphate will be higher than it should be.
(ii) the calculated percentage purity will be higher than it should be.
This is because the presence of Fe impurities causes extra mass in the precipitate.

The student's response in the pre-lab test

113 (Reading question 2(b)) What does this tell you about your
114 answers to: 1(a) and (b) above? Nothing. (laughs).

The student's response in the post-lab test

111 It indicates that the sulphates did in fact go to completion
112 because they were in abundance (- difficult to decide what
113 word she used here sounds like "abundance") so then

---

[36]The answer to this question is based on the answer to the previous question. If the student got the previous answer wrong, we will not be able to tell whether she knew the effect of iron impurities in the lattice. To gauge whether the student knew this, I should rather have asked the question, "How do you think that impurity iron ions incorporated into the crystal lattice will affect the percentage by mass and the percentage purity calculated in question 1(a) & (b)"

[37]The lecturer who designed the model answers did not think of this answer. Neither did the demonstrator. It, therefore, doesn't seem surprising that the student didn't either - in any of the two tests.

114 sulphates were in abundance (- difficult to decide what word
115 she used here sounds like "abundance").

What the student did/did not learn as a result of the lab

- The answer to this question is based on the answer to the previous one. Since, as suggested in question 2 (a), the student had forgotten that the *red* colour indicated Fe ions, she had to answer this question in terms of her suggestion that these reagents indicated the presence of sulphate ions. Her nonsensical answer is the result.

  One may speculate that if she had remembered that the red colour indicated Fe ions, she probably would have got this answer correct ! This is because it appears that she did understand how her results would have been affected if Fe ions were clinging to the precipitate. (See her answer in the post-lab test, to 'how would these impurities have affected her results ?' (question 4(b)), as well as her answer given in her *lab report* about how the *Fe ions* would affect the results (ie. "the mass of the formed precipitate would have been much greater, which would have left her with um almost over 100% purity")).

  Student 1's lab report also indicates that she did not learn the effect of Fe ions *incorporated* into the crystal lattice. Nevertheless, it does show that she understood the implications for the results if impurities were *clinging* to the precipitate. Thus, because she forgot that these two reagents indicated the presence of Fe ions, her answer to question Q2(b) may not be an accurate reflection of the amount of meaningful learning that took place regarding the presence of Fe ions in the precipitate.

4.2.8. Analysis of question 3(a)

The question

(3) Before she decanted the liquid, she added agar-agar solution drop wise to the mixture over ten minutes.

(a) What does the word "decant" mean ?

The model answer

In this case, "decant" means to pour off the liquid (through the filter funnel), leaving the solid behind in the beaker.

The student's response in the pre-lab test

133 STUDENT 1: I don't know.
134 RESEARCHER: Okay - fine.

The student's response in the post-lab test

... (laughs) That decant means to separate the
120 liquid from the precipitate through the hole (??? - its difficult
121 to decide what word she used here, it sounds like "ill") and
122 pour it out into a filter funnel or something, just to make sure
123 that the precipitate is on its own. And sort of like get rid of the
124 water....

What the student did/did not learn as a result of the lab

- The student learned the meaning of the word decant as a result of the lab session (ie. "to separate the liquid from the precipitate". She did not, however, learn it as a result of her pre-lab preparation because in the pre-lab interview, she indicated that she still didn't know what it meant. (The word 'decant' is mentioned in the manual but it is not defined - neither was it defined by the demonstrator). It was only after a discussion with her friend about the procedure and further reflection on the wording of the manual during the lab session that she finally came to a crude definition of it;

STUDENT 1:	I think we actually got it wrong to start with ... because when you, when you supposed to ... I think actually that's supposed to mean 'separates' in a way.
RESEARCHER:	What, to 'decant' ...
STUDENT 1:	Ja
RESEARCHER:	... means 'to separate' ?
STUDENT 1:	I think ... because it says take it through the filter paper retaining the precipitate in the beaker, in other words leaving it in the beaker. So I would ... its got something to do with like separating it from the precipitate - I think.

(Extract taken from the description)

4.2.9. Analysis of question 3(b)

The question

(b) Why did she add agar-agar solution ?

Model answers

(1) She added agar-agar solution to coagulate the precipitate (ie. to make it stick together in a nice clump at the bottom of the beaker).
(2) This is done because;

(i) the barium sulphate precipitate formed initially floats around the solution without settling at the bottom of the beaker because the crystals are so small and fine. Agar-agar makes the crystals that have formed stick together (ie. it coagulates the solid) and sink to the bottom of the beaker. This allows the chemist to simply decant the liquid leaving the solid behind in the beaker. If the solid was not allowed to coagulate, and was just poured into the filter cone, the fine precipitate would soon clog up the apex of the filter paper cone causing the filtration process to be slow.

(ii) larger crystals are less likely to be washed through the filter paper. Agar-agar ensures that the crystals that do form will stick together, they will thus be too big to wash through. Barium sulphate crystals are so fine that they get into the pores of the filter paper where they slow down the filtration process.

The student's response in the pre-lab test

(See lines 135 - 138 of the pre-lab test for the student's response to this question.)

135 STUDENT 1: ... Okay, I don't know what
136 that is.
137 RESEARCHER: Okay, have you ever heard of agar-agar?
138 STUDENT 1: No.

The student's response in the post-lab test

(See lines 126 -128 of the post-lab test for the student's response to this question.)

126 Why did she add agar-agar solution? To help the solution
127 coagulate and the precipitate is easier to use or make the
128 precipitate stick together better.

What the student did/ did not learn as a result of the lab

- *The student learned what the agar-agar was used for in this lab.* Although she said that it was to help the *solution* coagulate, she said that it also made "the precipitate stick together better".

- The pre-lab interview[38] with the student revealed that she had encountered the word "coagulate" before the lab session in another course.

70 RESEARCHER: Okay. And then the word "coagulate" what do you think that
71 means?
72 STUDENT 1: It means come together - okay - that's like you are putting two
73 substances together and they are mixed in to one solution -
74 but it's like a - so like syrup. It's when two solutions come
75 together and mix like that.
76 RESEARCHER: Tell me did you figure that out on your own or did somebody
77 else tell you or ...
78 STUDENT 1: That I knew, ja.
79 RESEARCHER: Well how come you knew that?
80 STUDENT 1: Biology - if you take biology you have to know what
81 "coagulation" means.

(pre-lab interview, lines 70-81)

Thus, she did not learn the meaning of the word "coagulate" as a result of this lab session.

4.2.10. Analysis of question 4(a)

The question

(4) After she had transferred all the precipitate to the funnel, she wanted to make sure that it was pure.

(a) Why did she want to make sure it was pure ? What impurities could have occurred in this case ?

The model answer

---

[38]This was held in the lunch hour before the lab session, when I interviewed the student to find out what she had learned as a result of her pre-lab preparation.

(1) She wanted to make sure that it was pure because if the precipitate was not pure, the final mass of precipitate would not be accurate and thus, the percentage by mass of sulphate that she calculated would not be accurate.

(2) The impurities that could have occurred are[39];

(a) Cl^-

(b) H_3O^+ ions

(c) Fe^{2+}

(d) NH_4^+

(e) agar-agar molecules

(f) Fe^{3+}

The student's response in the pre-lab test

(See lines 138 - 150 of the pre-lab test for the student's response to this question.)

... Well, impurities could have come
from the filtration or from the precipitate because if you
(pause) if you had to weigh the substance afterwards, it
wouldn't be the weight of the substance you are weighing
because there would be impurities - so you would have to first
have to make sure that it was pure before you could weigh it.
The impurities could have occurred during the adding of -
during the decating[40] of the liquid - adding of other solutions
because some of them might have remained between the
two others.

The student's response in the post-lab test

(See lines 130 - 140 of the post-lab test for the student's response to this question.)

... Well with the - um okay - other chemicals like
hydrochloric acid, which is there to just break up the products,
it could have those ions left, you also have um iron ions left in
the filtration[41] because filtration isn't exactly perfect. So it

[39]The student came to the pretest not having even read the lab manual for this practical session. She, thus, would not have known that we add HCl to the solution. Nevertheless, she should have known that agar-agar solution, iron ions and ammonium ions from AFS would be three types of impurities that are in the precipitate, since all of these are mentioned in previous questions.

[40]This incorrect spelling reflects what she actually said.

137 basically just gets your precipitate to form - to go to the other.
138 So to be able to get just one specific thing there you have to
139 wash it over and over and over so many times to get only
140 what you want.

What the student did/did not learn as a result of the lab

- In the pre-lab test, student 1 didn't mention any chemicals that may have been adhering to the precipitate, she only related the parts of the experiment where she thought that impurities could have crept into the precipitate eg. "the filtration", "the adding of other solutions" and "during the decating of the liquid". To me this indicates that she didn't know any chemicals that could contaminate the solution. The student's response in the post-lab test, "other chemicals like HCl" shows that she learned that HCl could be a source of impurity ions.

- Her remark, "hydrochloric acid, which is there to just break up the products" shows that she did not learn the purpose for the addition of HCl in this experiment. This information was learned through an interchange with the demonstrator, after she had added 5 ml of HCl rather than 0.5 ml.

- She also learned that iron ions would be present as an impurity but we cannot say for sure whether she learned that there are two types of iron ions that might occur as impurities, since she did not make any mention of this. We also cannot say for sure whether she knew the source of the iron impurities since she did not mention either.

4.2.11. Analysis of question 4(b)

The question

> (b) How would her results have been affected if the impurities mentioned above were present ?

The model answer

It depends which impurities we are talking about.
(i) Cl^- ions, NH_4^+ ions and agar-agar molecules will *increase* the apparent percentage purity and the percentage by mass.

---

[41] Her use of the word "filtration" both in the pre-lab test and here does not seem to be the conventional usage.

(ii) Fe^{x+} ions could (a) *decrease* the apparent percentage purity and the percentage by mass if they are incorporated into the lattice *or* they could (b) *increase* the apparent percentage purity if they are merely clinging to the surface of the precipitate.

The student's response to this question in the pre-lab test

(See lines 150 - 162 of the pre-lab test interview for the student's response for this question.)

155 STUDENT 1: ... Ah, there
156 would be - the product formed would have had a greater mass
157 so then the percentage purity or whichever you worked out
158 would have been incorrect.
159 RESEARCHER: How would it have been incorrect?
160 STUDENT 1: um - it would have been a greater percentage ? Because then
161 if it was less mass you would have a less percentage purity or
162 ... or results.

The student's response to this question in the post-lab test

(See lines 142 - 147 of the post-lab test for the student's response to this question.)

... Okay well again, the mass of
144 the formed precipitate would have been much greater, which
145 would have left her with um almost over 100% purity because
146 all the carbon or ions that are left in there just make that extra
147 mass.

What the student did/ did not learn as a result of this lab session

- Student 1 already knew before the lab that impurities can increase the weight of the precipitate and that this in turn gives us a percentage purity that is too high. Therefore, the fact that she expressed the same views in the post-lab test does not mean that she learned it as a result of the lab session.

- She did not learn how iron ions *incorporated* into the lattice affect the accuracy of the final result (ie. they actually cause the calculated amount of sulphate ions to be less than what it actually is). She did, however, mention Fe ions as a *type* of impurity in the post-lab test for the previous question, but she did not mention here that iron impurity ions might do something different (as opposed to the all others) to the final weight of the precipitate. This

is not surprising because, even though there was a question on the effect of iron ions in the lab manual, (1) the demonstrator did not give the students aid with regard to it and (2) even if she had given them aid, the model answers (see appendix D) only refer to the effect of iron ions if they *cling* to the precipitate. They do not mention that iron ions can in fact be incorporated into the lattice, neither do they mention that the effect of this[42].

- The student didn't say anything about *percentage by mass* in the pre- or post-lab test, thus we should not use these answers to speculate on her understanding of this concept.

4.2.12. Analysis of question 4(c)

The question

(c) If there were impurities there, how could she remove them ?

Model answer

(1) if we pour warm water over the precipitate, any impurities on it will be washed away.

The student's response to this question in the pre-lab test

(See lines 162 - 170 of the pre-lab test interview for the student's response to this question)

...By filtration, (writes "filtration")
164 [12] - filtration um diffraction (writes "diffraction") [13]
165 RESEARCHER: You said "diffraction" what does ... what do you mean by that?
166 STUDENT 1: Diffraction is separation of the different products
167 by boiling, I think - the different boiling points.
168 RESEARCHER: So how would you do that?
169 STUDENT 1: Well you would use the diffraction tube and when it boils then
170 it separates at different times through the exit.

The student's response to this question in the post-lab test

[42]This could be due to two factors, either the lecturer #2 did not think of the fact that Fe ions could be incorporated into the lattice of the barium sulphate or she did not think that the students should learn it and thus did not include it in the model answers.

(See lines 149 - 158 of the post lab test interview for the student's response for this question.)

150 Okay, again, um, by continually washing the precipitate to
151 make sure that all the ions are out and testing it with um silver
152 nitrate to ensure that it doesn't form a precipitate and um ...
153 that's just to make sure that they are all out. To ... again,
154 when the filter paper is heated to remove the carbon and
155 things to make sure that it is only the precipitate that is
156 weighed and filtration - or diffraction again because ...
157 (uttered unclear words sounds like "you might have had
158 scope")

What the student did / did not learn as a result of the lab session

- The student successfully learned that one way to remove impurities from a precipitate is to wash it continually.

- In both tests the student mentions that *diffraction* and *filtration* could be used to remove impurities. In both the pre-lab and post-lab test she uses these words vaguely. Her description of diffraction in the pre-lab test sounds very much like fractional distillation (which is totally inappropriate in this case because the final product is not a liquid). While her use of the word 'filtration' is even more indefinite (the fact that she mentions filtration as a method of removing impurities from a precipitate that has already been filtered shows that she must have had some misunderstanding of the term 'filtration'). In the post-lab test, she mentioned these two words again, but because of poor sound quality in the recording, whether or not she learned something was not determined.

4.2.13. Analysis of question 4(d)

The question

(d) How could she test that the impurities were no longer there ?[43]

---

[43]This question hinges on whether the student was able to answer the previous one correctly. Only if she knew (1) which impurities might have occurred and (2) how to remove them, would she be able to suggest a test to see if they were all gone. A better way of trying to elicit the desired information from her would have been to ask, "If *chloride ions* were clinging to the precipitate, how could she remove them and how could she test when they were gone ?". The student was only expected to mention the Cl^- ions and the test for them anyway. Although if she had mentioned all four types of impurities (ie. Cl^-, Fe^{3+}, NH_4^+ and agar-agar) in 4 (a), according to the question she would have been required to mention a test for all of them. In the actual experiment, however, the only impurities that they actually tested for, were the Fe^{3+} ions and the Cl^- ions. The test for the Fe^{3+} ions was

The model answer

(1) To test for chloride ions we react fresh filtrate with silver nitrate and see if it forms a precipitate
(2) Fresh filtrate can be caught in a clean container and the silver nitrate can be added to this.
(3) Silver nitrate reacts with chloride ions to form a white precipitate of silver chloride. Thus, any chloride ions that will have been washed through the filter paper into the beaker will react with the silver nitrate to form a white precipitate.
(4) If a precipitate does form after the addition of silver nitrate, chloride ions were washed off the precipitate and there may be more still clinging to the precipitate.
(5) Washing should therefore continue.
(6) When a precipitate no longer forms after the addition of silver nitrate to the fresh filtrate, we can assume that all chloride ions were washed through the filter paper in the previous washing and that the precipitate is now free of chloride ions.

The student's response to this question in the pre-lab test

(See lines 172 - 177 in the pre-lab test interview for the student's response for this question.)

172 (Reading question) How could you test they are all gone?
173 You could theoretically work out what the percentage yield
174 should have been and then with the new mass work it out and
175 if it is accurate enough, then it would be pure - or she could
176 react it with a known substance that it should form a particular
177 precipitate or whatever - ok.

The student's response to this question in the post-lab test

(See lines 160 - 166 of the post-lab test interview for the student's response for this question.)

160 ... How could you test that they are
161 all gone? Okay again use um silver nitrate or an indicator
162 that would indicate the presence of them.
163 RESEARCHER: How would you do this?

---

mentioned in question 2 (a) while the Cl^- and NH_4^+ ions have not been mentioned so far in the test.

164 STUDENT 1: Um Okay, you would drop it in the - you take the solution with
165 a dropper and just put in drop-wise a few drops of silver
166 nitrate to precipitate the ions into the filtration - wait, I can't
167 even ... (recording becomes very faint for about 1 second).

What the student did/ did not learn as a result of the lab session

- Student 1 learned that in this case, the presence of impurities was tested for with silver nitrate. She did not, however, say which impurities, so we cannot say that she knew it was the test for chloride ions. In the pre-lab test, she merely mentioned reacting it with "a known substance that it should form a particular precipitate". In the post lab test, she referred to, "silver nitrate or an indicator that would indicate the presence of them". She, therefore, learned that silver nitrate was an indicator for impurity ions. The student, however, should have already been familiar with this qualitative test for Cl^- ions since it is generally done at the school level.

4.2.14. Analysis of question 5

The question

(5) There is one final twist in the story! Before she could weigh the final dry precipitate that she collected in the filter paper[44], she got rid of the filter paper ensuring that not one grain of the (barium)[45] sulphate was lost in the process.

(a) Pick out the equipment that she could have used to do this (naming each piece as you do).

---

[44]This is a rather ambiguous statement. "Before she could weigh the final dry precipitate that she collected in the filter paper ..." implies that the final *dry* precipitate has been collected in the filter paper. What was meant by the question was, "after filtration, the wet precipitate is retained by the filter paper. Before she could accurately determine the weight of the precipitate, she had to dry it and get the solid off the filter paper ensuring that not one grain of it was lost in the process. How could she do this ?". In both the pre-lab and post-lab tests the student, understandably, did not interpret the question as intended and the researcher had to try to explain it to her in a different way. Perhaps this question would have made more sense to her if it had come after question 3 in the skills test. Then she could have used the actual filter paper and wet precipitate. The best way to elicit the information desired would have been to ask, "Describe and explain the most accurate method you can think of for determining the exact weight of barium sulphate precipitate collected in the filter paper after filtration."

[45]I should have added the word 'barium' to this question as well. This would clarify for the student what part of the experiment I am talking about. This is because the sulphate is spoken of in different ways at different parts of the experiment. Eg. sulphate in AFS, sulphate ions in solution, sulphate in barium sulphate and percentage by mass of sulphate. Just to use the word "sulphate" without qualifying which state one is talking about can make the question slightly confusing, and even more confusing for a person who is not too clear about what is going on anyway.

(b) Demonstrate (using the equipment you have picked out) how you would go about doing this, giving reasons why you would do what you are demonstrating and explaining what would be happening to the chemicals as the experiment proceeded. Also emphasise any precautions that you would make to ensure that you got the exact amount of precipitate when you had finished[46].

The model answer

(The equipment to be picked out is in italics)

(1) Instead of simply scraping the precipitate off the filter paper at the risk of losing some of it, we burn the filter paper away using ashless filter paper. This is done because barium sulphate crystals are so small that they stick in the pores of the filter paper and we will lose a substantial amount of it if we simply try to scrape it off.
(2) Ashless filter paper is specially designed filter paper that, when heated slowly, will decompose to carbon without a flame and, upon further heating, oxidise into CO_2 and H_2O and escapes into the atmosphere.
(3) Since the barium sulphate precipitate is relatively stable, it won't decompose on heating.
(4) This can be done using a *crucible and lid.*
(5) The crucible and lid is weighed empty, and then weighed again with the dry barium sulphate in it after the filter paper has been burned away.
(6) We must ensure that the weight of the crucible and lid does not change during the heating. by;

(i) washing and scrubbing the crucible and lid thoroughly with soap, water and a brush
- We do this because we need to make sure that the weight of the crucible and lid is constant throughout the heating process. Any non-permanent stains and other impurities attached to the crucible and lid prior to heating may come off during the heating and affect its weight. Therefore, *before* we preweigh the crucible and lid, we should try as far as possible to wash these off.

(ii) preheating the crucible and lid to red hot before preweighing it.
- This is done in order to burn off any impurities that might come off while burning the filter paper away.
- Place the crucible and lid on a *pipeclay triangle* that is supported by a *tripod.*

---

[46]The phrase "emphasise any precautions that you would make to ensure that you got the exact amount of precipitate" was worded in this way to see if the student would (1) mention washing the crucible and lid before heating it and (2) heating and reheating the crucible to ensure that all the carbon has been oxidised after the initial weighing.

- Make sure that the lid partially covers the crucible (this allows impurities on the inside of the crucible to escape into the atmosphere).
- Light a *Bunsen burner*
- Heat the crucible and lid until red hot

(iii) using *tongs* to handle the crucible before it is preweighed

- This is done because moisture from the hands may be deposited on the crucible and affect its weight.

(iv) using the tongs take the lid off the crucible and place it on a clean *white porcelain tile.*

- The lid is first placed on a porcelain tile rather than in a desiccator because the desiccators used in the WITS 1st year labs are too small to place the lid and the crucible side by side inside one. Thus, the *crucible* must be placed in the desiccator first *and then* the lid on top of it. So the lid must be taken off the crucible first and placed on a clean white tile.

(v) the crucible and lid should be left to cool in a closed *desiccator* after preheating. (It is important that the crucible be cooled to more or less room temperature. If it were not, we would be unable to handle it in order to weigh it accurately).

- The cooling is done in a desiccator for the reason that moisture in the air could condense on the side of the crucible and affect its weight, and a desiccator ensures that this will not happen because the silica gel at the bottom absorbs all the moisture. The lid of the desiccator should be closed in order to ensure a closed system so that no further moisture from the air can affect the weight of the crucible.

(7) Once the crucible and lid have cooled, they should be taken (in the desiccator) to the balance room where they will be taken out of the desiccator (using tongs) and preweighed.

- (This must be done as quickly as possible to ensure that as little moisture from the air as possible is deposited on them).

(8) Weigh the crucible to as many decimal places as possible.

(9) Place the crucible back on the pipeclay triangle supported by a tripod.

(11) Partially cover the crucible with the lid. The lid should then be resting partly on the crucible and partly on the pipeclay triangle.

- This ensures that there is free access to oxygen (in the air) while the filter paper is being heated. If the lid were placed on the crucible so that it was completely closed, the paper would not burn as well. It also ensures that carbon dioxide and water can escape freely from the crucible.

(12) Fold the moist filter paper cone around the precipitate and place it, point down, into the crucible.

- If we don't fold the filter paper, it won't fit into the crucible, and the wet precipitate will be able to splutter out while the paper is being heated.

(13) Light the Bunsen burner again. Make sure there is only a small flame (big enough to cause the water to evaporate but small enough to ensure that it doesn't evaporate too quickly and cause spluttering).

(14) When water vapour is no longer coming out of the crucible, the flame may be increased slightly so as to carbonise the paper. This is done for about 20 minutes.

- The flame must still not be too strong to ensure that the paper does not catch alight, for this could cause (1) further spluttering, (2) the carbon to react with the barium sulphate to form barium sulphide and (3) the deposition of soot onto the inside of the crucible lid.

(15) When the paper has completely carbonised, the flame can be increased to full strength so that the remaining carbon will oxidise speedily.

(16) Turn the bunsen burner off and wait for 1 or 2 minutes

- This is to prevent overheating the desiccator and its contents

(17) Transfer the crucible and lid (using tongs so as not to transfer impurities onto the crucible and lid) to a desiccator to cool.

(18) Take the crucible and lid and contents (in the desiccator) to the balance room once more and accurately weigh them to as many decimal places as possible.

- After weighing, they may be touched with the hands once again since we are going to heat them again and any impurities transferred onto the crucible by the hands will be burned off.

(19) Reheat the crucible and lid and contents for a further 15 min and then reweigh the crucible and lid and contents and see if the weight is within 5 mg of the previous weighing (using the same weighing procedure as above).

- This is to be sure that all the carbon from the ashless filter paper has evolved into the atmosphere as carbon dioxide. If not, further heating will result in the oxidation of the remaining carbon causing the weight of the crucible to change. If all the carbon has indeed oxidised to carbon dioxide, then further heating will make no significant difference to the weight of the crucible and lid and contents and the weight of the barium sulphate will be accurate.

(20) If the weight does differ by more than 5 mg then the last two steps should be repeated until two successive weighings differ by no more than 5 mg.

- Once one is sure that no more carbon from the filter paper is in the crucible and lid and that their weight has been recorded, the crucible and lid may be touched with the hands once again.

The student's response to this question in the pretest

(See lines 179 - 224 in the pre-lab test for the student's response for this question.)

179		(Reading the next question) There is one final ... ! Before she
180		could weigh the final dry precipitate that she collected in the
181		filter paper, she got rid of the filter paper ensuring that not
182		one grain of the sulphate was lost in the process. Pick out
183		the experiment[47] that she could have used to do this (mumbles
184		the question again) Before she could weigh the final dry
185		precipitate, ... she got rid of the filter paper ensuring that not
186		one grain of ... . I don't know what that means
187	RESEARCHER:	Ok what ...
188	STUDENT 1:	... because if she's got rid of filter paper then she can't use
189		the filter paper - there isn't any filter paper.
190	RESEARCHER:	What she did is she had the product on the filter paper ...
191	STUDENT 1:	Ja.
192	RESEARCHER:	And then she got the, she took the product off the filter but
193a		she didn't leave one drop of product on the filter paper
193b		behind.
194	STUDENT 1:	Oh. Okay.
195	RESEARCHER:	How did she do that?
196	STUDENT 1:	How she did it? Um hmm.
197	RESEARCHER:	I don't have the equipment - that - it says "pick out the
198		equipment" so just tell me what it is. If you can think of
199		any - if you don't know ....
200	STUDENT 1:	Well, there should be something that you can suck it up with.
201	RESEARCHER:	Okay. (unable to contain a laugh)
202	STUDENT 1:	... to suck the filter paper. I don't know, these collection
203		things.
204	RESEARCHER:	Ok collection.
205	STUDENT 1:	Ja. Demonstrate how you would go about doing this, give
206		(laughs) why you would do what you are doing ... what you
207		are demonstrating and explaining what would be happening
208		to the chemicals as the experiment proceeded.
209	RESEARCHER:	Okay, c you can't demonstrate because I don't have the
210		equipment but you can just tell me what you may have done.

[47] Although the question reads equipment, the student read 'experiment'.

211 STUDENT 1: Well first of all - okay - that's if they had one of things that I
212 mentioned .. but ja, it is like a vacuum cleaner with a sack or a
213 bag or something. No, but that won't work because it is in
214 there. So ...
215 RESEARCHER: It is in where - it is in the little sack?
216 STUDENT 1: Ja. so then you still have to get it out of there.
217 RESEARCHER: Ja.
218 STUDENT 1: Okay. So how would she have done that? um You see it is
219 dry so you can't use it. (pause) If it is dry and she - you could
220 just wipe it off with one of those little spoons.
221 RESEARCHER: Okay.
222 STUDENT 1: Because I mean if it was still in crystal form they might stick a
223 bit but it is dry so it should stay.
224 RESEARCHER: Okay.

The student's response to this question in the post-lab test

(See lines 175 - 309 in the post-lab test for the student's response for this question.)

175 (Researcher switches to the video)
176
177 STUDENT 1: Ok well ... (reading the question) demonstrate how you would
178 go about doing this ... (paused to read the question quietly
179 and the question paper down) I don't actually have to have a
180 ...
181 RESEARCHER: Just show me what you would do instead of instead of doing
182 the experiment show me what you would do, you know what I
183 mean, just pretend that the chemicals are there and...
184 STUDENT 1: (Picking up the question paper again) Ok well I still don't ...
185 you've got the dry precipitate in the filter paper and she got
186 rid of the filter paper ...
187 RESEARCHER: mmhm
188 STUDENT 1: ... ensuring that not one grain of solid ... but if it is dry am I
189 allowed to wet it, I can do anything I want to.
190 RESEARCHER: ja
191
192 She then put the question paper down.
193
194 STUDENT 1: Ok well ...

She picked up a glass filter funnel in the one hand and a conical flask in the other.

RESEARCHER: So now which question are you doing ? You are doing ...
STUDENT 1: ah (b) (she put the conical flask down and pointed to the question paper)
RESEARCHER: You are doing question (b) demonstrate how you would go about doing this, how about, how you would go about separating the precipitate from the filter paper.
STUDENT 1: Ja, Ja.
RESEARCHER: so you are trying to get the precipitate off the filter paper
STUDENT 1: Ja

She then placed the glass funnel in the neck of the conical flask, and reached for a piece of filter paper from it's box that was on the desk. She then folded the filter paper in half and then in half again. She opened it up from the middle so that it made a conical shape and placed it in the filter funnel (it did not pop out this time). She then reached for the bottle of AFS and unscrewed the lid.

STUDENT 1: I actually knew something this time.
RESEARCHER: Ja

She then picked up the spatula and used it to take a spatula-full of AFS and place it in the filter paper. She then put the spatula down and placed the lid back onto the AFS bottle.

RESEARCHER: Ok ja, just pretend that it is the precipitate
STUDENT 1: ja
RESEARCHER: ... that you have just finished

She then lifted the filter paper (with the AFS in it) up out of the funnel

STUDENT 1: And then you take it ...
She then placed the filter paper back in the funnel, and still holding the piece of filter paper against the funnel with her thumb she moved the funnel (with the filter paper in it) with the conical flask to another spot on the desk.
STUDENT 1: Well the easiest to do, is to ensure that you don't let any of it

escape.

After this, she took the funnel (still holding the piece of filter paper in it) out of the flask and held it over a beaker that was right in front of her.

STUDENT 1: ok get a bigger beaker but ...

Then, holding the funnel with one hand, she lifted the filter paper (still in the conical shape) out of the funnel and poured the AFS out of the filter paper, through the funnel, into the beaker.

STUDENT 1: Just pour in

She then looked down into the funnel and then placed it back into the neck of the conical flask. After this she opened the filter paper up and held it vertically over the beaker, she then took the spatula and scraped the filter paper with the spatula (as if there were crystals on the filter paper) (see figure 7 below). She then folded the paper in half and then in half again.

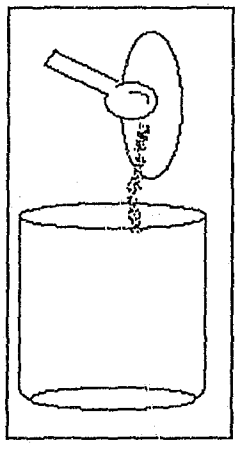


Figure 7: Scraping the filter paper with a spatula

STUDENT 1: Ok if it is dry its easy enough

RESEARCHER: Ok lets say it was wet on there

STUDENT 1: oh ok

RESEARCHER: you know in that part of the experiment ...

STUDENT 1: Ja

RESEARCHER: ... where it is wet, we just finished filtering and now you want to ...

STUDENT 1: Ok

RESEARCHER: ... get the, the wet (student 1 reached for the conical flask with the funnel resting in its neck and opened the filter paper

again) precipitate off the filter paper and you want the filter paper away. So that theres no ... theres not one grain of sulphate, barium sulphate on the pre... on the filter paper.

STUDENT 1: Ok well if I had, ok if it was wet (reached for a plastic wash bottle with water in it) then say ok the beaker would be a bit bigger but ... (moved the conical flask with the funnel in it out of the way)

RESEARCHER: mhm

STUDENT 1: ... you still had some on (held the filter paper vertically over the beaker again), you'd wash it off with (picked up the wash bottle with water in it) warm water otherwise it separate the products

RESEARCHER: mhm

STUDENT 1: then you ... (using the wash bottle to squirt water onto the filter paper and run into the beaker) (see figure 8)

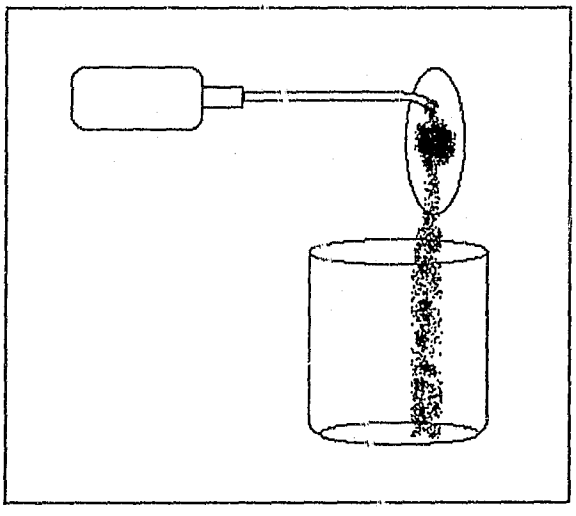


Figure 8: Washing the filter paper

... carefully just wash it down into your beaker to make sure there's nothing left. And if there's still something left, you use a rubber or a (picking up a spatula and then putting it down again) ... ja ok there isn't a rubber near it (taking a glass rod without a piece of rubber on the end and scraping the filter paper with it) (see figure 9)

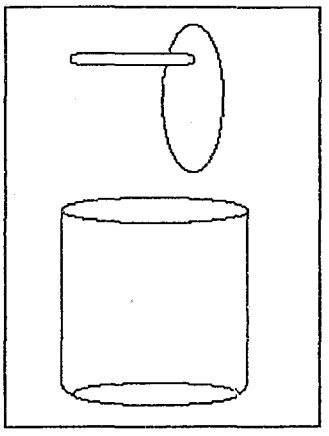


Figure 9: Scraping the filter paper with a glass rod

... scrape it down into the beaker (putting the glass rod down) and get rid of the filter paper (scrunching up the now wet filter paper and placing it on the desk) ... and if there's still solution on the sides of the filter funnel then you would also ... (picked up the filter funnel out of the conical flask and held it over the beaker and squirted some water down it)

RESEARCHER: mhm

STUDENT 1: If there was anything left you would also just rinse that off to make sure that everything was inside.

RESEARCHER: Ok

STUDENT 1: hmm

RESEARCHER: thanks

Researcher and student turn back to the tape recorder

Immediately after the post-lab test, the student was asked some general questions in order to validate some of the answers and to clarify some issues that the researcher had noted in the lab session the day before. It was desirable to do this as soon as possible so that the student's memory of the previous day's experiences would still be fresh.

The post-lab interview

RESEARCHER: Can I ask you just some general questions? What do you think if I said "ashless filter paper" what does that mean to you?

STUDENT 1: Well, I ... I think that that means there's .... ok there is something obviously missing in that paper that not there

normally is, but it could mean that if it is ashless that it has got as little carbon as possible in because ash is carbon so I would say it has got - ja - as little carbon as possible so that it would weigh less or when you burn it like we did yesterday - that um - although there would be little carbon to burn off so that it wouldn't affect your mass.

RESEARCHER: And why were you burning it yesterday?

STUDENT 1: Well if ... if you wet precipitate, it is very difficult to get that all off. It is not going to form crystals in this case, so you would have to wait a while, so you would burn it - you would still have the sulphate ions there but to burn it you would then release the vapours and the carbon to just get your sulphate ions left.

RESEARCHER: So, what is actually happening in the crucible while you burning away the carbon, the, the ashless filter paper?

STUDENT 1: um the sulphates are remaining. Okay it is barium - barium sulphate is in the crucible -

RESEARCHER: No, just let me refine my question. Let us say you take the filter paper out of the funnel, right?

STUDENT 1: M'm

RESEARCHER: Put it in the crucible and you light the flame. Okay?

STUDENT 1: M'm

RESEARCHER: Okay. Then what is happening now that you have lit the flame?

STUDENT 1: Well the paper is disintegrating - so it is burning away to ashes.

RESEARCHER: Okay.

STUDENT 1: Becoming white ash.

RESEARCHER: Okay.

What the student did/did not learn as a result of the lab session

- In view of the fact that the post-lab test was conducted one day after the actual lab session, it seemed most surprising that the student's answer was totally unrelated to her experience in the laboratory. All the other answers so far had been connected to the experiment A6 in some way, and there appears to be no reason why this one should have appeared different to the student. Nevertheless, her answer in the post-lab test was completely different to what she experienced in the additional lab A6. So vast is the divergence from what was

done during the laboratory session, that it was even suggested that the student may have deliberately tried to be provocative. There is, however, no evidence any where else to support this assertion. The explanation for her course of action may, therefore, be because she did not learn the underlying concepts sufficiently. The evidence above certainly points to the fact that she knew the *result* of ashing the filter paper (ie. to get rid of the filter paper ensuring not one grain of precipitate is lost in the process), but not *why* it is ashed (ie. because the barium sulphate gets stuck in the pores of the filter paper whether it is dry or wet).

Her answer to the question, "why were you burning it [the filter paper] yesterday ?" (lines 14-19, post-lab interview) shows that she thought the *result* of heating the filter paper would be to "release the vapours and the carbon to just get your sulphate ions left [in the crucible]". But her *reason* for the burning was not because this is the only way to successfully ensure that not one grain of barium sulphate is lost. She thought it was because she would have to *wait a while* for the precipitate to dry on the filter paper. To her, burning the filter paper was merely a *quicker* way of isolating the barium sulphate than scraping the precipitate off the paper after it had been left to dry (perhaps overnight).

This was confirmed in the post-lab test, even though in both tests, the student mistakenly thought that the precipitate was *dry* on the filter paper[48].

Note also that in the pre-lab test, she suggested, "you could just wipe it off with one of those little spoons" (lines 219-20, pre-lab test), while in the post-lab test, she said, "And if there's still something left... *scrape* it down into the beaker " (lines 287-296, post-lab test). Both of these statements show that she did not learn that *scraping* is not effective enough to remove *all* the grains of barium sulphate from the pores of the filter paper (even if it were dry).

Also, in the post-lab test, after she had scraped the filter paper with a glass rod, she scrunched up the filter paper and placed it on the desk saying, "and get rid of the filter paper" (line 297, post-lab test). Hence, her method for "getting rid of the filter paper" was to scrunch it up, *even though she knew that one could burn ashless filter paper away into the atmosphere*. These actions confirm the assertion that she did not learn that barium sulphate crystals stick in the pores of the filter paper. Scraping the precipitate off the paper

---

[48] In the pre-lab test, she said, "If it is ***dry*** ... you could just wipe it off with one of those little spoons" (lines 219-20, pre-lab test). In the post-lab test, she said, "you've got the ***dry*** precipitate in the filter paper" (line 185, post-lab test). At this point in the experiment, the precipitate is definitely not dry, it is extremely wet since it has just finished being washing with warm water. (The student's confusion in this matter can be traced to the unclear way that the question was phrased - see the first footnote in the analysis of this question).

is not a very efficient method of isolating all the barium sulphate precipitate and determining its exact amount.

It is extremely surprising, nevertheless, that the student didn't make the connection between the question here and the skills covered in the lab session the day before. Her failure to do so probably does have its roots in a lack of understanding of these concepts as was shown above (nowhere in the lab manual was she given opportunity to reflect on these ideas), but this may be only part of the answer. The student may also have been so mentally disengaged as she was carrying out the activities in the lab session that she simply forgot the procedure the day before. This would have been an extreme case of recipe following.

- The student also did not learn that ash is incombustible inorganic waste. She thought it was carbon. Her statements in the post-lab interview also suggest that she did not learn why ashless filter paper doesn't leave any ash (ie. because the paper carbonises and then the carbon is oxidised). This, however, is also not surprising since it is not explained in the lab manual.

4.2.15. Analysis of question 6

The question

(6) What does the phrase "gravimetric analysis" mean ?

The model answer

Gravimetric analysis is a kind of quantitative chemical analysis involving weighing as the sole method of measurement.

The student's response in the pre-lab test

229 STUDENT 1: Okay. Well I would say it is doing experiments and then
230 weighing the final product to analyse what is lost and what is
231 formed.

The student's response in the post-lab test

314 STUDENT 1: Ja. Describing the chemicals and um I think observing the
315 properties by use of percentage purities and the use of their
316 masses by portionalities of what the substances are in each

317 ... each compound and the percentage of how much is in
318 there, so it is basically analysing the compound by the
319 different masses of the different components.

What the student did / did not learn as a result of the lab session

- It is interesting to note that in tutorial 8 the student was required to 'explain the meaning of gravimetric analysis' while L.G. (4.13) requires the student to be able to 'explain what is meant by a precipitation reaction and describe the use of such reactions in gravimetric analysis'. Furthermore, in ordinary lab O5 (Title: What is the formula of hydrated barium chloride ? A gravimetric analysis)[49], the definition for a gravimetric analysis is *directly given* in the introduction to be a "quantitative chemical analysis involving weighing as the sole method of measurement" (Laboratory Notes, First term 1999, Chem 101, University of the Witwatersrand Department of Chemistry, p. 5/1). Thus, the student should have been familiar with the term and its definition.

  The post-lab test indicates, however, indicates that as a result of experiment A6 the student incorrectly learned that gravimetric analysis *only* involves analysing compounds by percentage masses and percentage purities. The student's answer in the pre-lab test was a more general definition - ie. that gravimetric analysis involved "doing experiments and then weighing" (this could be loosely interpreted to mean 'weighing as the sole method of measurement in an experiment). In the post-lab test, however, the student *specified* the use of the results by stating that gravimetric analyses involve, "analysing the compound by the different masses of the different *components*" (ie. percentage by masses). Thus, her answer appears to have regressed from a more general definition to one that only includes the specifics of this experiment. It therefore appears that her more general definition gained in ordinary lab O5 was erased by her more recent experience in the laboratory the previous day.

  Thus, the student did not learn that gravimetric analyses include *any* experiments that involve weighing as the sole method of measurement, rather than only experiments that use the weights obtained to determine *percentage purities* and *percentage masses.*

4.2.16. Analysis of question 1(a) - skills test

The question

---

[49]This lab session was held 3 weeks prior to A6.

(1a) Accurately weigh out about 0.3 g of ammonium ferrous sulphate [into the beaker provided][50]. (report your results in the space provided below).

The model performance

(a) Take a beaker to the accurate balance weigh it accurately

Every time the balances are used, the student should;

(1) check that the balance is tared before placing anything on it

(2) after placing something on the balance wait for the digital reading to stabilise (usually indicated when the "g" (ie. grams) indicator appears).

(3) if the balance does not stabilise, the student should take an average value or find another balance.

(b) take the beaker and the AFS to the rough balance

(c) place the beaker on the rough balance, note the weight and then add about 0.3 g AFS to it

(d) take the beaker + AFS to the accurate balance and weigh it accurately

(e) subtract (a) from (d) to get the accurate weight of AFS

Results should look as follows;

Weight of beaker =	g	(I)
Weight of beaker + AFS =	g	(II)
Weight of AFS =	g	(I)-(II) = (III)

If a watchglass, a weighing bottle or a piece of filter paper (or some other container whereby the AFS must be transferred into a beaker) is used instead of a beaker, the following steps should be added;

(f) transfer the AFS from the container to the beaker

(g) take the container back to the accurate balance and determine the weight

(h) subtract (a) from (g) to get the weight of AFS still adhering to the container

---

[50]On the day of the pre-lab interview, it was noticed that there could be a problem with the wording of the question. If it was worded, "accurately weigh out about 0.3 g", the student may just take a piece of filter paper and weigh out 0.3 g onto the piece of filter paper without transferring it to a beaker. The phrase "into the beaker provided" was inserted with a pen. In doing this, it was intended that the student use a watchglass (or some other suitable container), to weigh out the substance and *then* transfer it to a beaker (weighing the empty watch glass once again to check how much AFS remained on it after the transfer). The student, however, did not do as was expected. She took a beaker and weighed out 0.3 g AFS straight into it. For the post lab, this phrase was not inserted and the question was left as it was originally without adding the phrase. The student then took a piece of filter paper and weighed out the AFS on that. Upon reflecting on this, it was observed that using filter paper really made no difference to the first five steps of the procedure, it only meant that a further four steps should be *added* (see model answers). (Note: The fact that the question was different in the post-lab test, does not mean that the student's response reveals nothing to us about what she learned as a result of the lab session).

(i) subtract (h) from (e) to obtain the exact weight of AFS in the beaker
(j) alternatively, one could subtract (g) from (d) to obtain the exact weight of AFS in the beaker

Results should look as follows;

Weight of the empty container =	g (IV)
Weight of the AFS still adhering to the empty container =	g (I)-(IV) = (V)
Weight of the AFS in the beaker =	g (III)-(V)

The student's response in the pre-lab test

239 STUDENT 1: In that lab, are we allowed to transfer things in there ? No ?
240 RESEARCHER: Ja you can there's a ... there's ... ja you can, it doesn't matter
241
242 Student 1 took a beaker and headed towards the balance room. On approaching the
243 balance room the researcher pointed out the balances that she could use.
244
245 RESEARCHER: The two scales that you can use, there's one here (pointing to a
246 rough balance right near to the door) and there's one over here
247 (walking over to an accurate balance on the other side of the room.)
248
249 Student 1 headed for the rough balance, after taring the balance she placed the empty
250 beaker onto it. It read 81.84 g
251 She then wrote on the question paper,
252 "Beaker = 81.84 g
253 Beaker + ammonium ferrous sulphate ="
254
255 She then took the beaker off the balance and then wrote,
256
257 "81,84
258 + 0,3
259 82,14 g
260
261 Then she took the spatula, scooped out about half a spatula-full of AFS, and placed the
262 AFS in the beaker. Then she placed the beaker on the balance again. It read 82.66. She
263 then took the beaker off the balance and scooped some of the AFS out with the spatula
264 into its original container and then placed the beaker back on the balance. It read 82.36.
265 She then took the beaker off the balance and once again scooped some of the AFS out

with the spatula. This time she did not put the AFS on the spatula back into its container but she held the spatula with one hand while placing the beaker back onto the balance. It read 82.16. She then placed the AFS back into its container. She then said to me;

STUDENT 1: I'm two out is that all right ?
RESEARCHER: Sorry ?
STUDENT 1: I'm two out or must I really really make it accurate ?
RESEARCHER: No no no it says "accurately weigh out about". If that's what you think then thats fine.

She then scooped a few grains of AFS back into its container using the spatula and replaced the beaker. It read 82.14. She then closed the AFS bottle, placed it on the bench next to the balance and circled (b) as the answer to 1(b) in the skills test and went back to the centre bench

The student's response to this question in the post-lab test

Student 1 took a piece of filter paper, a spatula and the bottle of AFS and went to the balance room. When she got to the balance room the researcher said;

RESEARCHER: So there's this one (pointing to a rough balance near the entrance of the room) and that one if you want to use it (pointing to an accurate balance on the other side of the balance room).
STUDENT 1: Ok

Student 1 then walked up to the rough balance - it read 0.01 g. She then tared it to zero and placed the piece of filter paper on it; it then read 0.72 g. She took the piece of filter paper off the balance, placed it on the desk and scooped a spatula full of AFS onto it. She then placed the filter paper onto the balance again - it read 1.12 . The "g" that normally appears when the balance has stabilised had not appeared yet when she took it off the balance and scooped some AFS off the filter paper into the spatula with her finger and placed it back in the AFS bottle. She then placed the filter paper back onto the scale. It read 1.09 . She took the filter paper off the balance once more and as before scooped some AFS back into its original container and then placed it back on the balance, it read 1.08 g. Once more she took the filter paper off the balance and scooped some of the AFS back into the bottle using her fingers and the

348 spatula provided. The balance read 1.06 g. This time, without taking the filter
349 paper off the balance, she scooped some more AFS onto the spatula using her
350 finger as before and placed it back in the bottle. The balance still read 1.06 g
351 once it had stabilised. She repeated this process twice more; the first time the
352 scale read 1.04 and the second it read 1.03 g. She then placed the lid back on
353 the AFS container, picked it up and screwed it back on properly. She then took
354 the filter paper off the balance and leaving the AFS on it, she took it back to her
355 bench. Once she arrived at the bench, she put it down on the bottom half of the
356 question paper for this question and wrote the following;
357
358 Filter paper = 0.72 g
359 Filter paper + a.F.S = 1.03 g
360 \a.m.s[51] = 1.03 - 0.72
361 (after using the calculator provided she wrote)
362 = 0.31 g

What the student learned as a result of the lab session

- The evidence appears to indicate that the student did not learn that to *weigh something out accurately* in her case means to weigh it out *to 3 decimal places* (since this is the limit of the most accurate balance available to her). Most surprisingly, in both the pre- and post-lab test, the student used the rough balance exclusively. In the lab session, however, she *only* used the accurate balance. *In all three cases*, therefore, she only used *one* balance (ie. she didn't follow the procedure outlined above). It is also evident that in each case she used the balance *closest* to her. (Most likely, in the pre- and post-lab test, if the accurate balance had been on the side of the room closest to her, rather than the rough balance, she would have used it). It should also be noticed that the researcher did not point out to her in the either of the tests that one was an accurate balance and one was a rough balance. During the lab session, the rough balances are stuck away at the sides of the labs, and the accurate balances are in a central place very near to her. Thus, if an accurate balance had been closest to her in the pre- and post-lab tests she probably would have used it rather than the rough balance. It, therefore, appears that the student did not understand the significance of the word "accurately" and its implications for the choice of balance in the task presented to her[52].

---

[51] Although these writings of the student appear to be illogical, they are what she actually wrote (see appendix B).

[52] The student had probably never translated the words "rough" and "accurate" as something to determine her actions during the laboratory activity. This compartmentalisation of the psychomotor domain from the cognitive domain could mean that she had not yet internalised these concepts to the point where she thought that they were something to *apply* during the lab session.

- In the pre-lab test, the student made sure that she had exactly 0.30 g of AFS. This indicates that she did not understand the significance of the word 'about' in this question. She also seemed to display the error of confusing the concept of 'accuracy' with getting *exactly* 0.3 g (because she said, "I'm two out [ie. 0.02 g out from 0.30 g] or must I really really make it *accurate* ?"). By the time of the *pre-lab interview*, however, it appeared that she had corrected the former mistake of interpreting the given instruction to weigh out *exactly* the amount indicated, while the second error had been not been cleared up. The following interchange took place;

63 RESEARCHER: Great. And then what would you say they[53] are asking you to
64 do you when they say accurately weigh out about 0.3 grams?
65 STUDENT 1: Well first of all - okay - 0.3 grams is very difficult to accurately
66 - to actually pin that amount on the actual - the scale but you
67 would have to get say about approximately .02 or .03 grams
68 or either way as long as you have that because it is just an
69 estimate amount.

(Pre-lab interview, lines 63-69)

During the lab session the following conversation took place between student 1 and friend 2 that provides further evidence that she already knew that she didn't have to weigh out exactly 0.3000 g;

FRIEND 2: The mass of the ammonium ferrous sulphate was point three grams hey ?
STUDENT 1: Ja well which ever you ... yours came to be.
FRIEND 2: Aw shucks ... No, what do you mean ?
STUDENT 1: Like you didn't have to weigh exactly ... well, I didn't ... mine wasn't exactly [hers had come to 0.247 g].
FRIEND 2: No mine was exactly. When I'm good, I'm good.

In the post-lab test, even though she spent much time taking small portions of AFS off the filter paper, she measured out 0.31 g of AFS rather than exactly 0.3 g. The evidence, therefore, appears to indicate that the student learned the significance of the word 'about' in the question posed to her as a result of the *pre-lab preparation*. Since there is ***no***

[53]Referring to the lab manual

explanation given for the phrase 'accurately weigh out about 0.3 g' in the lab manual, it seems unlikely that this would have been the case, however. And it is not improbable that the student *did know* how to 'accurately weigh out about' a certain mass in the pre-lab test but didn't do it for some reason.

The following exchange, however, indicates that the student was *thinking about not* taking exactly 0.3 g.

270 STUDENT 1: I'm two out is that all right ?
271 RESEARCHER: Sorry ?
272 STUDENT 1: I'm two out or must I really really make it accurate ?
273 RESEARCHER: No no no it says "accurately weigh out about". If that's what you
274 think then thats fine.

(Pre-lab test, lines 270-274)

Thus, though she made sure that she had exactly 0.3 g it appears that she was thinking of only weighing out 0.2 g. (Her phraseology, however, does indicate that she was making the error of mistaking the *concept* of 'accuracy' with getting *exactly* 0.3 g. This error did not appear to be cleared up by the time of the post-lab test).

- The fact that she took a piece of filter paper instead of a beaker in the post-lab test confirms findings of question 5 (ie. that she did not learn that filter paper is porous and crystals are likely to stick in the pores). It is only acceptable to accurately weigh out something onto a piece of filter paper if one *reweighs* the paper once the solid has been transferred to the container one is going to use. In the post-lab test, the student did not transfer the AFS from the filter paper to another container and reweigh the paper. In the lab session the day before she did transfer the AFS from the paper to a beaker, but she did not reweigh it once she had transferred the chemicals. Thus it seems plausible in the case of the post-lab test to infer that if the student had been required to continue further with the experiment, she would not have reweighed the filter paper.

4.2.17. Analysis of question 1(b) - skills test

The question

How self confident were you that you knew what you were doing while you were carrying out the above task ? (circle the option that best describes you)

A. very self confident
B. quite self confident
C. not so self confident
D. not self confident at all

The student's response in the pretest

B.

The student's response in the post-lab test

B.

How the student improved

The student's confidence did not change as a result of the lab session. She felt quite self confident in both cases even though she definitely was wrong in some respects.

4.2.18. Analysis of question 2(a) - skills test

The question

(2a) Get as much of the solid into this piece of filter paper as you can !

The following was provided,
(1) a beaker with a solution of water and HCl (conc) with a $BaSO_4$ precipitate already coagulated at the bottom ready to decant
(2) distilled water in a plastic wash bottle
(3) a policeman
(4) a piece of filter paper

The model performance

(1) The student should fold the filter paper so that it fits into the funnel
- Fold the filter paper in half and then in half again (and in half again if necessary).
- Open it up, and use the folds to make a cone shape that will fit into the glass funnel

(2) The student should decant the liquid through the filter efficiently and without mess
- Pour the liquid through the filter funnel, leaving the solid behind in the beaker. (This makes the whole filtration process faster, because the apex of the filter paper is not

clogged up with solid precipitate and the liquid can flow through the filter paper with relative ease.)

- Care should be taken that the level of the liquid poured into the filter cone does not rise above 1/3 of the way up the filter paper.

(3) The student should wash the remaining precipitate with the distilled water provided

- Not *too* much water must be used to ensure that as little as possible of the precipitate redissolves and passes through the filter paper.

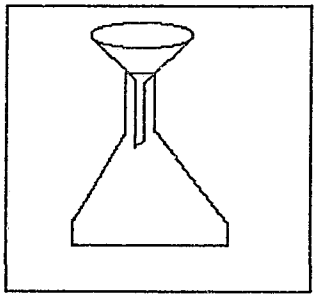
(4) The student should dislodge any fragments of precipitate that adhere to the beaker with the aid of a policeman and ensure that they land up in the filter paper with the aid of hot water.

(5) She should also wash the end of the glass rod with warm water and allow the washing to fall into the filter paper.

- This ensures that no barium sulphate that adheres to the policeman as a result of the previous step is lost.

The student's response in the pre-lab test

285 Student 1 took a piece of filter paper and then looked at the equipment on the desk
286
287 RESEARCHER: Let me come this side so that I can get out of the light (moving to the
288 other side of the desk).
289
290 Student 1 then took a filter funnel and asked
291
292 STUDENT 1: Can I use any of these ? (Pointing to the equipment on the desk)
293 RESEARCHER: Anything ja.
294
295 She then set the filter funnel in the top of a conical flask (see figure 10)



296
297 Figure 10: Funnel in conical flask
298

and then began to attempt to fold the filter paper. She first rolled it up into a cylindrical shape (see figure 11) and tried to put it into the funnel like that,

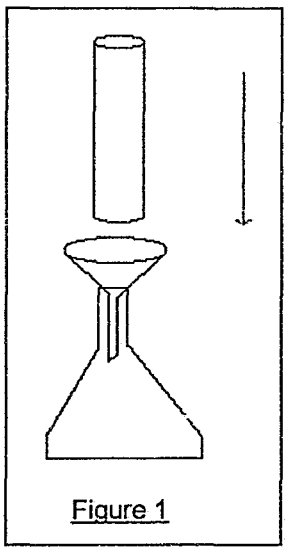


Figure 11: Folding the filter paper into a conical shape

but it didn't fit properly and she took it out. She then rolled it up again (sticking her finger through the middle this time) and tried to put it back in the funnel exactly like before but it still did not go. She then took it out again and unfolded it and stared at it for a while. She then placed the filter paper (unfolded) horizontally over the funnel (see figure 12) and then pushed it down in the middle,

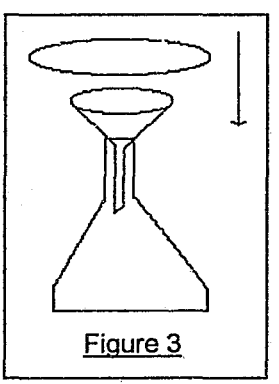


Figure 12 : Holding the filter paper horizontally over the funnel

it turned into a conical shape in the funnel. She then pressed it on the fold and tried to leave it in the funnel, but it merely popped out. She then took it out of the funnel

(holding it in the conical shape with her hand), looked at it for a while and placed it back in the funnel pressing on the fold again. It nearly stayed in the funnel but she took it out again unfolding it and said;

STUDENT 1: Ok I don't know how to do this, ... the filter paper. (Folding it along the fold made previously into a conical shape again)

RESEARCHER: Ok well, it doesn't matter if it like messes all over the place just try.

STUDENT 1: Am I allowed to make a hole in it ?

RESEARCHER: Ja, do what you want to hey.

She then unfolded the filter paper and pushed a hole in the middle of it with her finger and folded it back into a conical shape. She then moved the conical flask with the funnel in it closer to her, (still holding the filter paper in a conical shape with her one hand). Once she had placed the filter paper in it, she picked up the funnel with her right hand and the beaker with the liquid and the solid in it with her left hand. As she was just about to decant the liquid through the filter paper (with the hole in it) when she stopped, put the beaker down, took the filter paper out of the funnel (still holding it in a conical shape) and looked at the hole at the apex. She then unfolded the filter paper again and then made a conical shape again and put it in the filter funnel again and held it in the funnel with her right hand.

RESEARCHER: I tell you what I am gonna do, just to speed up time, so that there is not so much time, I'm gonna throw some of this out just so that there is not so much water, it doesn't matter how accurate you are (researcher poured some of the liquid down the drain).

STUDENT 1: ok

RESEARCHER: Just so that it goes quicker, then you don't have to ...

STUDENT 1: Do you have any other filter paper ? I don't think you are supposed to make a hole in this.

Researcher got a box of filter paper for her. She took another piece of filter paper placed it horizontally over the filter funnel and pushed it down in the centre into the funnel with her index finger. She then took the filter paper out of the funnel (still holding it in a conical shape) but placed it straight back into the funnel. She then held it (that is the filter paper) in the funnel with her one hand and pushed it flat on the folds with the other hand. Holding it in the funnel with her one hand she then picked up the beaker and poured some of the liquid into the funnel leaving the solid behind. Since the funnel was a very small one, the top of the filter paper stuck out of the funnel. She did not allow the level of the

liquid to go higher than about 1/3rd up the side of the filter funnel. She then let most of the liquid she had just poured in pass through the filter and then poured more liquid into the funnel. While she was waiting for the liquid to pass through this time, she peered into the beaker and then swirled the liquid around in it gently. (It didn't affect the solid, which was collected at the bottom, very much). She then poured a little more liquid into the beaker.

RESEARCHER: So just tell me, I can't see into the filter paper, why are you pausing like that.

STUDENT 1: Ah, because it .. (puts the beaker down on the bench and pulled at the filter paper which was sticking out of the funnel. It was now stuck to the side of the funnel because the solution had crept all the way up it) if you put too much water in then ... its easier just to (picked up the beaker again) let most of it run to the bottom until you put some more in.

RESEARCHER: Ok.

She then poured a little more liquid into the funnel, waited until most of it had passed through and then poured some more into the funnel. She then repeated this process. At this point I switched the video off since I didn't want to waste battery time waiting for her to pour all the liquid out of the beaker. When I switched the video on again, she had just poured and was waiting when I asked her;

RESEARCHER: You said there is no specific reason why you wait it's just easier ...

STUDENT 1: Ja.

RESEARCHER: ... why you wait.

STUDENT 1: Because the more full it is the slower it takes so

RESEARCHER: Mmm ...

She then poured and waited another four times (never allowing the level of the liquid to rise higher than 1/2 way up the filter funnel). Before she poured more liquid (plus solid at this stage) into the funnel, she squirted some distilled water from the wash bottle into the beaker. The fifth time she poured liquid into the funnel, a lot of the solid stuck to the side of the beaker. She then took a wash bottle and squirted water on the side of the beaker causing the solid to be washed back into the beaker. The sixth time she poured mixture into the funnel some solid (but not as much as the last time) stuck to the side of the

beaker. Now she tried a different strategy. Tilting the beaker over the funnel so that the liquid would run into the filter paper she squirted water from the wash bottle on the inside base of the beaker (see figure 13). All of the solid was then washed into the filter paper.

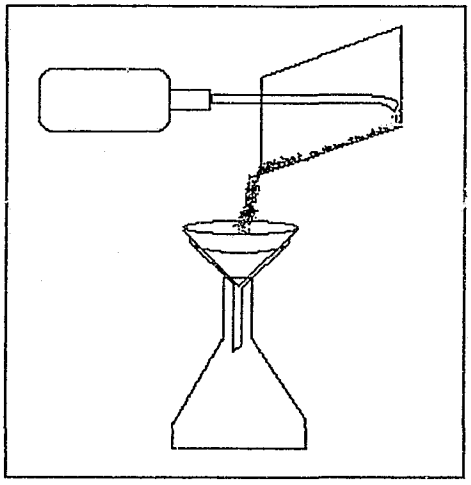


Figure 13: Washing the precipitate out of the beaker (pre-lab test)

RESEARCHER: Where is that beaker that you had of it ? ...Where is this thing hey ?

Student 1 reached over and placed the beaker she had just finished using on the desk in front of the camera. As I focused the camera on the beaker I saw a few (not many) grains of precipitate on the sides and on the bottom of the beaker.

RESEARCHER: Is that as much as you could get out ? Are you satisfied ?

STUDENT 1: Mhm

The student's response in the post-lab test

... She then reached for a conical flask which had a filter funnel resting in it and folded the filter paper in half and then in half again. Pushing it on the folds she opened it up so that it made a conical shape and placed it in the filter funnel. After this, she picked up the beaker of solution + precipitate, sat down on a stool by the bench and holding the funnel in one hand poured some of the liquid in the beaker into the funnel. She then waited until it had all filtered through and poured more liquid into the funnel from the beaker and waited again (both times, she did not allow the liquid to fill the paper more than half way, nevertheless, the filter paper was wet from the top to the bottom).

390
391 RESEARCHER: Ok so just check if there is solid in there.
392 STUDENT 1: No not yet.
393
394 The researcher then switched off the video camera in order to save battery time while she
395 was merely pouring liquid through the filter and waiting for it to seep through the filter
396 paper. When the camera was turned on again, she poured liquid + solid into the filter
397 paper and while waiting pointed out to the researcher;
398
399 STUDENT 1: (pointing to the tape recorder) This is still recording.
400 RESEARCHER: Oh is it still recording, thanks it doesn't matter.
401
402 She then poured liquid + solid through the filter funnel once again and then reached for a
403 plastic wash bottle with distilled water in it. She almost began to wash the precipitate
404 remaining in the beaker through the filter funnel, but then paused for about 20 seconds
405 just before she did it.
406
407 RESEARCHER: So what were you waiting for there ?
408 STUDENT 1: Just so that it could go down a bit, because when you wash it you
409 use quite a bit of liquid so it is easier for it to just flow.
410
411 She then proceeded to wash the solid out of the beaker as in the pre-lab test. Tilting the
412 beaker over the funnel so that the liquid + solid would run into the filter paper she
413 squirted water from the wash bottle on the inside base of the beaker. Most of the solid
414 was then washed into the filter paper.

415 She then waited until most of the water had run through the filter paper and then repeated
416 the process once more, squirting enough water into the beaker until pretty much all the
417 precipitate had been washed into the filter. She then inspected the beaker and decided to
418 squirt more water into it. This time she collected the water in the beaker and then poured
419 it into the filter. No precipitate remained in the beaker.

What the student did / did not learn as a result of the lab session

- The student learned how to fold the filter paper correctly so that it would fit into the funnel. The student's problems with folding the filter paper in the pre-lab test (lines 299-251) cleared up when her friend showed her how to fold the filter paper during the lab session.

- The student did not learn that she should add the minimum amount of water when washing the barium chloride into the paper because it might redissolve. Both in the pre-lab (lines 385-392) and the post-lab tests (lines 411-416), the student used copious volumes of water to wash the barium sulphate in the beaker into the filter paper. Since the lab manual gives no instruction about this, it is not surprising that she did not pick it up.

4.2.19. Analysis of question 2(b) - skills test

The question

How self confident were you that you knew what you were doing while you were carrying out the above task ? (circle the option that best describes you)

A. very self confident
B. quite self confident
C. not so self confident
D. not self confident at all

The student's response in the pretest

C.

The student's response in the post-lab test

B.

How the student improved

After the lab session the student felt more confident about carrying out the task, but surprisingly enough, she did not feel confident enough to mark off very confident.

4.2.20. Analysis of question 3(a) - skills test

The question

Wash the precipitate that you have collected with warm[54] water and test the filtrate with a few drops of silver nitrate solution (report what you observe). Continue washing until fresh filtrate no longer show any signs of forming a precipitate.

---

[54]On the day of both the pre-lab and post-lab test, the water in the wash bottle was not heated for the student and she simply used it cold.

The following was provided
(1) a dropper
(2) silver nitrate solution
(3) distilled water in a plastic wash bottle
(4) medium sized conical flasks to catch the filtrate

The student should know the following in order to successfully complete this question

(1) to "wash the precipitate" means to squirt water from a wash bottle onto it and allow the water to filter through the filter paper.
(2) "fresh filtrate" is the liquid that has just come out of the end of the filter funnel after squirting water on the precipitate in the filter paper
(3) The following procedure should be used;

(a) squirt water from a plastic squeeze bottle into the funnel below the top of the filter paper
(b) ensure that the water level does not rise more than 1/3 of the way up the filter paper
(c) the student should have about three or four clean beakers (or other suitable containers) ready, near the funnel, to catch the fresh filtrate
(d) place a beaker (or other suitable container) under the funnel to catch the fresh filtrate
(e) after a sufficient volume has collected, add a few drops of silver nitrate solution
(f) observe if a precipitate results
(g) if one does, repeat (d) - (f)

The student's response in the pre-lab test to this question

405 Student 1 read the question (not out aloud this time) and reached for the filter paper still
406 in the funnel from the last question. She opened it up and held it vertically over a clean
407 beaker and, using water from a plastic wash bottle, washed the $BaSO_4$ precipitate off the
408 filter paper into the beaker (see figure 14) until it was all in the beaker.

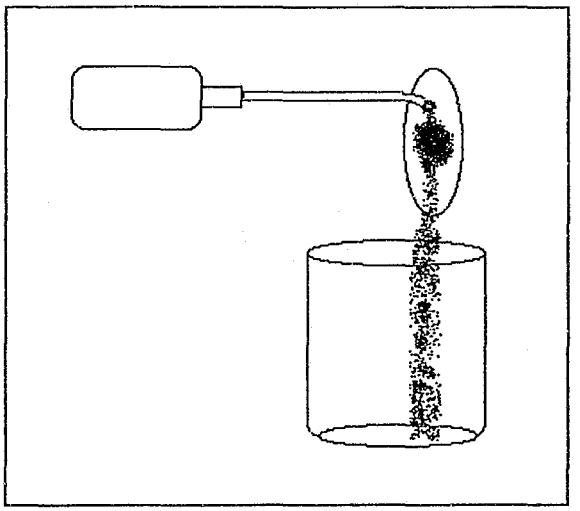


Figure 14: Washing the precipitate off the filter paper

She then silently read the next task, took the bottle of silver nitrate and added a healthy volume dropwise into the beaker with the water and barium sulphate precipitate in it.

RESEARCHER: Just turn here a second, what solution is that ?
RESEARCHER

Student 1 turned the bottle of silver nitrate to the camera to show the label, silver nitrate. She then added a few more drops to the beaker.

RESEARCHER: So it says there continue test ... washing, where where are you up to now ?

STUDENT 1: um wash the precipitate with warm water and test the filtrate with a few drops of silver nitrate.

RESEARCHER: Ok

She then picked up the beaker and looked into it. And then took her pen, the beaker in the other hand, and began to write something but interrupted herself saying,

STUDENT 1: So if nothing happened then nothing happened.

RESEARCHER: I think just write what you, what you think.

She then wrote down in the space provided for the answer "After the silver nitrate was added there was no change in the colour but the solid precipitate has collected at the bottom of the flask."

The student's response in the post-lab test to this question

Student 1 then waited for all the water from the washing (in question 2) to pass through the filter paper and then lifted the filter funnel off the neck of the conical flask with one hand and put a few drops of silver nitrate into the flask with the other (see figure 15)

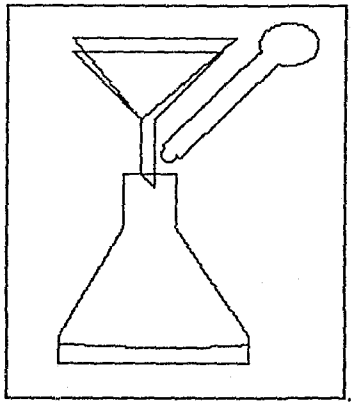


Figure 15: Testing with silver nitrate

RESEARCHER: So, it is forming a precipitate ...

STUDENT 1: ... precipitate ja.

RESEARCHER: So, what does that tell you ?

STUDENT 1: So that tells me that there is still ions in there or ... ja iron ions in the um precipitate so I have to wash it some more.

RESEARCHER: Ok

She then took the filter funnel out of the conical flask completely and held it (with her hand) over the beaker that she had been using to decant the liquid in the previous question (even though clean ones were available). She then began to squirt water from a plastic wash bottle into the funnel (see figure 16). The level of the water did not rise more than 1/3 of the way up the filter paper; then she allowed the resulting solution to drip from the funnel into the beaker. She waited for this water to pass through the filter paper and then added some more water in exactly the same manner as before.

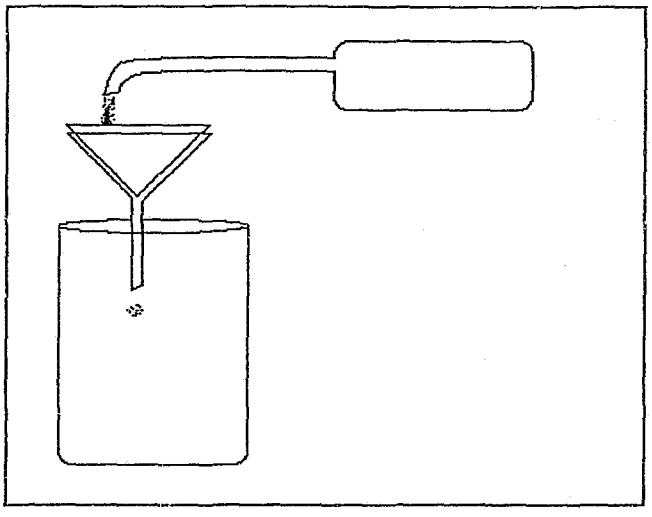


Figure 16: Washing the precipitate

RESEARCHER: If you want to you can use that clamp over there

She then shifted the beaker and the funnel to the iron grid on the bench she was using. Resting the funnel in the beaker she reached over and lowered the clamp to a height she preferred. She then placed the funnel in the clamp and closed the clamp tightly on it, placing the beaker under it (see figure 17).

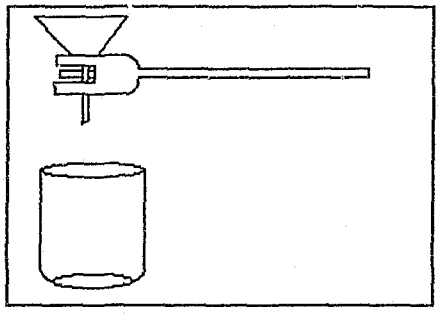


Figure 17: Clamping the funnel

Once all this was set up as in the figure above, she added a few drops of silver nitrate solution to the beaker. A precipitate formed.

RESEARCHER: So it did form a precipitate there !

STUDENT 1: Ja.

Moving the beaker out from under the funnel, Student 1 replaced it with a clean one. She then squirted water into the funnel again and allowed the water to drip down into the beaker. She then put the wash bottle down and sat back. After a while she peered into the funnel and then sat back again.

RESEARCHER: So what are you waiting for now ?
STUDENT 1: just for most of the liquid to ... filtrate so that I have to did it again I still won't have the old ions in the solution.

After waiting for a little while longer, she added silver nitrate to the beaker, picked it up and swirled the liquid in the beaker around a bit and put it back down on the bench.

RESEARCHER: Did it form a precipitate ?
STUDENT 1: Mhm very slightly
RESEARCHER: What ... if you had to do it again, what would you do ?
STUDENT 1: oh well I would just continue doing what I am doing until it doesn't form a precipitate
RESEARCHER: Ok great so ... its just that last one.

What the student did / did not learn as a result of the lab session

- The student learned that to "wash the precipitate" means to squirt water from a wash bottle onto the precipitate in a funnel and allow the water to filter through the filter paper. In the pre-lab test, the student merely washed the precipitate off the paper into the beaker. Student 1 learned this from her friend who explained to her how to wash the precipitate after she (student 1 that is) suggested washing it as she did in the pre-lab test.

- The student did not learn that the silver nitrate was reacting with chloride ions. She thought it was reacting with iron ions (line 511). The lab manual at this point does not give a very clear explanation for the appearance of a precipitate. Neither was this reaction covered in any previous lab sessions or learning goals (although at some stage it should have been covered in the school syllabus).

- The student learned that if the silver nitrate formed a white precipitate when added, then the barium sulphate precipitate still had impurities in it, and she had to keep on washing. (lines 511, 512). She also learned that the precipitate was free from impurity ions when she added silver nitrate and no white precipitate formed (lines 555-6). (The lab manual does not explain this part of the experiment in much detail. Student 1 and friend 2 tried to work out

what was going on from the text but were not able to). The description indicates that she learned this through a conversation with the demonstrator.

- She also learned that one should not allow the fresh filtrate to collect in the same beaker that was used to previously test for impurity ions since she took a clean beaker each time she was going redo the silver nitrate test (line 540).

4.2.21. Analysis of question 3(b) - skills test

The question

(3b) How self confident were you that you knew what you were doing while you were carrying out the above task ? (circle the option that best describes you)

A. very self confident
B. quite self confident
C. not so self confident
D. not self confident at all

The student's response in the pretest

C.

The student's response in the post-lab test

B.

How the student improved

After the lab session the student felt more confident about carrying out the task, although surprisingly enough, she did not feel confident enough to mark off very confident.

4.2.22. Analysis of question 4 - skills test

The question

(4) What sorts of preparations would you suggest our chemist make before she came into the lab ?

The model answer

(1) make sure you understand all procedures
(2) write out places to fill in readings
(3) leave blanks for calculations
(4) make sure you are able to identify all materials and chemicals
(5) make sure you are able to identify all equipment
(6) make sure you understand all underlying theory

The student's response in the pre-lab test

RESEARCHER: Okay, will you just read the question and then answer it.
STUDENT 1: Okay. It says: What sorts of preparations would you suggest the chemist make before she came into the lab? Okay. No. 1. I would ensure that she knew the procedure that she wants to do when she came into the lab and makes sure that she has got everything that she needs or at least knows what everything looks like before she comes into the lab and it also helps to know what the product is or should be before you come into the lab so that once you do that you know you are on the right track in case you make a mistake - and um (pause) also another thing is to formulate a conclusion before you come into the lab so that when you finish with the experiment you can see if it compares with what the difference between what you thought would happen and what actually happened. Ja.

The student's response in the post-lab test

562 STUDENT 1: What sort of preparations would you suggest our chemist
563 make before she comes into the lab? Okay, No. 1 again,
564 (inaudible) She must have all the equipment that she needs,
565 goggles, um her coats and anything else that she has to bring
566 along like with us, we have to bring our, our spoons and you
567 know, you don't get those. She must know what, what's
568 supposed to happen, she must know what the equation is,
569 she must know what the reaction is going to be so that she
570 can um be able to compare what you think is supposed to
571 happen and what does happen and also so that it runs
572 smoothly. If you know what you are supposed to do and what

573 is supposed to happen next, then it is easier to follow and you
574 understand it better. So it is important to know what each
575 chemical - what colour change happens so that you can be
576 able to check, like for example, those two chemicals again.
577 You have to know if it turns red what it means and what and
578 what presence exists there. And just basically to actually
579 prepare the report sheet and to prepare for the lab so that
580 you know and can compare and ... (sounds like "see
581 straight").

How the student changed as a result of the lab

The student's answers to this question reveal her aims for the laboratory experience. Her answer didn't change much; in both cases she mentioned that one should "know the procedure" and "formulate a conclusion" prior to the lab. In the post-lab test, however, the student did mention that a report should be prepared although she did not say to what extent. This change may be attributed to the fact that prior to this lab, all the additional lab sessions could be handed in five days after the lab session. In this one, however, the demonstrator unexpectedly required that the students hand them in on the same day because it was nearing the end of the term.

Chapter 5

Factors that affect meaningful learning in the laboratory : Part 1

5.1. Introduction

In this chapter, the results from the pre- and post-lab tests, as well as the description outlined in the previous chapter have been interpreted. In doing so, the factors which were observed to affect the student's learning in the laboratory have been described. Along with the pre- and post-lab tests and the description, data obtained from (1) pre- and post-lab *interviews*[55], (2) an interview with the demonstrator prior to the lab session as well as (3) an interview with lecturer #2 (the lecturer in charge of the first year laboratory sessions) have all been used to contribute the arguments put forward. For each factor, recommendations to improve the amount of meaningful learning that occurs in the lab have been put forward.

The recommendations from this study are made specifically as a result of one experiment with one student. Nevertheless, since both may be considered as 'typical' of the first year undergraduate chemistry class, it is possible to use them as a 'working hypothesis' for most other chemistry university lab sessions in the undergraduate years.

5.2. Factors that affected meaningful learning in the laboratory

5.2.1. The role of the demonstrator as perceived by the demonstrator

5.2.1.1. Interpretations

From the description two noteworthy observations about the demonstrator's role can be made;
(1) she outlined on the board how the students were to transform the experimental data into a percentage by mass and a percentage purity (this was not given in the lab manual).
(2) she also told student 1 exactly what to do when she did not understand what was written on the board[56].

---

[55]The post-lab interview transcript has not been included to conserve space, but may be obtained on request from the author.
[56]Student 1 asked the demonstrator a total of 6 questions about how to do the calculation required by the lab manual. In every case, the demonstrator simply gave her the answer.

In the interview with the demonstrator after the lab session, she revealed what she thought the learning aims of this experiment were.

17 RESEARCHER: Why do you think that the students were made to do this
18 last lab that they did? What do you think the university
19 was wanting them to 'get' by doing it?
20 DEMONSTRATOR 1: Maybe to see new ways of testing, for example, purity
21 and what they have got and realising that this is how you
22 would go about it. I mean how do they know what they
23 have synthesised is actually what it is ? So it is just one
24 of the simple ways of testing it and also may be working
25 - sort of lab skills as well - just developing new skills.
26 RESEARCHER: What sort of lab skills would you say?
27 DEMONSTRATOR 1: Working - well semi - it is quite a small scale in a way
28 and also just learning to work carefully and with greater
29 accuracy.

(Post-lab interview with the demonstrator, 17-21)

In the same interview she also revealed her reason for simply presenting the students with the solutions.

.... and then obviously I always like
138 to show the calculation because I never used to show it
139 to them before and I discovered that 99% of the people
140 don't actually know how to do the calculations or
141 understand what is required.
142 RESEARCHER: Okay. Okay. So you did that on the board beforehand?
143 DEMONSTRATOR 1: Yes. Because otherwise they don't know how to do it.
144 RESEARCHER: Okay.

(Post-lab interview with the demonstrator, lines 137-144))

This last interchange indicates that the demonstrator had probably given the students the answers in the pre-lab talk in more than one previous experiment. If student 1 was aware of the fact that the demonstrator would simply give the solutions in A6, she may have thought it unnecessary to ensure that she understood how to do the calculations prior to the lab session.

Whatever the case, the demonstrator mentioned that most of the time, the students came to the laboratory not knowing how to do them.

It should be noted, however, that by simply supplying the students with the answer, the creative thinking processes involved in *deciding **how** to transform the data obtained* into a percentage by mass and a percentage purity were bypassed. In this case, the students merely had to try to understand the *demonstrator's* logic. Leaving the students to try to work out how to do the calculations on their own probably would have meant that they spent much more time reflecting on the concepts involved. This in turn could have resulted in more meaningful learning of the concepts involved.

In the post-lab test, however, Q1 (a) & (b) indicate that the student could perform the calculation of a percentage by mass of sulphate in AFS correctly, while she nearly got the percentage purity calculation correct. Since the calculations in the test were equivalent to those attempted during the lab session, it appears the student was able to understand the demonstrator's logic to some extent. Consequently, if one of the learning aims for this experiment was for students to be able to calculate the percentage by mass of sulphate in AFS in this setting, a measure of success seems to have been attained. The question remains, however, whether student 1 would have been able to do equally well, if not better, if she had been left to work out how to do this problem by herself.

Thus, it appears that because no guidance was given to the demonstrator about how to facilitate the learning process in this experiment, she was led to make her own decisions about (1) what the learning aims of the experiment were and (2) how best to facilitate their realisation by the students. In this case, the demonstrator's perceived learning aims were not unreasonable (see the extract above taken from the post-lab interview with the demonstrator). Nevertheless, because clear learning aims were not supplied, a different demonstrator may have come up with different learning aims. The description reveals that the demonstrator decided that the best way to facilitate *her* aims would be to (1) outline how to do the required calculations on the board and (2) answer any questions that the students may have had about them. It is also evident from the interview transcript above that her teaching strategy had changed as a result of experiences in previous lab sessions.

5.2.1.2. Recommendations

The following recommendations are made to the chemistry department in the light of these observations;

(1) the learning aims for an experiment should be made more clear to the demonstrator. This will allow him/her to make better judgements about how best to facilitate meaningful learning during the lab session.
(2) directions about the best way to facilitate meaningful learning and the realisation of the aims of an experiment should also be given to the demonstrator (what this boils down to is simply telling the demonstrator how to teach and the extent to which (s)he should give aid to the students).
(3) It is not recommended that the demonstrators simply be given the learning aims for an experiment and thereafter be left to decide how best to facilitate the realisation of these aims on their own. The reason for this is three-fold.

Firstly, the first year chemistry *major* demonstrators at WITS are generally honours students who obtained the best marks in their third year class. Since they do not attend the first year lectures or tutorials, neither do they have a copy of the first year student manual, they are not sufficiently familiar with (i) how much work the first year students should have covered in lectures or (ii) what learning goals they would have already covered by each lab session. Secondly, on the whole, these demonstrators are not education students. They are chemistry major students. Many of them would not be familiar with the learner centred, constructivist pedagogy that probably would prove to be most effective in this case. Giving them the opportunity to plan how to teach students probably won't prove a very effective means of realising the aims that have been set forth. Thirdly, the demonstrators are studying themselves, and probably wouldn't appreciate having to take the extra time to decide how best to facilitate the given learning aims. Most of them would very likely welcome a 'demonstrator's manual' telling them exactly how to teach and what to tell the students, for example in a pre-lab talk, instead of having to spend extra time deciding on it before the lab.

Despite these three reasons to simply tell the demonstrators how to facilitate the achievement of the learning aims for the practical, they should still be given scope to try other approaches should the recommended teaching strategy be totally unsuccessful for some *unforeseen* reason.

The information referred to in (1) and (2) above should be included in a demonstrator's handbook which is given to the demonstrator at least 1 week prior to the lab session. At WITS, this has been done to some extent for the first year *ordinary* labs, but not for the additional labs[57]. Neither has it been done for a number of the 2nd and 3rd year lab courses. Doing this

[57]Even though a mark sheet was given to the demonstrator upon her entrance to the laboratory, this neither gave her sufficient time to make an informed decision about how best to present the pre-lab discussion or what information to hold back and what to reveal.

will help to ensure that the demonstrator teaches in a way that better facilitates the realisation of the learning aims.

Currently at WITS all first time chemistry demonstrators are required to attend a demonstrator's induction programme. This programme briefly introduces the new demonstrators to effective teaching methods and also gives them an opportunity to observe other more experienced demonstrators at work during a lab session. This programme provides an excellent introduction into the learning environment as well as acquainting them with what will be required from them. In addition to the induction programme, an outline of the aims of an experiment as well as a recommended teaching strategy for each lab session would no doubt greatly enhance their ability to facilitate meaningful learning.

Since the task of outlining the aims for each experiment and then articulating ways for the demonstrator to facilitate them involves a considerable amount of work on the part of the lecturer in charge of a lab course, it is recommended that a provisional step be taken until sufficient time is available for it. The lecturer could provide the demonstrators with a mark scheme for the lab session at least 1 week prior to the date that it is scheduled for. This should give them some idea of what the lecturer deems important and thus what to highlight to the students and what to simply leave out. Giving it to them 1 week prior to the lab session will ensure that they have had sufficient time to reflect on it and decide on how they are going to teach.

5.2.2. The assessment of the student

5.2.2.1. Interpretations

In the pre-lab interview, the student expressed her views about what would be assessed and what she thought she would need to do to get 100 % for this lab.

184 RESEARCHER: ... And then what do you think you are going to need to
185 do to get 100% for this lab?
186 STUDENT 1: Well, okay again, it wouldn't have much to do with the
187 practical side of it because you don't hand in a lab report so
188 you would have to really write a nice big conclusion.
189 Significant figures is important - so if they are not right then
190 you won't get 100% so you have to ensure that you do the
191 correct masses - that's your volumes - when you add and
192 subtract - you have got to be right. So significant figures and

193		a conclusion and also to write down your procedure because
194		if you don't write your procedure out then you don't get 100%.
195	RESEARCHER:	Does the demonstrator normally do that, take off marks if you
196		don't write in a procedure?
197	STUDENT 1:	Well she prefers - ja, she prefers that you write in a
198		procedure, if you don't then - I think she really takes off a
199		mark but she will indicate there that she wants to see the
200		procedure, especially in the ad-labs. In the other one you
201		don't really have - it is not that important.

(pre-lab interview, 184-201)

By the end of the lab session, the student had written out a procedure and a conclusion, she had spent some time with the demonstrator checking that her significant figures were correct, and she had also answered all the questions listed in the lab manual. All these aspects of the laboratory were to be marked. She had not, however, conducted the test for Fe ions (she copied the answer from her neighbour), while she had only heated and weighed her crucible once (rather than continuing until two successive weighings were within 5 mg). It may be that in the first instance, because the actual 'doing' of the experiment was not going to be assessed, the student felt free to skip out the test for iron ions when she was pressed for time. On the other hand, since the student was required to reflect on the *meaning* of the test for Fe ions through question (c) in the lab manual, she did make an effort to reflect on and answer it. Her answer in question 2 (a) and (b) of the post-lab test shows that she did not remember the significance of the red colour. Nevertheless, her answer to question 4(b) in the post-lab test shows that she did understand the implications of the presence of impurities clinging to the precipitate (which is the answer that she put forward for question (c) in the lab manual).

One of the learning aims laid out by lecturer #2 (see appendix B) was that the student should learn that the crucible is reheated and reweighed to improve the accuracy of the results - not simply to practice the technique. In her model answers (see appendix D), she allocated 6 marks to its successful completion[58]. Student 1 only heated and weighed the barium sulphate in the crucible *once*. The lab manual does tell the student to do more than one weighing and reheating but the student felt free not to do this when she was running out of time, possibly because she

[58]The lab manual only instructs the student to 'record all masses' - no indication of the number of times the student should weigh the crucible was given. Unknown to the student, however, the demonstrator's model answers stated - "Students should heat and cool the sample ... at least 3 times ... Assign 6 marks here - 2 for every weighing - if they have only 1 mass then award 2 marks !".

thought that it would not be assessed and that it wasn't important[59]. She gave me her reasons for leaving it out in the post-lab interview.

145	STUDENT 1:	Well again the time for me to do, but I new that the results
146		wouldn't be changed that much. And again, someone had
147		done it or two had done it, and their's would make quite sure
148		that it would - it was between say 0,1 or 2 grams. So find that
149		it wasn't - and a ...
150	RESEARCHER:	Why do you think they make you do that?
151	STUDENT 1:	It is just so that it can prove to you in case that you have
152		handled the crucible beforehand when you go and weigh it.
153		And when you reheat it and you weigh it again you might not
154		touch it a second time or something else might ... or all the
155		carbon hasn't been burnt properly. So then you can actually
156		see if you have done it correctly the first time.

(Post-lab interview, lines 145-156)

In this case, her answer indicates that she did understand that the repetition was to make sure 'you have done it correctly the first time' (ie. to ensure the accuracy of the result). But her statement, 'I knew that the results wouldn't be changed that much' indicates a lack of commitment to this aim. If, however, the student knew that this part of the experiment was to be assessed, she may have been more committed to actually make an effort and do this part of the experiment (in any event she probably would not have felt sufficiently justified by simply seeing if her friends' results were within 0.1 - 0.2 g of their first readings). Note: the demonstrator *did* explain in the pre-lab talk *why* they should reheat and reweigh, but she did not allude to the fact that it was to be assessed in the report.

Although lecturer #2 had stressed the importance of accuracy in the model answers (which were given to the demonstrators just before they started the lab session) the demonstrator did not pick this up prior to the lab session and did not stress its importance to the students. If the lab manual had stressed to the student that the number of times and the accuracy of the weighings would be marked, the student probably would have had a clearer idea of its importance.

It appears, therefore, that the student made an effort to hand in everything that *she thought* was going to be assessed, while those aspects that she thought would not be directly assessed, she

---

[59]The lab manual states "Reheat for 15 minutes, cool and re-weigh. Repeat the cycle until successive weighings differ by less than 5 mg" (Additional laboratory course manual, p. 32).

simply left out when she realised that time was running out. As a result of this, she did not (quite justifiably) spend time reflecting on the parts of the experiment that were not assessed and this could have caused her not to learn as much.

5.2.2.1. Recommendations

The following recommendations are put forward to the chemistry department;

(1) Increase the content validity of the assessment[60].
The degree of validity for a particular method of assessment may be determined by deciding "if it measures what it is supposed to measure" (Bertrand and Cebula, 1980). If the purpose of an assessment is to measure a range of behaviours, and it only measures one of those behaviours, the test result has a low degree of *content* validity. Thus, in order to determine the degree of content validity of a test result, one must first find out the 'performance criteria' (or behavioural objectives) that the test/assessment is directly measuring. Once this has been done, one should then note the degree to which these tested criteria overlap with the 'universe' of performance criteria for the learning experience.

Hudson (1973) noted that "statements of observable behaviour" are what "the examination instructor needs to have before him if he is to prepare a valid examination" (p, 18). Thus the importance of explicitly outlining the learning aims of a laboratory session is once again highlighted. The chemistry department should, therefore, outline everything that they want the students to learn as a result of the lab session and ensure that as much of this as possible is assessed.

This, however, introduces an important issue with regard to the statement of performance criteria for an assessment. In that it is often difficult to state some of the intended aims of a teaching programme in behavioural terms (eg. has a positive attitude towards chemistry) and, thus, it may not be possible to form standard performance criteria to test the extent to which these aims are achieved (see Atkin, 1968). "Validity, no matter how it is determined, is based on some measure of behaviour. Before the validity of the test can be ascertained, the *relationship* between *the behaviour* to be evaluated and the *purposes for the test* must be determined" (Bertrand and Cebula, 1980). If the teacher finds it difficult to state what type of behaviour (s)he is looking for, (s)he will not be able to determine whether or not the assessment scores lack validity.

---

[60]There are three types of validity, (1) content validity (Bertrand and Cebula, 1980), (2) criterion-related validity (Frith & Macintosh, 1984) and (3) construct validity (Gronlund, 1976).

Nevertheless, it would still benefit the teacher to clearly articulate the aims of the learning experience. Then assess as many of these aims as are possible by including questions and exercises in the lab manual. Where the time available is scarce, and assessment of *all* the aims is not realistic, the lab teacher should prioritise the aims. Where the aims of a lab session involve actual manipulative skills and techniques which require direct observation, the teacher can employ the method outlined below to measure these.

Once all the lab sessions for the year have been designed, the department should decide which manipulative skills and techniques they would like to assess (more than one a session would be too many). The demonstrator could then inform the students that at the end of each lab session, three or four of the students (depending on the number of labs in the year) will be required to demonstrate a skill learned via the experiment that day (eg. filtration, use of the spectrophotometer, titration to an end point etc.). It is crucial that the students are not told who is to be assessed so that all will ensure that they are able to perform the skill by the end of the experiment. The demonstrator can then observe these three or four students performing the skill (which shouldn't take more than 5 min a student) and give them a mark for 'skills' by means of a prescribed mark sheet supplied by the Chemistry Department. It is also important, however, that the choice of the students be totally random so that they won't be able to predict who will be assessed on a particular day and thus will be on their toes all the time. If there are 20 students in a group, 20 lab sessions a year, and four students are assessed at each lab session, it works out that each student will be assessed four times a year. The fact that most students finish the lab session at different times means that the demonstrator should be available for each one being assessed. An advantage of this method of assessment, is that it is not necessary to try and eliminate copying. This is because even if a student observes one of his peers conducting the test, this could be considered as part of the learning process. As long as that student is not given assistance while (s)he is demonstrating the skill, (s)he has not cheated.

Another option for the measurement of manipulative skills (albeit an indirect one) is the 'practical examination' at the end of the year requiring that students do an experiment and hand in a report. It can be argued, that if the students have not acquired the manipulative skill, they won't get adequate results. This, however, is not always the case. The researcher has witnessed one of these examinations and observed that some students broke equipment, spilled chemicals on their workbenches (and on themselves), handled the burettes in unconventional ways, didn't have a methodical way of letting the titrant into the conical flask, yet they still obtained relatively reasonable results. It is also true that a reasonably intelligent student can 'fix' his/her results so that they are more precise (granted they still have no idea of their accuracy). Through individual observation, the assessment of 'skills' becomes more accurate and fair. Students who are neat, methodical, steady etc. can be given credit.

(2) The student should also be *aware* of *everything* that will be assessed.
As was seen above, the 'typical' student will make an effort to complete everything for which they will obtain marks. If they are only partially aware of the parts of the experiment that will be assessed, the student might be disadvantaged, for example, by leaving out parts in order to save time.

5.2.3. The amount of time available to the student to conduct the experiment.

5.2.3.1. Interpretations

In experiment A6, the time available affected what the student learned. This is because the student simply didn't do the parts of the experiment that she did not have time for. Thus, caution should be employed when making the students figure out how to do the calculations on their own for in this case they probably would need a considerable amount of *extra time*. A press for time may cause less learning to occur if the students really have no idea of what to do.

Student 1 couldn't remember what the red colour indicated when adding ammonium thiocyanate and ortho-phenanthroline to the barium sulphate (see question 2 (a) & (b) in the post-lab test). As can be seen from the dialogue below, she didn't do this part of the experiment because she was pressed for time (she simply copied her partner's answers).

126 RESEARCHER: Okay. And while I am thinking about it, remember yesterday,
127 you didn't - there was a part of the Lab Manual you were
128 supposed to test for the red - the red - you didn't get to that.
129 Do ... you say you didn't get to that?
130 STUDENT 1: No.
131 RESEARCHER: Okay, okay, was it because you were running late?
132 STUDENT 1: Well that and because the one next to me he had already
133 done it so I saw what it would have been.
134 RESEARCHER: Okay.
135 STUDENT 1: You can basically see the same things.

(Postlab interview, lines 127-135)

By the time the student began to write the answer to question (c) (which covers the iron ion tests) in her lab report, it was already 5:04 pm - over the time allotted. The press for time

caused her to reflect on this question much less than was intended. And thus, less learning must have occurred.

The interchange above, recorded in the post-lab interview, shows clearly that she didn't spend a sufficient amount of time reflecting on this part of the experiment in order to understand it correctly. This is because she tried to justify her actions by saying, "the one next to me he had already done it so I saw what it would have been". It is, of course, not a valid inference that her results would have been the same as her partner's. Her partner's sample of barium sulphate did not necessarily contain the same concentration of iron ions as hers.

The post-lab test also indicates that she did not spend sufficient time contemplating the use of ammonium thiocyanate and ortho-phenanthroline in the experiment because she proposed that they indicated the presence of *sulphate ions*. If she had actually done the tests, it is likely that in the post-lab test she would have remembered that these chemicals indicated iron ions.

There was also one other part of the experiment that the student did not do because of time.

137 RESEARCHER: Okay. In the Lab Manual it talks about - it says: " ... the
138 carbon will slowly burn away. When ignition is complete, stop
139 heating and then after one or two minutes transfer the crystal
140 into to the desiccator to cool. Accurately weigh the crucible
141 and the contents. Re-heat for 15 minutes, cool, re-weigh and
142 repeat the cycle ..." Did you do that yesterday?
143 STUDENT 1: No.
144 RESEARCHER: Okay so what made you not do that?
145 STUDENT 1: Well again the **time** for me to do

(Post-lab interview, lines 137-145)

Although, as was shown in section 5.2.2.1., she did understand why this part of the experiment was done, she didn't do it, however, because of the time shortage and because she thought that it wouldn't be assessed.

The student was allotted 3 hours to complete the lab. She entered the laboratory at 1:58 pm and left at 5:20 pm - twenty minutes overtime. Although an exact note of how much time she spent 'on task' was not made, there are only three places in the description of her activities in the laboratory where it was noted that she spent time 'off task'.
(1) She left the key for her locker at home and she had to go and sign for a spare one.

(2) She and her friend spent some time discussing their lab reports.
(3) She spent a short time discussing her weekend with her friend.
At various stages in the procedure, she also spent time washing her dirty equipment. These events may have contributed to the time shortage. But on the whole, student 1 spent most of her time 'on task'. During the long periods involving (1) the addition of chemicals (ie. agar-agar and barium chloride) and (2) the heating of the crucible and lid, the student spent her time completing her lab report. The demonstrator implied that the extra time needed was not a result of time 'off task' when twice she was heard to say that this was "a long lab".

5.2.3.2. Recommendations

In this case the old adage, "less is more" is applicable. Making students do too many things in too short a time can cause students to actually learn less than what is desired. If a teacher wants his/her students to explore all the implications of an experiment, (s)he must ensure that there is ample time to do so. Although it can be argued that too much time could result in more time wasting in the lab, this can be countered by making sure that every aspect that is to be reflected on is assessed (see 5.2.2). Nevertheless, the time factor needs to be carefully balanced with the proposed teaching method used to facilitate meaningful learning in the laboratory. The demonstrator also needs to be made aware of the learning aims so that (s)he will not bypass the whole aim of a question, either giving the students the answer when it is intended that they are to spend time reflecting on it (or not telling them anything when in fact time is of the essence).

In this experiment, the lab report *should* have been handed in one week later, but (unknown to the researcher) the demonstrator had decided to make the students hand in the reports the same day as the experiment, because it was nearing the end of the term. This could have worsened the time shortage (even though there are long gaps in the procedure where the student is required simply to wait while heating the crucible and lid). This is because it is possible to follow the procedure outlined in an unthinking manner, not understanding the purpose of many of the steps. Forcing students to complete a lab report during the lab session means that they are required to actively reflect on the questions and data transformations during their time in the laboratory. This will actually slow the students down, (although it may not be a totally bad exercise).

One suggestion that would avoid the demonstrator giving too little assistance to the students would be to outline in the *lab manual* how to do the calculation. In doing this, the lecturer would be giving the students clues about how to go about determining the percentage purity from the experimental and theoretical percentage by mass. The advantage of outlining it in the lab manual, is that (1) the demonstrator would then not have to spend time before hand

explaining it to the students, and (2) the lecturer can supply as detailed or as sparse an explanation as desired - depending on how capable the students are thought to be. The students would then be encouraged to think through the lab manual's explanation for how to calculate the percentage purity. If they had any difficulties on top of that, they could ask the demonstrator who would simply provide the necessary aid. The shortcoming of this suggestion is that it is unable to stop the demonstrator from revealing too much to the students upon request. If, however, there is some information that the lecturer would especially not want the demonstrator to reveal to the students in order for them to work it out on their own, it should be mentioned in the demonstrator's handbook (as suggested in 5.2.1.2).

5.2.4. The learning aims of the experiment as perceived by the student

5.2.4.1. Interpretations

In the pre-lab interview, the student was asked about the aims for the experiment.

32	RESEARCHER:	So could you tell me, just in your own words, what is the aim
33		of this experiment?
34	STUDENT 1:	Again, to see what the percentages are there - or to see how
35		much sulphate is in the actual raw product.
36	RESEARCHER:	Okay. And what do you think that is the most important part
37		of the lab - let me rephrase that. Do you think that there are
38		any parts of the lab that are crucial to getting good results?
39	STUDENT 1:	Ja, the preparation of the crucible is very crucial because if
40		you don't - the specific method of heating it to make sure that
41		you don't put you own sweats or water on anything, then the
42		mass can be thrown out completely. So careful consideration
43		must be taken in with the crucible, that is the most important
44		part.
45	RESEARCHER:	Are there any other important parts?
46		If you can think...
47	STUDENT 1:	No.

(Pre-lab interview, lines 32-47)

The introduction of this experiment (see appendix D) stresses the importance of "the conditions employed" on the "form and purity of the precipitate". If one of the aims of the experiment was

for the student to learn about the importance of specific conditions, the student did not perceive it. As a result of this, she did not make any real effort to meaningfully learn these conditions.

The student asked the demonstrator a total of 9 questions throughout the lab session. In all nine cases it was because the student was unsure of *what* to do, not *why* it was being done (ie. the *reason* for the specific conditions). It appears that the student did not make an effort to ask questions about what *she* thought she didn't have to learn. The post-lab test indicates that the student did not learn that the whole *reason* for using the crucible is because the small barium sulphate crystals will get stuck in the pores of the filter paper (see question 5). It also indicates that the student did not learn that barium chloride should be added in excess (rather than sulphate ions - see question 1(d)). She also did not learn that it is the choice of the chemist (rather than the balanced equation) that determines which reagent should be in excess (see question 1(c)). All of these cases have to do with the specific conditions of the experiment at hand. If the student had perceived them to be learning aims of the experiment, she may have made more of an effort to learn them, by asking the demonstrator some questions.

The description of the lab session supports the assertion that the student only really made an effort to learn the things that *she* mentioned as the aims of the experiment. For example in the pre-lab interview, she mentioned that an aim of the experiment was "to see what the percentages are there - or to see how much sulphate is in the actual raw product". Consequently, she spent a lot of time in the laboratory making sure with the demonstrator that she knew how to do these calculations.

5.2.4.2 Recommendations

It should be made quite clear to the students what the learning aims of an experiment are. In doing so, they are more likely to make an effort to learn what the teacher intends them to learn. It is not recommended, however, that these learning aims simply be listed at the beginning of the experiment. Aboderin and Thomas (1996) noted how test scores among Nigerian students were significantly greater when behavioural objectives were interspersed in the text rather than all at the end or the beginning of a text. It may also be useful to intersperse the questions pertaining to the experiment in the text as well. This will encourage the student to reflect on theory while (s)he is actually doing each part of the experiment, rather than having to think back to it at the end of the whole process.

Chapter 6

Factors that affect meaningful learning in the laboratory : Part 2

6.1. Introduction

This chapter is a continuation of the previous one in that it continues to discuss the factors that affect meaningful learning in the laboratory. What makes it different, however, is that part of it arose through a critical appraisal of the current literature specifically related to teaching and learning in the laboratory rather than directly from the data (the data collected, however, confirms it). The factor outlined in section 6.3 of this chapter is similar to the factors outlined in the previous chapter. Nevertheless, it has been placed in this chapter because a clearer understanding of the issues involved may be gained after one is acquainted with the arguments put forth in section 6.2.

6.2. Practical work : aims and outcomes

This section starts off with some important definitions which hold significant implications for many of the assertions made later on. From there, a discussion of how the *type* and the *context* of a lab session affect the learning that occurs has been outlined. The place for the verification lab session to facilitate meaningful learning has also been revised and the assertions made are shown to be confirmed by the data. Finally, recommendations have been put forward as to how to facilitate more meaningful learning in laboratory sessions.

6.2.1. Meaningful and rote learning of skills : A definition

It is easy to understand, the definition of meaningful learning as it applies to the learning of *concepts* (section 1.4.2). Novak (1984) described in great detail the use of concept mapping in order to assess "changes in cognitive structure as a result of meaningful learning" (p. 609). The greater the learner's ability to hierarchically organise concepts for a subject and 'link' new concepts with what (s)he already knows, the greater the amount of meaningful learning that has occurred. Novak and Gowin (1984) also describe a heuristic device called 'Gowin's Vee' which "can help students to *organise* written or oral exposition, and it can also be a useful tool for evaluating student's *understanding* of exposition" (p. 115, italics added). This device, along with concept mapping, aids and evaluates the learning of *concepts* in a way that can enhance

students' *understanding* of how underlying theories and philosophies influence their interpretation of the results[61].

Much of the learning that occurs in the laboratory, however, also inevitably involves the learning of specific *manipulative skills* and techniques commonly employed by practising chemists. Does it, therefore, follow that it is possible to *meaningfully* learn a specific manipulative *skill* or technique (eg. filtration or 'the use of a standard spectrophotometer') ? Exactly how may the amount of *meaningful* learning for a particular manipulative *skill* or technique be measured ? Questions such as these must be answered if the factors that affect meaningful learning in the laboratory are to be thoroughly explored. The aim of this section, therefore, is to derive a definition for the meaningful and rote learning of 'skills'.

It certainly seems reasonable that just as it is possible for an individual to rote learn random 'chunks' (Miller, 1956) of unrelated knowledge without actually linking them to what is already known, so it is also possible to rote learn a manipulative skill without actually making links to what is already known. This will occur when a skill is learned without knowing how it applies to what is already known. Such learning of skills, apart from meaning, without making the necessary links could be termed rote learning according to Ausubel's definition given in section 1.4.2.. Thus, in order to facilitate the desirable 'links' to concepts that will give the skill meaning, the student must understand *why* the skill is being employed in the *context* of the learning experience. Just learning manipulative skills, apart from context, apart from meaning, apart from understanding *why* they are being used, can only result in rote learning.

Roth (1998) commented that "the most surprising aspect about science education is that there does not exist a theory that links material activities to the appropriation of conceptual practices ... which may be the reason why it is so unclear what students and teachers have to benefit from hands on experiences" (p.1089).

White (1996), however, described seven different *types* of knowledge between which a student may perceive desirable 'links';

(1) propositions - "facts or beliefs" (p. 765).
(2) images - "mental pictures ... [eg.] a line drawing of a square (representing a cube) with a horizontal line (representing liquid level)" (p. 765).
(3) episodes - "recollection of events [in this case in the laboratory] in which the person took part or at least observed" (p. 765).
(4) intellectual skills - "procedures" (p. 765).

---

[61]For more information see Novak & Gowin (1984)

(5) motor skills - "learned physical movements" (p. 765).
(6) strings - "knowledge, usually verbal, that one has learned by heart so that they are recalled in unvarying forms" (p. 765)
(7) cognitive strategies - "general skills of thinking which, by definition, are not tied to specific content" (p. 765).

Whenever a student perceives 'links' between any of these types of knowledge, greater meaning has been added to his/her own knowledge. In the present case, in order to learn a particular *skill* meaningfully, the student should make links between the relevant 'motor skills' and the 'propositions', 'images', 'strings' and 'episodes' which may already have been assimilated and which explain *why* a motor skill is being employed in the context of the experiment at hand. The same reasoning would apply to the meaningful learning of 'intellectual skills' which White (op cit.) defines as 'procedures'.

Take for example, a student learning how to 'filter'. If (s)he learns how to filter without learning how it is related to previous knowledge of precipitates, mixtures etc. rote learning of the procedure and any motor skills involved will occur. However, some meaningful learning will have taken place if (s)he were to learn for example that;

- the liquid in question is poured through specially designed paper *because* it is desired that the solid separate from the liquid and the solid can't pass through the paper but the liquid can,
- the filter is not filled more than 1/3 full with liquid *because* some crystals may creep over the top of the paper and be lost.
- the liquid is poured into the filter *after* the filter paper has been placed therein so that the precipitate will be collected.

Further meaningful learning can take place when students are provided with opportunities to learn how to 'filter' in different contexts (ie. different types of filter paper, different sizes of the precipitate crystals, different amounts of reagents etc.). This is because more links to previous knowledge can be made. It should be noted that there is a close connection between motor skills and intellectual (or procedural) skills. Both involve following instructions, but motor skills may be incorporated into an intellectual skill (in order to carry out a certain procedure, certain motor skills will be performed in a particular sequence). The rote learning of some intellectual skills may even merely involve the learning of some motor skills in a particular sequence.

Meaningful learning of motor skills, therefore, may also occur if, as is possible with the intellectual skill of filtration, the student makes links between the procedure followed and the motor skills incorporated in it (ie. where does the folding of the filter paper (a motor skill), or the pouring of the liquid through the filter (another motor skill) actually fit into the whole

filtration procedure). Meaning learning of intellectual skills, however, will only occur when links between what is being done and why it is being done are perceived.

Thus, simply giving a student a recipe to follow in a lab manual, without him/her knowing *why* (s)he is doing what (s)he is doing, facilitates only the *rote* learning of intellectual (or procedural) skills (which are also referred to as techniques in this report). It may, however, promote *some* meaningful learning of the motor (or manipulative) skills that are incorporated into the procedure because the student may learn where they fit into the given procedure. Nevertheless, further meaningful learning of motor skills by making links between these motor skills and any relevant concepts will not occur. The more student learns the *reasons* for what (s)he is doing, the more meaningful learning will have taken place[62].

6.2.2. The learning aims for laboratory work

Reflecting upon the aims for laboratory work put forward in the literature, it is evident that many of them are not specific to the learning of science. Further still, some of the aims are not specific to learning in the laboratory. For example, Lunetta and Hofstein (1980) list aims like 'develop creative thinking', 'develop problem solving skills', 'develop skills in communication', 'develop skills in working with others', 'promote intellectual development'. Aims such as these could be realised through non-science related activities alone (eg. group work in a tutorial setting, homework questions, involvement in a theatre production, or a course in general mathematics). On the other hand, there are other aims that are only realisable through a science course, and still others that are only realisable in the science laboratory. It is therefore, important that *these* aims be identified, and the factors that affect their realisation be explored.

In table 8 below, the aims put forward for practical work by Lunetta and Hofstein (1980) (see table 1, section 1.4.3.) have been adapted and only those aims that are specific to *science* have been included. Notice also, that all of the aims listed below, except 'meaningful learning of scientific concepts' and 'enhance attitudes towards science' are specific to learning in the *laboratory* (ie. if these aims are to be realised, they *have* to be done through learning experiences in the chemistry laboratory).

---

[62]The same reasoning holds true for scientific inquiry *skills* which so many herald as an aim of science practical work. It may appear to be possible, however, to classify these skills as falling under White's (op cit) cognitive strategies which, according to White are "general skills of thinking which by definition are not tied to any specific content" . Nevertheless, since scientific inquiry skills are a *learning* aim of science practical work (which means that it is possible to *learn* them) they must be tied to some form of content. Meaningful learning of scientific inquiry skills would involve forming links between a particular method of science inquiry and *why* it is being employed. (See subsequent sections in this chapter for a fuller explication of this argument). This means that they too would fall under the category of intellectual (or procedural) skills.

Table 8: The aims of laboratory activity - adapted from Lunetta and Hofstein (1980)

Domain	Aim
Cognitive	(1) Meaningful learning of scientific concepts (2) Convince students of the plausibility and fruitfulness of the teacher's conception of the 'nature of things' - as opposed to their own misconceptions - by verification and refutation
Practical	(1) Meaningful learning of scientific inquiry skills (ie. scientific method) (2) Meaningful learning of specific manipulative skills and techniques commonly used by practising chemists
Affective	(1) Enhance attitudes towards science

6.2.3 The effect of the 'type' of lab session on the skills learned

Pavelich and Abraham (1979) classified laboratory sessions into three *types* - verification lab sessions, guided inquiries and open inquiries (see table 2, section 1.4.4.1.). As was seen in section 1.4.4.1. they proposed that the nature (or *type*) of lab session is a factor that will determine what sorts of skills students *employ* and *learn* as they engage in laboratory activities.

Table 8 above, lists two types of general science related ***skills*** (each type obviously comprising a vast sub-set of skills);
(1) those related to scientific inquiry and
(2) those related to manipulative skills and techniques commonly used by practising chemists.
The *type* of lab activity will, therefore, determine whether the student will potentially be able to learn skills related to scientific inquiry or simple manipulative and intellectual skills related to the work of practising chemists.

For example, in the verification type laboratory session, the skills that characterise *scientific inquiry* are performed by the teacher for the student. The student is merely required to follow the instructions laid out in the lab manual by the teacher. Can students be expected to learn these scientific inquiry skills when in fact they are not expected to use them (or even reflect on them) during the course of their lab work ? Unlikely ! To learn these skills, students must of necessity, engage in guided or open inquiry type lab sessions in which they will be required to actively engage in (and reflect on) the method of inquiry.

6.2.4. The effect of the context of the lab session on the skills learned

In the definition of the meaningful learning of skills given in section 6.2.1., it was mentioned that a skill could only be meaningfully learned if the student understands *why* the skill is being used in the *context* of the laboratory session[63]. The more the student links the intellectual, scientific inquiry or motor skill being employed to the *context* of the lab session, the more meaning the skill will have in the student's mind and the more meaningful learning will have taken place. Another factor, therefore, that affects the amount of meaningful learning that occurs in the laboratory is the *context* of the learning exercise. The context of a laboratory session will affect whether the students are able to learn *skills* meaningfully, in a rote fashion or even at all.

Consider the following specific examples which illustrate this point more clearly.

It has already argued in 6.2.3., that if the aim for a laboratory session is for students to 'meaningfully learn scientific inquiry skills', *only* guided or open inquiry type lab sessions should be employed. Even so, just giving the students a scientific problem to investigate without telling them *how* to go about investigating means that they will have to invent the process of scientific inquiry entirely on their own, in a few hours ! Consequently, students will most likely learn very little about scientific enquiry[64].

Suppose, however, that students are told *how* to go about the scientific inquiry. If *meaningful* learning of 'scientific inquiry skills' is desired, then they will need to understand *why* they are employing such skills (ie. why are we going about this inquiry in this way ?). This cannot be done in any sort of meaningful way, however, without somehow involving the history and philosophy of science in the *context* of the laboratory session. Simply telling students how to do an inquiry without telling them why it is done in that way can only facilitate the rote learning of scientific inquiry skills.

An example from the literature shows clearly how many have overlooked the context of the laboratory session as a factor that affects the meaningful learning of certain skills.

---

[63]That is except for motor skills in which some meaningfully learning may occur if the student makes links between a certain motor skill and *where* (not *why*) it fits into a given procedure. Nevertheless, it is also possible for further meaningful learning of motor skills to occur if a student makes a link between the motor skill in question and the *reasons* for its use in the procedure.

[64]Obviously there are different *degrees* of guidance that may provided for a 'guided inquiry' lab session. It should be noted, however, that by offering guidance to students about how to go about the inquiry, we automatically set the method of scientific inquiry - whether it be inductivism, falsificationism, Lakatos' method etc.. Say a teacher chooses to force the students to use Popper's falsification method in the inquiry. The teacher comes up with assertions, and tells the students to falsify them. In this case, the teacher has come up with part of a method of inquiry and expects the students to design the actual experiment. It is not likely, however, that the students will learn (in the few hours provided for the lab) any more about falsificationism than they have been told by the teacher. More than likely they won't discover, for example, the short comings of falsificationism (ie. the theory dependence of their observations etc.) and thus the failings of their results. Thus, the students won't learn more about the specific method of inquiry that they are engaged in than they are specifically told.

In Pavelich and Abraham's (op. cit.) guided inquiry format students were told "what problem to investigate and what experiment to do" but were required to "generate their own analysis and explanation of the data" (p. 100). They, quite rightly, proposed that verification lab activities alone would not give their students sufficient "experience with aspects of scientific enquiry" and they thus opted for a guided inquiry format for many of their lab sessions to fulfil this aim.

However, they excluded any sort of context for the meaningful learning of these inquiry skills. In their paper, they made no mention of any effort to acquaint their students with the history and philosophy of science in their inquiry format program. Their only reference to provoking the students to reflect on the *methods of inquiry* employed was when they told them how the lab report would be marked. They reported that it "is explained to the students that in science data can be interpreted many ways, and as long as that interpretation follows logically from their data, it is a reasonable one and will be accepted by us" (p. 102).

Matthews (1994), points out that "[d]iscovery in any educationally serious sense implies knowledge claims, which in turn imply students having good reasons for their beliefs or hypotheses, and this in turn implies some account of *what constitutes good reasons*, which finally requires an epistemological position that cannot be purely individually generated. Such epistemology, or protoepistemology, arises from more or less sophisticated social interaction. A good reason for a putative knowledge claim might be, "I believe it", subsequently it might be, "My mother told me," then it might be "The book says so", then it might be "This very well-received book says so" and so on with increasing epistemological sophistication." (p. 147, italics added).

Pavelich and Abraham did give their students a good reason for a putative knowledge claim by saying that it had to follow "logically from the data". What they did not do, was explain how or why they arrived at "criteria for an explanation of a natural phenomenon" (Fensham et al, 1994, p. 6). Neither did they define what constitutes as 'logical'.

Because their reason for the acceptance or rejection of a particular explanation was given without the students understanding *why* it was given, or its philosophical context, the skill of drawing knowledge claims from data could not have been learned in a meaningful way by their students. The students could only have *rote learned* that the process of drawing knowledge claims from data must be 'logical'. This is because they were not asked to give any thought as to *why* it must be logical, or to any other criteria for the acceptance of a knowledge claim.

There have been theories throughout the course of history that could not have been constituted as 'following logically from the data' but were clung to despite these difficulties[65]. This indicates that 'logicalness' cannot be the sole criterion for the acceptance of theory. Not giving students the opportunity to reflect on these issues means that it is highly unlikely that they will leave the laboratory having *meaningfully* learned how to make satisfactory explanations for data that will be accepted by a scientific community[66].

It may also be argued that since the students were not told *how to be logical*, it seems highly unlikely that they could have learned this skill at all (rote or meaningfully). The students had to work out, entirely on their own, what it meant for an explanation to follow logically from the data. What are the criteria ? Who decides what is logical and what is not ? This is what Matthews (op. cit.) is referring to when he says that an "account of what constitutes good reasons ... requires an epistemological position that cannot be purely individually generated". A general consensus has to be reached within the scientific community about what we believe to be 'logical'. Different people may have different views about what is logical and what is not.

If Pavelich and Abraham, therefore, wanted their students to at least rote learn the skill of being 'logical' then they needed to define how to be logical and make sure that their students conformed to this definition. If they wanted this skill to be learned in a *meaningful* way, then they should have included discussion on *why* scientific explanation should follow logically from the data, as well as on the history and philosophy of science and the scientific community's choice of knowledge claim criteria[67].

6.2.5. Is there a place for the 'verification' laboratory session ?

---

[65]"When Maxwell published the first details of the kinetic theory of gases in 1859, in that very same paper he acknowledged the fact that the theory was falsified by measurements on the specific heats of gases." (Chalmers, 1982, p. 67). Even though Maxwell's theory did fit most of the data, there was some puzzling evidence that indicated that his theory may have been erroneous. Nevertheless, it was not abandoned despite the fact that it did not follow logically from *all* the data.

[66]To cause the students to think that the *only* reason for the acceptance of a theory or explanation is that it be 'logical' doesn't seem to be wrong in itself, but it doesn't teach them very much about scientific method. Surely if we want to 'foster the skill of scientific inquiry' the students should at least be slightly acquainted with terms like 'induction', 'deduction', 'falsify', 'refute', 'positive/negative heuristic', 'paradigm' etc.. These terms and ideas may appear to be a bit above the average first year student, but they are implied in the aims that Pavelich and Abraham put forward when they stated that lab course was supposed to "give the student experience with aspects of scientific enquiry" (p. 100).

[67]Fensham et al (1994) propose that "the criteria for an explanation of a natural phenomenon" is that it be "elegant and parsimonious and connected with other phenomena" (p. 6). They also allude to Posner et al (1982) who suggest that an explanation should have intelligibility, plausibility and fruitfulness. Terms like these also need to be defined and explained to the students if meaningful learning about scientific inquiry and the generation of knowledge claims is to occur.

Despite the criticism that verification lab sessions cannot facilitate the meaningful (or even rote) learning of scientific inquiry skills, this certainly does not mean that they have no use. Indeed they do appear to have the potential to facilitate some meaningful learning.

The verification laboratory session;
(1) provides an opportunity to *rote* learn manipulative *skills* (without the students understanding why they are being used). This would involve simply giving students instructions to follow with no explanation.
(2) provides an opportunity to *meaningfully* learn manipulative *skills*. This is done by furnishing a *context* for the experiment (which would normally be supplied in an introductory discussion of the relevant scientific concepts).
(3) can be used to facilitate the meaningful learning of scientific *concepts* (as opposed to *skills*) by providing the student with opportunities to make further links between 'propositions', 'images', 'strings' and 'episodes' (White, op. cit.) that were previously unrelated. This use for the verification lab session, however, is not specific to the laboratory and may be done by means of lectures and tutorials as well.

Most science educators would probably agree that the point is not so much whether the verification laboratory *can* facilitate the three aims mentioned above, but rather whether these aims can be facilitated *more efficiently* by some other means (be it guided and open inquiries or lectures and tutorials).

6.2.5.1. Effective methods of learning scientific concepts

When it comes to the rote and meaningful learning of science *concepts*, there is some debate. Science educators are presented with what appears to be four options. They can attempt to cause their students to learn *concepts* meaningfully through (i) lectures, demonstrations or tutorials, (ii) verification laboratory sessions, (iii) guided inquiry laboratory sessions or (iv) open inquiry laboratory sessions.

White (1996) put forward one line of argument in favour of the laboratory over lectures and demonstrations. He argued that "*Engagement* is what gives student laboratory work the advantage over demonstrations. A demonstration may occur in front of students' eyes without them taking any real notice of it, while setting up equipment and recording observations requires at least some attention" (p. 765, italics added). By being forced to actively reflect on what is being done, there is a greater chance of students *remembering* what they did (ie. forming 'episodes' - a type of knowledge in which the student recalls events in which (s)he took part or at least observed - see section 6.2.1). Meaningful learning will take place when students link the

'episodes' formed to other kinds of knowledge already assimilated. White's argument in favour of laboratory work because it is more conducive to the formation of episodes is not irrefutable, however. He, even, admits that "You do not have to be central to the action to form an episode; for some of my clearest ones, I was no more than a spectator. But central or fringe, you have to be engaged; you must take notice and process the event into your mind" (p. 765). And finally he goes on to acknowledge that his argument "presumes that the demonstration and experiments are of much the same quality; exciting, dramatic demonstrations are likely to be more powerful than hum-drum laboratory experiences" (p. 765). Thus, well designed demonstrations or lectures also have the potential to cause students to form episodes because they also have the potential to capture students' attention.

In the light of White's (op cit.) arguments, therefore, it appears that the extent to which laboratory work is more *memorable* and *outstanding* than lectures, tutorials and demonstrations, is the extent to which it is better able to cause meaningful learning to occur.

Another line of argument in favour of laboratory experiences over lectures and tutorials is that 'seeing is believing'. Students verifying in the laboratory the theory done in lectures and tutorials may see the concepts presented to be more plausible and fruitful to them, while simply doing tutorial questions may not necessarily cause them to adopt a theory as plausible or fruitful.

Although this certainly could be the case much of the time, it is not necessarily always the case[68]. According to Popper's hypothetico-deductive method, "The most searching test of a new hypothesis centres on those predictions which are *not* derivable from current theory. Even better are those [predictions] which current theory contradicts. *Falsification*, rather than verification is the central feature of Popper's philosophy, and every attempt to test a theory is an attempt to falsify it. Whilst universal statements cannot logically be confirmed by singular observation statements, however numerous, they can be refuted by singular statements. The observation of one black swan falsifies the theory that all swans were white" (Hodson, 1982, p. 113, italics in original). Thus, even though many students may accept a theory as plausible and fruitful because of its verification by experiment, there may be some who would not agree that mere verification should be the basis for their acceptance of the theory as plausible or fruitful. In such a case though, the student may ask to systematically attempt to *falsify* the theory. If this happens, the teacher (who sincerely desires to see his/her students learn meaningfully) has no option but to comply ((s)he could also, of course, tell the students to "just accept it because I say so". This, however, does not appear to be a viable option).

---

[68]There does not appear to be any research on this aspect of laboratory work

With these points in mind, therefore, the traditional, 'verification' laboratory session does not appear to hold that much greater benefits in store than well designed lectures and tutorial questions when it comes to the meaningful learning of science *concepts*. Nevertheless, more research into these areas needs to be conducted.

Traditional verification lab sessions may not hold a greater advantage over lectures, tutorials and demonstrations when attempting to bring about the meaningful learning of science *concepts*, but what about guided or open inquiry lab sessions ?

It has been argued that the best way for a student to learn scientific concepts is through guided discovery where (s)he is required to contrive and 'construct' his/her own new knowledge through the discovery experience. Fensham et al (1994), however, recognised a distinction between the pedagogical role of the teacher in the construction of knowledge and in discovery. They maintain that construction can be guided to a greater or more subtle extent than discovery learning so that the meanings of the learners will be closer to those of 'textbook science'.

> "[A] metaphor of the teacher 'parachuting in' ... distinguishes parachuting from 'free fall' (the teacher landing heavily on the students' views, squashing them underground) and from 'floating endlessly above the surface' (leaving the students to make whatever sense they like). To parachute is to drop lightly but effectively on the appropriate place at the appropriate time. Judging when and where to do it is an advanced skill, requiring the teacher to have both pedagogical and content knowledge. ... the practice of these skills ... is pedagogy that is learner centred but teacher controlled in a way that there is always something the learners are called on to construct. This is the most significant of the differences between the discovery learning approaches advocated in the 1960's and the constructivist-based approaches" (Fensham et al, 1994, p. 6).

If the aim of a lab session is to cause students to construct (or meaningfully learn) scientific *concepts*, then leaving students to draw their own interpretations from data (ie. the teacher 'floating endlessly above the surface' as in inquiry lab sessions) does not necessarily facilitate this. There are a number of reasons for this;

(1) what students deem important to observe, will depend on their prior knowledge of the subject. This point was made by Johnstone (1993) when he observed that the uninformed

student cannot tell the difference between the 'noise' and the 'signal' of the experiment. "The stray bubble becomes as important as the colour change or the temperature change. Often the vital 'signal' is missed because the pupil has been beguiled by the 'noise' " (Johnstone, op. cit., p. 120). What students decide to observe, will be guided by their prior knowledge of the subject. Since their prior knowledge will consist of their own prior conceptions (which probably will include some misconceptions) it seems unlikely that much meaningful learning of scientific concepts will take place. This is an aspect that is commonly known as 'the theory dependence of observation' (Chalmers, 1982).

> ' ... theory precedes observation in science. ... insofar as the theories that make up our scientific knowledge are fallible and incomplete, the guidance that theories offer as to what observations are relevant to some phenomenon under investigation may be misleading, and may result in some important factors being overlooked. " (Chalmers, 1982, p. 33)

"By the mid-1960's there was enough written in the history and philosophy of science to cast doubt upon the inductivist views so characteristic of inquiry learning. The clear and detrimental effects of this separation of science education from the history and philosophy of science in the 1960's is a powerful argument for doing everything possible to prevent the separation recurring" (Matthews, 1994, p. 147-8).

(2) many scientific concepts are counter-intuitive. Expecting students to come up with these concepts from the data alone in a few hours during a lab session is quite unreasonable (especially in view of the fact that it took some of the best brains in the world decades to discover and refine them).

If it is desired that students learn (or construct) new scientific *concepts* specifically through experiences in the *laboratory*, the science teacher is left, therefore, with two pedagogical options;
(1) simply presenting the students with the information and concepts that (s)he wants them to learn via the introduction and procedure of the lab manual (this is what would be considered by Fensham et al (1994) as 'free falling'),
(2) or using the learner centred, teacher controlled method described by Fensham et al as 'parachuting in'.

There are powerful arguments that (2) above is the better pedagogy. Firstly it starts off at the level of understanding that the student has, rather than the level of understanding that the

teacher *assumes* the student to have. Secondly, if the student is not able to construct the relevant concepts through one approach, the teacher will be able to spot it easily and be able to change his/her approach to a more appropriate one for the particular student.

It also, however, has a number of disadvantages.
(1) The 'parachuting in' method assumes that an sufficient time is available to both teacher and students to facilitate the student's construction of the relevant concepts. This is frequently not the case. 'Parachuting in' would normally begin by the student revealing his/her present understanding of the concept in question. The teacher may see flaws in it and challenge it by pointing out (1) the implications of the student's point of view and (2) the implications of the 'textbook' point of view. (S)he would then take steps to prove, by experiment (this is where the laboratory comes in), that the student's idea of the phenomenon in question is inferior to the scientific community's conception of it.

Described in this way, 'parachuting in' amounts to Popper's falsification method of conducting science. The student puts forward a hypothesis, the teacher challenges it by putting forward a hypothesis that (s)he believes to be better. The teacher then decides on an experiment that will confirm his/her hypothesis and refute the student's. The teacher and the student together decide on the implications of their hypothesis for the experiment. The experiment is then conducted and if the student's hypothesis is refuted (s)he is supposed to be sufficiently convinced that the teacher's ideas are better and meaningful learning will have taken place. If the student is not sufficiently convinced the whole process begins again. This may be a powerful way to learn concepts, but it requires a great deal of time.

(2) The second disadvantage of 'parachuting in' is that it needs an experienced, skilled teacher who is able to time his/her interventions in such a way that it *leads* the student to the answer while still requiring him/her to *construct* the relevant concepts. This type of science teacher has usually been a scarcity in undergraduate science laboratory courses (especially at WITS) where post-graduate chemistry students are normally used as laboratory teachers.

(3) Its third disadvantage is that even if an appropriate teacher were available, for parachuting in to be most effective, classes should have no more than 10-12 students. It would take an especially gifted teacher to adopt a learner centred approach with a class of more than 100 students (the average size of an undergraduate chemistry class at WITS).

If, therefore, it is desired that students meaningfully learn concepts through experiences in the laboratory experience, in most circumstances, it will *have to* be presented with the underlying

concepts in the introduction and the procedure of the laboratory manual (ie. 'free falling' on the students).

6.2.5.2. Effective methods of learning manipulative (or motor) skills

When it comes to the rote and meaningful learning of manipulative (or motor) *skills*, it is apparent that learning *cannot* be facilitated through lectures or tutorials (it is not possible for someone to learn to drive a car simply by hearing a lecture about it). If it is desired that students learn these skills it will *have* to be through experiences in the laboratory.

In order to make distinctions between what can and cannot be learned through each type of lab activity, however, it is important that, at this stage, a clear definition of each of the different types of laboratory activity be stated. As a starting point of convenience, Pavelich and Abraham's (op cit.) meanings of the terms 'verification laboratory session', 'guided inquiry laboratory session', and 'open inquiry laboratory session' will be used.

The reader is referred back to table 2, section 1.4.4.1., where these classifications are made explicit in table form.

- A *verification lab session* starts by introducing students to concepts and then moves on to confirming these concepts by means of experimental data. "The first thing the students encounter when they see the verification lab manual is a detailed explanation of the chemistry they are going to encounter in the laboratory. The students are expected to read this introduction before coming to lab and to have understood it to some degree before beginning the lab work. Therefore in the verification format, the students are expected to understand the concepts before they experience the data. The next thing the students see is a detailed description of the chemical procedures they are supposed to go through. Most often the lab manual also includes an explanation of how the data obtained are to be analyzed to generate some specific number." (p.100).

- A *guided inquiry lab session*, according to Pavelich and Abraham, is one where students "are *not* given a theoretical introduction or methods of data analysis; they are given only explicit experimental instructions. Thus they are told what problem to investigate and what experiment to do, but they are required to generate their own analysis and explanation of the data" (p. 100). Through the explicit instructions given, the students are also told what data to collect.

One example of a guided inquiry experiment that they give, is where "students are instructed to dissolve various ionic solids in a beaker of water in which is suspended a thermometer. They are instructed to record their observations. They will observe that with some dissolution reactions the water temperature increases while with others it decreases. They are then asked to draw conclusions from these data. Through this experience and from discussions with other students and/or the lab instruction[69], the students form the idea that chemical reactions are connected somehow with heat" (p.101). In this case, the students, via the lab instructor, were provided with clues about which ideas or explanations were worth persuing and which were not. No textbooks or other resources were available to the students. They were expected to come up with the ideas entirely on their own. If none were forthcoming, the lab instructor could lead the students to the right answer. Pavelich and Abraham also describe the length of time taken for their guided inquiry activities as "one lab session timed to precede the lecture discussion of the topic" (p. 100).

- Pavelich and Abraham's definition of the *open inquiry lab session* is that students be allowed to "control all aspects of the investigation from choosing the problem through explaining the data. Consistent with this, the lab manual for open inquiry is simply a series of short, experimentally ambiguous statements (called systems) suggesting possible areas the student may want to investigate" (p. 101). Some examples of systems include, (i) "Investigate the heat lost or gained when a specific chemical or group of chemicals are added to water" (p. 101) or (ii) "Investigate the heat lost or gained when water at a high temperature is added to water at a lower temperature" (p. 101) or (iii) "Investigate the heat lost or gained with any other system or any modification of any of the above systems" (p. 101). They also mention that "students are reminded that they can do any investigation as long as it relates to the topic of heats [the topic under discussion in the lectures]" (p. 101). In this case, no resources other than input from fellow students is allowed - students may not ask the lab instructor for assistance. The length of time taken to conduct an open inquiry lab session is described as "one to two lab sessions timed to coincide with the lecture discussion of the topic" (p. 101).

It should be noted, however, that these are very narrow definitions of the guided and open inquiry lab sessions. Nevertheless, they are interpretations of these terms that some science educators may have[70].

---

[69]Notice that, according to this definition of the guided inquiry lab session, other resources (vis. the library) are not available to the student.

[70]Certainly Pavelich and Abraham (two science educators) held these views !

It was argued in 6.2.3. that guided inquiry and open inquiry lab sessions do have the potential to facilitate the meaningful and rote learning of scientific *inquiry* skills (if an appropriate context is provided). It also appears to be possible to cause students to meaningfully learn manipulative skills via *guided* inquiry sessions. This is because according to the definition above, the students are given "explicit experimental instructions" which includes what data to collect. Students are not, however, given the *explanations* for the data and the *method of data analysis*. These they must come up with on their own or with the aid of the lab instructor. In most cases (especially at WITS), the lab instructor, being a postgraduate chemistry student and not a skilled science educator, will free fall the students and simply give them the answers. In such a case, it will be possible for the students to *rote* learn the relevant manipulative skills from the procedure provided as well as make links to underlying concepts provided to them freely by the lab instructor. A lab instructor skilled in the learner-centred "parachuting in" pedagogy probably could do much better though.

Open inquiry lab sessions, as defined above, appear to be a different story altogether. These types of lab sessions *do not* appear to be able to facilitate the meaningful learning of basic manipulative skills and techniques. The main reason for this is as that in order for the students to conduct an open inquiry, they will have to draw on the manipulative skills and techniques that they have already learned. If students haven't learned the necessary manipulative skills and techniques yet (because they are expected to learn them during the inquiry) they will have to *re-invent* these manipulative skills during the exercise. It does seem highly unlikely that this will occur if the only resources available to the students are the input of other students in the class !

The question to ask, therefore, is whether verification or guided inquiry lab sessions, as defined above, will be most effective in causing students to *meaningfully* learn manipulative skills. The researcher is of the opinion that verification lab sessions will probably work better given the circumstances that many South African chemistry undergraduate students find themselves in (vis. large classes with unskilled lab instructors). Simply providing the students with the underlying theory in the lab manual, bypasses much of the input from the lab instructor - who may or may not be skilled in communicating chemistry theory to others. Writing out everything the student needs to know in the lab manual gives the lab instructor much more time to think about what and how to communicate to the students the information they need.

6.2.5.3. Summary of the place of the verification laboratory

In summary, therefore, there appear to be two main uses for the traditional 'verification' lab session as described by Pavelich and Abraham (op cit.),

(1) to facilitate the rote and meaningful learning of *manipulative skills* and *techniques* commonly used by practising chemists. This aim is laboratory specific and can only be realised through the activities in the laboratory (although, as was argued above, open inquiries won't facilitate this aim either).
(2) to facilitate meaningful learning of *scientific concepts*. This, however, can usually only be done in undergraduate chemistry classes by the 'free fall' technique outlined by Fensham et al (op. cit.) (except under exceptionally favourable circumstances where it may be possible to adopt the 'parachuting in' approach).

The science teacher who is using the verification laboratory to facilitate the rote and meaningful learning of manipulative skills (s)he might as well kill two birds with one stone. 'Links' from the skills employed to the concepts that furnish its context can easily be supplied to facilitate meaningful learning of manipulative skills, while *at the same time* the teacher may also provide an opportunity for the student to create links between *concepts* that were previously unrelated in the student's minds.

The meaningful learning of concepts through traditional *verification laboratory sessions* also does not appear to hold a much greater advantage over the meaningful learning of concepts through well designed tutorials, lectures and demonstrations. This is for two reasons;
(1) Verifying a concept, does not necessarily prove its plausibility or fruitfulness. Systematic attempts on the part of the students to falsify it would probably prove to be of greater effect if plausibility and fruitfulness were the science teacher's aim. Such systematic attempts, however, cannot be facilitated through verification laboratory sessions and the teacher would have to turn to an inquiry lab session which would take a great deal more time.
(2) Episodes (which are a type of knowledge described by White (op. cit.) as recallections of events) can also be formed through lectures, tutorials and demonstrations that will cause students to be sufficiently engaged.

Nevertheless, teachers should not be led to think that the traditional verification laboratory will facilitate the meaningful learning of scientific *inquiry* skills by their students.

6.2.6. A new name for an old type of lab session

After reading through the lab manual for experiment A6 (appendix C), it becomes clear that it was not meant to 'verify' any concepts to the student. (If desired, adjustments in the layout of the manual could easily have changed the purpose so that it *verified* that the percentage by mass of sulphate in AFS is what it is). Nevertheless, what the experiment *did* do was outline to the students a procedure for gravimetrically determining the percentage by mass of sulphate in AFS.

It also provided a context for some of the skills to be learned meaningfully (eg. to decant, to filter, to ash the filter paper, etc.). Thus, it is recommended that laboratory sessions of this type should be called 'procedural' laboratory sessions rather than 'verification' laboratory sessions as done by Pavelich and Abraham (1979). The procedural lab session's order, choice of problem, experimental design, data analysis and data explanation are all set by the teacher (exactly the same as a verification lab session - see table 2, section 1.4.4.). Nevertheless the act of 'verifying' a concept by means of the laboratory never really occurs in the procedural lab session. Rather students are simply expected to follow a procedure, and attempt to understand why, in the light of the textbook theory, it is being done in that way. This is what seems to be the case in experiment A6. Students were not given a procedure and required to show that the data confirmed (or verified) the theory. Rather they were simply given a procedure to follow with explanations for why certain conditions and techniques were used. Thus they were not confirming (or verifying) any concepts. They were simply being acquainted with a procedure and the explanation for it.

Procedural lab sessions as verification lab sessions, nevertheless, *are* able to facilitate the meaningful and rote learning of manipulative skills and techniques because they also provide opportunity for the students to link any skills learned with relevant concepts. Where they differ from verification lab sessions is that the argument of 'seeing is believing' (section 6.2.5.1.) does not apply. In a verification lab session, the lab designer is attempting to show to the student that the concept in question is in fact *plausible*. In the procedural lab session, the lab designer's assumption is that students *already* see the concepts in question as plausible (thus these concepts do not need to be 'verified' to them). The activities in the procedural lab session, therefore, are demonstrating to students the *fruitfulness* of the concept in the context used for the experiment.

Since all aspects of the procedural lab session are identical to those of the verification lab session (except for that mentioned directly above), the arguments put forward with regard to the meaningful and rote learning of scientific inquiry skills in a verification lab session must hold true for procedural lab sessions as well.

6.2.7 Evidence from experiment A6

- The data collected indeed shows how a 'procedural' lab does not facilitate the meaningful learning of scientific inquiry skills. (These would include the *planning* of the experiment and the *choosing of the many conditions* necessary to obtain accurate and precise results). The following observations confirm that student 1 did not learn certain aspects of the planning

for this experiment nor did she learn why a number of the conditions were specifically chosen.

(1) Question 5 of the pre- and post-lab comprehension test shows that she did not learn why the filter paper was ashed (as opposed to merely scraping the precipitate off the filter paper).
(2) Question 1(c) of the pre- and post-lab comprehension test shows that she did not learn that *barium chloride* must be in excess (rather than sulphate ions from the AFS).
(3) Question 1(d) of the pre- and post-lab comprehension test indicates that she did not learn that it is the chemist who determines which reagent should be in excess, and that this depends on which reagent (s)he wants to react completely.
Thus, even though the introduction in the manual highlighted (and to some extent explained) the importance of choosing the specific conditions employed, the student did not learn them. This is probably because *she* was not required to *choose* these conditions or *reflect* on many of them in any way. This, therefore, confirms the assertion that a procedural lab session cannot facilitate the rote and meaningful learning of scientific inquiry skills.

The fact that there were also a number of stages in the procedure where the student did not understand *why* she was doing what she was doing further confirms the assertion that a procedural lab session cannot facilitate the meaningful or rote learning of scientific inquiry skills.

(1) The student did not understand why the AFS + acid solution should be diluted with 200 ml water. The following dialogue occurred during the lab session;

Researcher: I just want to ask you, you, you measured out exactly 200 ml there. Is there any particular reason why you got exactly 200 mls or ...
Student 1: No, again its just because ...
Researcher: ... because the lab manual says so.
Student 1: It makes me feel better if I do exactly what it says
Researcher: Say that again.
Student 1: It makes me feel better
Researcher: Why ? Because you ... ?
Student 1: because then you've got more chance of it becoming right
Researcher: oh Ok thanks

(Extract taken from the description)

Since it is definitely not necessary for the student to add *exactly* 200 ml at this point in the procedure, one can clearly see that she really didn't understand why she was doing this part of the experiment. Since the answer to 'why' is not given to the students in the lab manual, neither is it required in the assessment, the student did not reflect on it at all. Her aim was merely to do this part of the experiment exactly as described in the manual, so that it would cause the experiment to 'become right' and produce the right results.

(2) The student did not understand why HCl must be added to the dissolved AFS.

Researcher: Let me ask you, you weighed out ... you measured out exactly five ml's or didn't you, you ? Why did you weigh ... measure out exactly 5 ml's ? Is there any specific reason ?
Student 1: No.
Researcher: Just because the lab manual says so.
Student 1: Ja, its wrong I think.
Researcher: You just did it wrong ?
Student 1: Um, no I'm not sure what I've done, I'm gonna go ask.
(Getting up to go to the demonstrator).
Researcher: Ok let me come with you.

Student 1: (approaching demonstrator 1) If you add like way too much hydrochloric acid is it gonna destroy the whole thing now ? ...
Demonstrator: ... I don't know whether it's gonna affect your results or not. ...
Student 1: Must I do it again ? ...
Demonstrator: You'll soon see whether its working or not.

(Description)

Clearly the student had no idea why she was adding the HCl to AFS solution.

(3) The student had a limited idea of why the barium chloride should be added to the AFS + acid solution.

Researcher: Can ... I saw you measured out exactly 10 mls of barium chloride, is there any specific reason why ?
Student 1: No, again the same reason.
Researcher: Is because ...
Student 1: It just makes me feel better, ja.

Researcher: Just because the lab manual says so.
Student 1: Ja.

(Description)

Here again the student had no clear understanding about why she was doing this part of the procedure.

These three cases make it clear that the student did not make any effort to learn scientific inquiry skills through this lab session. Rather it was merely giving her an opportunity to reflect on some of the concepts involved - this could also have been done if the *data* had simply been *given* to the student and she was told to calculate the percentage by mass and percentage purity in a tutorial type setting (the demonstrator would then no longer be a demonstrator, but a tutor).

It could be argued that actually getting students to handle materials aids the meaningful learning of the concepts involved[71]. The argument put forward here, however, is that this won't occur when the students don't understand half the steps (or even one of the steps) that they took in the procedure. It probably would have been better just to give them a tutorial question and reduce the 'noise' (Johnstone and Wham, 1982) of the whole exercise. 'Procedural' labs cannot, therefore, be claimed to be a good way of enhancing the meaningful learning of concepts (it is not *impossible*, but a better way may be by means of low noise, high signal tutorial type questions).

- What laboratory activity *can* do (that no other form of teaching will do) is promote the meaningful and rote learning of manipulative skills. This was shown to be the case for filtration. Question 2 of the skills test indicates that the student correctly rote learned how to filter as a result of the lab session. It was also the case for the washing of the precipitate and the testing of the fresh filtrate with silver nitrate (see Question 3 of the skills test and question 4(c) of the comprehension test).

- In case number (2) above, the reason why the AFS + acid solution is *diluted* with water is because barium sulphate is more soluble the more acidic the solution. Thus, the lower the pH, the less barium sulphate will be obtained. Dilution of the acid with water is, therefore, one of the necessary conditions for obtaining the exact amount of precipitate. The student,

---

[71] White's (1996) argument was that handling equipment helps the students to actively engage in the activity thus creating a greater opportunity for 'episodes' to form. A well designed tutorial question, however, also engages the students in an activity and can be just as (if not more) memorable as 'hum-drum' laboratory exercises such as measuring out approximate volumes of liquids.

totally oblivious to the reasons for choosing these conditions, simply followed the manual hoping that she wouldn't do something wrong and 'mess the whole experiment up'. Thus, *meaningful* learning of the procedure for gravimetrically determining the percentage by mass of sulphate in AFS was not facilitated because no context was provided (ie. explanations explaining the choices of many of the reagents and techniques were not provided). The best that could hoped for is *rote* learning of the procedure. Even this did not occur, however, since the student was not specifically required to actively reflect on the steps taken during the experiment. She may have learned some parts of the procedure, but she forgot the following parts of it;
(i) the student couldn't remember what the ammonium thiocyanate and ortho-phenanthroline was testing for (see question 2(a) of the post-lab test).
(ii) she also did not remember which reagent should be added in excess, barium chloride or sulphate ions from AFS (see question 1(d)).

- Case number (1) above, quoted from the description of the lab session, confirms that this lab was not 'verifying' anything in the student's mind. Her reason for following the lab manual exactly was because this would give her "more chance of it becoming right". This implies that she thought that there was one 'right' answer that should be obtained in the lab session and if the lab manual was not followed exactly, she wouldn't obtain it. If the student was 'verifying' something, her attitude surely would rather have been that the results would *prove* whether her own understanding or the lab manual (or teacher) was right or wrong.

- In order for a skill to be rote learned, the student at least needs a step by step procedure in front of him/her. If this is not provided, it is unlikely that the student will re-invent the skill on his/her own. This was the case for the intellectual (or procedural) skill of 'accurately weighing out about 0.3 g'. The pre-lab test indicated that the student had not yet acquired this skill (see question 1(a) skills test). Since the students had been required to perform this task in numerous other experiments, it was probably assumed by the lab manual designer that at this stage it was not necessary to outline in a step-by-step fashion how to go about it. The student (who had not even rote learned the skill yet), therefore, did not have the opportunity to rote learn it during the lab session. She invented her own procedure for the task and simply by-passed the whole procedure by only using *one* balance - both in the actual lab session and in the post-lab test. Her failure to even rote learn this skill could be due to the fact that at WITS, the students' ability to perform specific skills is never *directly* assessed, thus the students do not see the necessity of learning such skills properly (see section 5.2.2. for a full discussion of this factor and recommended assessment strategies).

- If no context is provided for a skill, the best one can hope is rote learning. Meaningful learning will occur when the student makes links between the skill (s)he is performing and the underlying concepts that explain why (s)he is doing what (s)he is doing. This principle was demonstrated when the student did not meaningfully learn how to ash the filter paper. Even though a step by step procedure was given for this task, much of the underlying theory for why it is done (ie. context) was not given. Thus, question 5 indicated that the student did not *meaningfully* learn it.

6.2.8. Recommendations

The following recommendations are made in the light of the discussion so far.

(1) Introduce the students to the laboratory by facilitating the *rote learning* of certain basic manipulative skills and techniques (eg. using the accurate and rough balances, using a burette and a pipette, using a Bunsen burner, etc.). This could be done by simply giving students a set procedure to follow or by presenting them with a demonstration of the technique or skill and then providing an opportunity to carry it out themselves. Once they have been introduced to some scientific concepts in the lectures and tutorials, they could then use these rote learned skills within a context where meaningful learning will be facilitated (eg. the use of the rough and accurate balances could be given in a context of the concepts of accuracy and precision, and the use of the burette and the pipette in the context of an acid-base titration).

In line with this suggestion, Johnstone and Wham (1982) proposed that students be taught important (manipulative)[72] skills "*for their own sake*, before using them for some investigation" (p. 72, italics added). Thus, in the context of the arguments above, the purpose for such a laboratory session becomes specifically that of *rote* learning manipulative skills and techniques. Once this has been achieved, the students can conduct 'investigations'[73] in order to learn these same skills *meaningfully* and also spend time reflecting on the concepts relevant to the experiment. Johnstone and Wham (op. cit.) suggest that employing such a sequence reduces the possibility of the 'information overload' that many students have encountered in the laboratory.

---

[72]In their paper, Johnstone and Wham (op. cit.) do not make a distinction between scientific inquiry skills and manipulative skills. This distinction is a necessity, however, because as was seen above, the two cannot be learned at the same time. The context of their paper, however, seems to indicate that they are alluding to the learning of manipulative skills.

[73]This type of scientific investigation is still set by the teacher - ie. it is a verification lab session or a procedural lab session. All the student is expected to do in this case is to make links between concepts (supplied by the context of the lab session) and the skills that have been previously rote learned. (S)he is not expected to use scientific inquiry skills.

The *meaningful* learning of skills could also be provoked by interspersing questions at various stages of the procedure to ensure that students are reflecting on why they are doing what they are doing.

As was noted in section 5.2.1. the demonstrator's role is also crucial to the success of the experiment, and once (s)he has been made aware of the learning aims of the experiment, a recommended teaching strategy should be provided. Demonstrators should be told to make students aware at all times of *why* a certain skill is being carried out. They should also always be on the look out for students who have incorrectly rote learned skills and perhaps it would be useful to give them a list of student problem areas to be on the look out for[74].

(2) The provision of a context (ie. the explanation in the lab manual that makes clear to the student why the experiment is being conducted as well as why certain skills are being employed) for the meaningful learning of skills means that *at the same time* the teacher can exploit the opportunity to facilitate the meaningful learning of any scientific *concepts* involved. This can be done by furnishing questions (or exercises) that require the student to reflect on these concepts (eg. concept mapping). Vee mapping (Novak and Gowin, 1984) also provides an excellent opportunity for the students to reflect on why certain manipulative skills were used and how they relate to concepts and theories covered in the lectures (ie. meaningful learning of skills).

(3) When the laboratory teacher decides that the students have meaningfully learned a sufficient number of basic manipulative skills and techniques, (s)he can then introduce them to a guided inquiry laboratory session (this would normally be at a third year or honours level). It should be noted that the guided inquiry format, can be guided in varying degrees depending on which type of scientific method the teacher wishes the students to learn about and which aspects of that method (s)he wishes them to focus on. Below, three approaches to the facilitation of the meaningful learning of scientific inquiry skills have been outlined.

- The teacher could start off by first causing the students to *rote learn* scientific inquiry skills. This is done by simply giving them a guided inquiry exercise and telling them exactly how to

[74]This is perhaps another area for further research - the investigation of manipulative skills and techniques that are most commonly incorrectly learned by students.

go about it (while at the same time making the students aware of the method of inquiry)[75]. The teacher does not necessarily have to provide the students with a context of the history and philosophy of science, but (s)he should require that the students reflect on how they were told to go about the inquiry. This could be done by (1) making explicit in the lab manual that the teacher wants them to notice the method of inquiry and (2) including questions on the definitions of some of the terms used in this method of inquiry (eg. hypothesis, conclusion, conjecture, refutation, positive/negative heuristic, paradigm etc.). From there, the students could be given a hypothetical problem and asked to outline, using the scientific method in the last experiment, how they would go about doing it. Once this is done, the teacher would describe how (s)he would conduct the investigation. This will enable the students to gain more insight into the strengths and weakness of this specific method. (Note: Simply giving students an experiment to do and making them go through definite procedural steps without making them *aware* of these steps by specifically requiring that they reflect on their implications for scientific inquiry, also probably means that they won't even rote learn the inquiry skill. This is because they won't have been reflecting on it as they merely follow the recipe outlined in the lab manual).

Once a particular approach to scientific inquiry (eg. Popper's hypothetico-deductive method) has been *rote* learned by actively following a recipe outlined by the teacher, the student could then be introduced to the shortcomings of the approach (eg. the theory dependence of observation etc.) through a discussion of the results with the teacher. The student could then be introduced to other approaches in a like manner.

- Alternatively, the teacher could simply give the students a course on 'the scientific method' introducing them to the contentions surrounding all points of view. (S)he could then supply them with problems to investigate, allow them to choose one of these, tell them how to investigate it, require that they actively engage in the investigation and then reflect on the shortcomings and strengths of the method proposed[76].

---

[75] As an example, the students could thus be given the task of 'verifying' or 'refuting' certain chemical laws (assuming they are rote learning Popper's scientific inquiry method). At this stage, however, they would already be expected to understand certain basic scientific *concepts*. Nevertheless, suggesting that the teacher tell them exactly how to go about the investigation does not mean that the answer of the practical becomes a set one - as it is in the 'verification' laboratory session. The students may find that the 2nd law of thermodynamics is falsified through their experiment. Nevertheless, since the aim of such an activity is not for them to learn the second law of thermodynamics, but rather for them to learn a certain way of doing science (ie. scientific inquiry skills), they should therefore not be penalised if their results do not verify it (unless of course the discrepancy was due to experimental design errors).

[76] Although there is no conclusive evidence at present, the researcher has reason to believe that this is the way most chemistry honours research projects at WITS are conducted. One vital part of the whole process is missing, however - the introduction to the history and philosophy of science. This means that, on the whole, the rote learning of scientific inquiry skills must be occurring. This provides further interesting avenues for research in science education.

- One other approach would be to introduce students to the scientific method through course work; give them a problem to investigate; let them decide on a method for investigating it; require that they actively engage in the investigation and then reflect on the issues that surround the project. This, however, requires a great deal more time and understanding of the issues than the other two approaches, and it is recommended that it be left until the students are reasonably familiar with the process of scientific inquiry.

(4) Only once the students have a sufficient meaningful understanding of a great number of scientific concepts, manipulative skills and techniques and the issues surrounding the scientific method can they be subjected to an open inquiry format. In most cases, the individual would probably not be a student any more but rather a doctor or professor who would very likely have a team of postgraduate and undergraduate students conducting experiments under his/her supervision.

6.3. Pre-lab preparation

The effect of pre-lab preparation on learning can be discussed with reference to a number of the points previously mentioned in the previous section.

6.3.1. Interpretations

By the time this research was conducted, the question of what and how much pre-lab preparation was required from the students had already been settled by the demonstrator and the lecturer. As a result of this, in all of the additional lab sessions that were attended by the researcher, nothing was said about pre-lab preparation (that was noted). Nonetheless, it was possible to gauge, to some extent, what was required of the students by noticing (1) what the introduction to the lab manual had to say about it[77] (2) what student 1 said she thought was required in the pre-lab interview.

Student 1 mentioned that she spent approximately 30 mins preparing for this session.

14 RESEARCHER: And tell me how long did you spend approximately preparing
15 for the lab?
16 STUDENT 1: Um ...
17 RESEARCHER: Tell the truth now, don't worry - ja.

---

[77] A copy of the lab manual's comments on what was required for pre-lab preparation has been included in appendix C

18	STUDENT 1:	Okay, I would say about half-an-hour.
19	RESEARCHER:	Okay, that is great - that is more than what most people
20		spend. Is that what you usually spend preparing for the lab ?
21	STUDENT 1:	Um no, it just depends on how long the experiment is - if there
22		is a lot of report then it will be a longer. But this isn't much of
23		a report.

(Pre-lab interview, lines 14-23)

The fact that she did prepare for the lab session was supported by these statements in the post-lab interview as well.

36		... Can I ask you, yesterday - now you do not
37		have to - you don't have to try to impress me but yesterday
38		did you do your preparation for lab report because you had to
39		hand it in? Did you do that lunch - after our interview[78]? Did
40		you go through the lab after that or not really?
41	STUDENT 1:	No.
42	RESEARCHER:	Is it? Oh I thought that may be you had and that's - okay.
43	STUDENT 1:	No.
44	RESEARCHER:	Okay. Okay
45	STUDENT 1:	I read it at home
46	RESEARCHER:	And you spent as - the the normal amount of time that you
47		would for a prac that length ...
48	STUDENT 1:	Yes.
49	RESEARCHER:	On your lab report - you didn't brush through it or anything?
50	STUDENT 1:	No.

(Post-lab interview, lines 36 - 50)

It is clear that she must have read through the procedure, because in the pre-lab interview she was able to answer the following questions without the lab manual in front of her.

1	RESEARCHER:	Could you tell me what you are going to be doing in the lab
2		today and why you are going to do it ?

[78]This is referring to the pre-lab interview.

STUDENT 1: Okay. um well first of all we are determining the mass - okay well I must say the procedure.

RESEARCHER: Ja, And what and why you are doing it?

STUDENT 1: Okay well we, um ... (pause) ok I know have to, we have to burn the -or heat up the ammonium ferrous sulphate. It is already pure because they purified it last week but we are going to heat it up with that method that is in our book so that we can determine and use specific indicators - see if there is anything present in the ah crucible and then we doing all this so that we can measure the percentage of the sulphate ions in the ammonium ferrous - so that is why we are doing this.

(Pre-lab interview lines, 1-13)

RESEARCHER: Okay. And what do you think that is the most important part of the lab - let me rephrase that. Do you think that there are any parts of the lab that are crucial to getting good results?

STUDENT 1: Ja, the preparation of the crucible is very crucial because if you don't - the specific method of heating it to make sure that you don't put you own sweats or water on anything, then the mass can be thrown out completely. So careful consideration must be taken in with the crucible, that is the most important part.

(Pre-lab interview, lines 36-44)

The summary of the *procedure* in her lab report (rather than a summary of the *aims* of the experiment) may be viewed in appendix D. It appears that this was not a careless use of words on the part of the student. She really believed that one of the pre-lab tasks was to summarise the procedure. This was revealed in the pre-lab interview.

RESEARCHER: Okay. And then what do you think you are going to need to do to get 100% for this lab?

STUDENT 1: Well, okay again, it wouldn't have much to do with the practical side of it ...

... and also to write down your *procedure* because if you don't write your *procedure* out then you don't get 100%.

195 RESEARCHER: Does a demonstrator normally do that, take off marks if you
196 don't write in a procedure?
197 STUDENT 1: Well she prefers - ja, she prefers that you write in a
198 *procedure*, if you don't then - I think she really takes off a
199 mark but she will indicate there that she wants to see the
200 procedure, especially in the ad-labs. In the other one you
don't 201 really have - it is not that important.

Pages 2-3 of the additional lab manual outline exactly what is required from the students with regard to pre-laboratory preparation. In summary, they have to prepare a 'report'/ 'records sheet' including the following:
(1) An introduction to the experiment which consists of a summary of the aims of the experiment.
(2) A referral to the page numbers in the lab manual where the procedure is outlined.
(3) Provision of space for results obtained (students are advised to draw up tables beforehand where necessary so that they "need only fill in the blank spaces [they] have created for [themselves] in the pre-lab report" (p. 2, lab manual)).
(4) Provision of space for discussion of the implications of their results once they have performed the experiment.
(5) Provision of space to answer any questions.
(Notice that it is not explicitly stated that the students should answer any of the questions prior to the lab session, or familiarise themselves with the calculations - they are instructed merely to leave space for results, discussion and answers to be filled in after the practical).

Overall, therefore, the two important tasks for the student in the pre-lab preparation would be (1) to summarise in his/her own words the aims of the experiment and (2) to prepare the results section so that it was waiting for the data to be filled into it. The *purpose* of each of these tasks in turn is discussed below.

With regard to the first task (ie. that of summarising the aims of the experiment), the researcher has already recommended that the *learning* aims of the experiment be made clear to the student. In experiment A6 such aims might have included;

- meaningfully learn how to (1) filter, (2) wash the resulting precipitate in water and (3) test the fresh filtrate for impunity ions.
- meaningfully learn how to calculate the percentage by mass of sulphate in AFS using the mass of the AFS and the mass of the resulting barium sulphate precipitate.
- further meaningful learning of the concepts of amount and stoichiometry.
- etc.

A distinction, however, needs to be made between the *learning* aims and the *scientific* aims of an experiment. The aims that the student is required to outline in the pre-lab preparation are not the *learning* aims for this lab, but rather they are the aims that *a chemist who might be conducting this experiment* might have. The student is thus expected to read through the procedure that is outlined, and give reasons (from the title of the experiment and the context provided in the manual) for why a chemist would be doing this experiment (ie. give the scientific aims of the experiment).

In experiment A6, the scientific aim of the experiment is stated in its title given in the lab manual - "Determination of the percentage by mass of sulphate in the sample of AFS by gravimetric analysis". In her introduction to the experiment in her lab report (in which she was instructed to "summarise briefly the aim(s) of the experiment , perhaps mentioning the technique(s) which will be used" (Additional lab manual p. 2) - see appendix C), student 1 simply copied out the first line of the lab manual's introduction. This, however, is neither an aim nor a technique used in the experiment.

Looking at what the student did for this task, it becomes clear that she did not understand its *purpose*. As a result of this, even though in the pre-lab interview she was able to articulate the scientific aim of the experiment to the researcher, *it wasn't as a result of this pre-lab exercise.*

11 STUDENT 1: ... we doing all this
12 so that we can measure the percentage of the sulphate ions
13 in the ammonium ferrous - so that is why we are doing this.

(Pre-lab interview, lines 11-13)

If done properly, however, this task forces students to familiarise themselves with the underlying theory of an experiment *as well as* the procedure to be used prior to their entry into the laboratory (in order to sufficiently understand the scientific aim of an experiment it is necessary that a student be familiar with the overall procedure to be followed as well as meanings incorporated therein). If, therefore, while summarising the scientific aim of the experiment a student realises that there are parts of the theory or procedure that are unclear to him/her, (s)he would be expected to take steps to understand it adequately. (In this case, however, even if the student had not misunderstood the instructions, she could have simply copied the scientific aim of the experiment from the title. This means she could have identified the scientific aims of the experiment with out familiarising herself with the necessary theory anyway).

Thus, even though this pre-lab task has the *potential* to cause a lot of meaningful learning prior to the lab session, it appears that the student did not learn anything much about the scientific aims of A6 by doing it in the way that she did. Neither did it help her to meaningfully learn much about the underlying theory of the practical.

It is interesting to notice that the model answers given to the demonstrator (appendix D) for experiment A6 did not allocate any marks to the exercises required by the pre-lab preparation. It is possible, therefore, that previous model answers did not allocate marks for pre-lab preparation either. It was further discovered, after the interview with the demonstrator, that for experiment A1 & A2 no model answers were provided. It is possible, therefore, that the demonstrator outlined to the students what was required of them with regard to pre-lab preparation in the first laboratory session (and that it was in accordance with the lab manual). But after A2, since no more marks were allocated for it, and since any sort of pre-lab preparation from then on was accepted without comment, the students' responses deteriorated until answers like those given by student 1 in A6 were acceptable. All that became necessary was that the students include some sort of pre-lab preparation (*no matter what it was*).

The description of the student's activities during the lab session reveals that the demonstrator did not mark or check her pre-lab preparation before her commencement of the experiment. At that time, however, the students were required to display their prepared lab reports to a demonstrator who was standing at the door of the laboratory checking that *some work* had been done (nevertheless, this was not a very searching check and pre-lab preparation of any quality is most likely to have been let through). Failing to produce a prepared lab report, would have resulted in the student not being permitted to enter the laboratory - that is until one could be produced.

The second task in the pre-lab preparation (that of preparing a report sheet which was just 'waiting' for the results), did not serve its purpose adequately either. Lecturer #2 outlined one of its the purposes;

650 LECTURER #2: Because you know if we are actually trying to move them towards -these
651 are the majors ...
652 RESEARCHER: M'm.
653 LECTURER #2: If you are trying to move them towards becoming true scientists...
654 RESEARCHER: M'm.
655 LECTURER #2: ... then this report sheet should be waiting for the data.
656 RESEARCHER: Okay.

657 LECTURER #2: And they should have an idea of how much space they need to leave to do
658 the calculations.
659 RESEARCHER: I see. ...
668 LECTURER #2: If you walk around to see how many students are actually behaving like
669 true research chemists - because a true research chemist has a research book and the
670 answers go straight into there.

(Interview with lecturer #2, lines 650-670)

Two other purposes for requiring a student to prepare the results section in the stipulated way may be;
(1) to familiarise him/her with the *form of the data* to be collected and
(2) to familiarise him/her with the *calculations* that will be used to *transform the data*.
If a student is not sufficiently familiar with the form of the data to be collected or how it will be transformed, (s)he will not be able to prepare a results section. This task, therefore, forces a student to make sure that (s)he can do the necessary calculations before (s)he enters the laboratory.

The description of the student's activities in the laboratory as well as the student's lab report (appendix D) reveal that she was not sufficiently familiar with the data to be collected or the data transformations in the laboratory session.

Firstly, the researcher also observed that the student did not enter the laboratory with calculations that were waiting for data. She simply had left space for calculations which she wrote in during the lab session. Secondly, the amount of space that she left for the percentage purity calculation (which she placed under the heading of 'Comparison') was insufficient. This resulted in very squashed workings. She also spent a lot of time in the lab session *learning* (rather than clarifying) concepts and calculations that should have already been learned by means of the pre-lab preparation (this was especially true with regard to the calculation of the percentage purity).

The extra information to assimilate during the practical session must have increased the 'noise' of the experiment for her, and an increase in 'noise', normally means a decrease in learning. To the unprepared learner "the incoming information may have no apparent structure because the very idea being taught is needed at the start to organise the new information. This is a vicious circle in which the student is trapped. He cannot discern what is important and what is incidental, what is the point of the lesson and what is merely supportive or peripheral in nature" (Johnstone and Wham, 1982, p. 71). The pre/post-lab test analysis of question 1 supports this

showing that student 1 failed to learn how to calculate the theoretical percentage by mass and the percentage purity of the AFS as a result of this learning experiment.

There appear to be three possible reasons why the student was not sufficiently familiar with form of the data or the calculations prior to the experiment.
(1) The student did not prepare a report sheet properly because, even though students were given *examples* of how to prepare report sheets in the ordinary lab sessions, they were not specifically told how to do it or what the features of a good or bad report sheet are. This also means that they were probably *rote* learning the *skill* of preparing report sheets and that only for the specific experiments conducted in the ordinary lab sessions. Meaningful learning of this skill will not occur because students are not told *how* to go about it or *why* particular ways of doing it are better.
(2) The student was aware that the form of her report sheet was *not* going to be directly assessed and thus didn't bother to do it properly.
(3) The student didn't prepare an adequate report sheet because she lacked an understanding of the concepts required to do so. The student spent a lot of her time in the laboratory learning what were for her new concepts, when in fact it may have been assumed by the designer of the experiment and the lab manual that she would have known these concepts prior to her entry into the laboratory. (The fact that no explanation for how to perform the calculation points to this assumption). Thus, there appeared to be a gap between the expectation of the designer of the experiment and the reality of the student's understanding - the designer of the experiment may have expected the students to know more than they actually did.

Further light is shed on this gap when one considers the following interchange with the demonstrator.

137		... and then obviously I always like
138		to show the calculation because I never used to show it
139		to them before and I discovered that 99% of the people
140		don't actually know how to do the calculations or
141		understand what is required.
142	RESEARCHER:	Okay. Okay. So you did that on the board beforehand?
143	DEMONSTRATOR 1:	Yes. Because otherwise they don't know how to do it.
144	RESEARCHER:	Okay.
145	DEMONSTRATOR 1:	Which is a problem

(Post-lab interview with the demonstrator, lines 137-145)

If the student was aware of this, she may have deemed it unnecessary to familiarise herself with the required calculations required because she knew that they would simply be given to her. The demonstrator's observation that when she didn't explain the calculations to the students 99 % of them didn't understand what to do, shows, however, that even before she started doing this, the students were not preparing adequately.

It appears, therefore, from the arguments put forward above that the student was not aware of what she was supposed to gain from both of the tasks in the pre-lab preparation and that as a result of this, she did not do it properly. (The fact that she didn't make sure that she was doing it properly is very likely due to the fact that it was not assessed - see section 5.2.3.). As a result of her inadequate preparation, the student spent much time in the laboratory learning concepts and parts of the procedure that should have been learned during the pre-lab preparation. She, thus, learned less than she could have from her activities in the laboratory.

6.3.2. Recommendations

The following recommendations are made in view of the discussions above;

(1) Stimulate students to do the pre-lab preparation properly by actively assessing it. This will ensure that students will make more of an effort to understand what is required of them. They will thus be more likely to learn what is intended from pre-lab preparation tasks.

(2) There are ways of familiarising the students with the procedure and the underlying theory of a practical session other than making them summarise its scientific aims (which are usually given in the title of the experiment anyway). If it is desired that students learn new theory or revise theory that should have been learned before they enter the laboratory, then specific conceptual questions (with references to the relevant learning goals and/or pages in the course textbook) should be set.

Steyn et al (1999) suggest an interactive multimedia computer program making use of text, graphics and video images be developed to support the laboratory experience. This tool may be extremely useful at a pre-lab preparation level for a number of reasons;

- it provides "the opportunity for frequent repetition and reinforcement" (p. 126).
- learners are actively involved in constructing their own knowledge because "hyperlinks that call for proactive inquiry can be used" (p. 126).
- marking done by computer is less expensive and less time consuming than paying demonstrators to mark students' work.
- feedback can be immediate.

- it also can be used as a means to reduce the number of students who simply copy other's pre-lab work. This may be done by designing 5-6 equivalent but not identical questions for each laboratory session. The computer will then decide at random which student will receive which question. Thus students who normally work together (the one copying the other) will in all probability find that they have different questions to answer.

An interactive multimedia computer program also ensures that students' pre-lab work will be marked *prior* to their entry into the laboratory. By stipulating that anyone who hasn't achieved more than 90 % may not be allowed into the laboratory, students may be more motivated to ensure that they understand the pre-lab questions before they do the experiment - this may also help to close the gap between the designer of the experiment's expectations of the students' understanding and the reality of the situation. This is because students will be required to have gained a certain amount of understanding if they wish to do the experiment.

In order to ensure that the students read through the procedure, pre-lab questions could be asked about information contained therein. Caution should be exercised, however, that these questions do not cover links that will be gained *during* the lab session. They should, therefore, only require the student to repeat information directly included in the procedure of the lab manual. This does not mean that they will need to have *learned* everything in the procedure before the lab session, but rather it ensures that they have at least read through everything contained therein prior to their commencement of it. Questions for this purpose could include things like, "What chemical is used to test for Cl^- ions in the fresh filtrate ?" and "how long must the filter paper be ashed ?" and "which two ions display red colour upon the addition of ammonium thiocyanate and ortho-phenanthroline ?".

Alternatively, students can be forced to read through the procedure by giving a summary of it. This task, however, apart from being more difficult to assess by means of a computer program, can only be done adequately once the student is sufficiently familiar with all the skills and underlying concepts to be used *in* the lab session. Students who do not understand certain parts of the procedure, or are unfamiliar with the techniques and skills to be used *during* the lab session will not be able to *summarise* what they are going to do. More than likely they will give in detail (copied from the lab manual) a list of things in sequence that they are supposed to do in the laboratory. This is because they will not be sufficiently knowledgeable to be able to determine what is merely detail and what is important.

(3) In the case of quantitative lab sessions, as is the case for experiment A6, specific pre-lab calculation exercises would do the job of familiarising students with the data transformations just as well (if not better) than the task of preparing a report sheet that is just waiting for the data.

There is one problem with the task of preparing a report sheet that warrants attention. Although it is possible for learning to occur by means of this activity, if a student does it incorrectly (this may be for various reasons), (s)he will have to rewrite it all out again *during* the lab session. This makes for a waste of time and a mess. As a result, students who are unsure of what to do will be less willing to write up a report sheet that is just waiting for the data. Not only that, but students will not know whether they have done the task correctly prior to their entry into the laboratory. Preparation by means of computer programs will enable students to be sure that they have completed their pre-lab preparation correctly prior to the lab session and that they fully understand all the necessary concepts.

The task of preparing a report sheet prior to the lab session also poses a problem when it comes to marking pre-lab reports. Students may write up a report sheet prior to the lab session, but may decide that they want to change some part or all of it to better suit the data collected. If pre-lab preparation is only marked *after* the lab session (which appeared to be the case for experiments A1 & A2), it will be impossible to assess the initial pre-lab preparation.

On top of that, since students were not specifically taught how to prepare a report sheet, or what features of a report sheet that is 'just waiting for data' are desirable, they probably won't learn them. If the preparation of a report sheet is considered to be an aspect of scientific inquiry, it could be rote and then meaningfully learned by specifically teaching it to the students[79]. The skill of preparing a report sheet could, therefore, be left to the guided or open inquiry where it can be specifically taught and students can learn why it is necessary and how to do it properly.

For these reasons, it is suggested that students simply be shown how to report the data in the lab manual and be required to *copy it out* prior to their entry into the laboratory. This will sufficiently familiarise them with the form of the data to be collected as well as the data transformations that will occur and it will also help to ensure that they always come to laboratory sessions with an adequately prepared report sheet. In addition to this, assessed pre-lab questions would go some way to help ensure that students are sufficiently familiar with the necessary theory.

---

[79] Admittedly a great deal of time need not be spent on instructing students with regard to this skill. Nevertheless, it should not be automatically assumed that all students will be able to perform it competently without being specifically instructed.

(4) Rather than requiring that students summarise the scientific aims of an experiment (which may or may not appear in the title of an experiment), they should specifically be listed. Like the *learning* aims (section 5.2.4), the researcher suggests with Johnstone and Wham (1982), that the *scientific* aim(s) of an experiment be interspersed in the text as well, rather than simply being listed at the beginning or end of an experiment (see figure 18). Doing this is a means to reduce the 'noise' of the experiment and it makes the scientific aim(s) of an experiment clearer to the student.

"Suppress the 'noise' ... not so much by a list of objectives at the beginning, but more as a function of the layout." (Johnstone and Wham, 1982, p. 72)

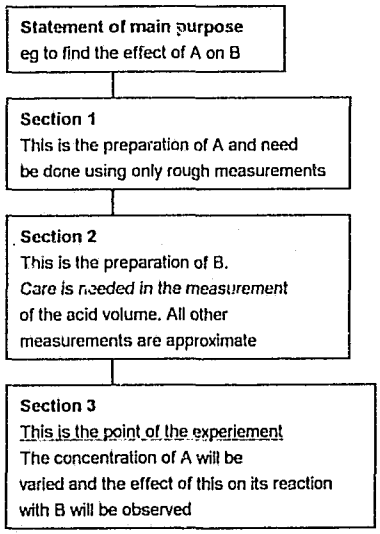


Figure 18: Possible arrangement of instructions in a manual

Students should be aware at all times of what they are doing, why they are doing it, and what they are supposed to be learning[80].

(5) It is recommended that the *demonstrator* be made aware of what is required of the students by way of pre-lab preparation. In doing this, (s)he could deal appropriately with those who have not prepared adequately rather than simply giving the whole class the solution.

---

[80]This means that two sets of aims should be included in the text of an experimental procedure; (1) the scientific aims, and (2) the learning aims (ie. what the student is expected to learn through it).

6.4. Conclusion

In this chapter, three factors that affect the learning that occurs in chemistry practical work were identified and discussed. These were (1) the *type* of lab activity, (2) the *context* of the lab activity and (3) the pre-lab preparation. The first two factors were different to those identified in the previous chapter in that they did not arise from the data, but from a critical appraisal of the current literature about practical work in science education. Recommendations were then put forward to the WITS chemistry department about how to facilitate more meaningful learning in the undergraduate chemistry lab sessions.

When categorising the different types of lab activities, it was found that the traditional classification system was insufficient and an additional type of lab activity, named a 'procedural' lab session was identified. The next chapter summarises the findings of this research, outlines its strengths and limitations as well as avenues for possible research that have arisen as a result of this work.

Chapter 7

Conclusions

7.1. Introduction

This final chapter, summarises the answers to the research questions posed in chapter 1 and outlines some strengths and limitations of the research. It also gives possible avenues for further research.

7.2. Answers to the research questions

7.2.1. Answers to the first Research Question

- What factors have 'typically' been affecting learning in the WITS chemistry undergraduate laboratory sessions ?

By analysing information gained from the pre- and post-lab tests, the description of the student's activities in the laboratory, the pre- and post-lab interviews, as well as interviews with the demonstrator and lecturer #2 (the lecturer who designed the mark scheme for the demonstrators and was in charge of the first year lab sessions), it was found that the following factors affected the learning that occurred;

(1) The role of the demonstrator as perceived by the demonstrator
(2) The assessment of the student
(3) The amount of time available to the student to conduct the experiment
(4) The *learning* aims of the experiment as perceived by the student
(5) The *type* of laboratory activity
(6) The *context* of the laboratory activity
(7) The pre-laboratory preparation affected meaningful learning

7.2.2. Answers to the second and third Research Questions

- How have these factors 'typically' been affecting the learning that takes place in the WITS chemistry undergraduate laboratory sessions ?
- How can we manipulate these factors to facilitate more meaningful learning in the WITS chemistry undergraduate laboratory sessions ?

The answers to these two research questions were closely related. The answers to the first question came from a detailed analysis of the pre- and post-lab tests and interviews, the description of the student's activities in the laboratory as well as the interviews with the demonstrator and lecturer #2. The answers to the second question were put forward in the form of recommendations made to the chemistry department in view of the answers to the first question.

7.2.2.1. The role of the demonstrator as perceived by the demonstrator

- Interpretations:

It was found that the demonstrator was not specifically told what her role in this laboratory session was, neither was she made aware of the learning aims for the experiment. As a result of this, she made her own decisions about (1) how much assistance to give to the students, as well as (2) what and what not to tell them. Consequently, for certain parts of the experiment the students were simply *given* solutions (rather than being presented with 'clues') and it is questionable whether they would have learned to apply the information gained to other similar settings as the designer of the lab session may have intended.

- Recommendations:

(a) The learning aims of a practical session should be made clear to the demonstrator in order for him/her to make better judgements about how to present information to students during the time in the laboratory.
(b) Recommended teaching strategies should be supplied to the demonstrators. This will enable them to make *informed* decisions about how to facilitate meaningful learning and the realise the aims of an experiment.
(c) Demonstrators should, nevertheless, have the freedom to alter the recommended teaching strategy if it is inappropriate to a particular group or setting.

7.2.2.2. The assessment of the student

- Interpretations:

This student made sure that she spent time reflecting on everything that was to be assessed. When she was pressed for time, she did not bother to reflect on parts of the experiment that would not be assessed. Since what she did not spend time reflecting on she did not learn, she probably would have learned more if more had been assessed.

- Recommendations:

It was, therefore, recommended that the content validity of the laboratory sessions be increased by assessing as many of the learning aims as possible. A method for assessing the manipulative skills of *all* the students was also put forward. It was also recommended that the students be made aware of *everything* that is to be assessed.

7.2.2.3. The amount of time available to the student to conduct the experiment

- Interpretations:

As a result of a scarcity of time, the student simply left out some parts of the experiment that she deemed to be unimportant. She, thus, did not spend as much time reflecting on these parts and, therefore, did not learn as much as she could have through the experiment if more time had been available.

- Recommendations:

A sufficient amount of time to finish the lab activities should be made available to the students. In this way, students will not be tempted to leave out parts that they think are unimportant or won't be assessed.

7.2.2.4. The learning aims of the experiment as perceived by the student

- Interpretations:

The student did not make an effort to learn the parts of the experiment that she perceived she was not expected to learn.

- Recommendations:

Students should be made aware of what they are expected to learn as a result of a lab session by making these learning aims clear and interspersing them in-between the text (or procedure) in the lab manual. By doing so Aboderin and Thomas (1996) noted how students test scores improved considerably.

7.2.2.5. The type and 7.2.2.6. context of laboratory the activity

What made these two factors different from the others, was that they arose after critical reflection on the current literature on learning in the laboratory rather than directly from the data. Support for the arguments put forward, however, was found in the data collected.

- Interpretations:

The *type* of laboratory activity: A student cannot learn inquiry skills when (s)he is not actively required to use (or reflect on) them during the lab session. Thus, traditional 'verification' type laboratory sessions cannot facilitate the learning of scientific inquiry skills - since much of the inquiry is performed for the student by the teacher. Thus, for students to learn inquiry skills, they must engage in laboratory sessions where the activity is of a *guided* or *open* inquiry type. In this case, the data showed that the student did not learn certain inquiry skills.

The *context* of the laboratory activity: In order to learn a *skill* in a meaningful way, a context needs to be provided that will enable the student to understand *why* (s)he is doing what (s)he is doing. Rote learning of a *skill* will occur when a student simply learns it without learning *why* it is being employed. As was pointed out above, guided or open inquiry activities in the laboratory are the *only* way that students will be able to learn science *inquiry* skills (verification lab sessions don't provide a context for these skills to be learned meaningfully).

Guided and open inquiry lab sessions, nonetheless, do not *necessarily* facilitate the rote or meaningful learning of inquiry skills. The reason for this is that students must specifically be told *how* to go about 'doing' science if they are to *rote* learn scientific inquiry skills (they cannot be expected in a few hours to re-invent a process that took centuries to develop). If meaningful learning of this skill is desired, (1) students should be told *how* to go about inquiry *and* (2) the context of the lab activity should include some history and philosophy of science for them to make 'links' between the method of inquiry and *the reasons* for it being employed.

The verification lab session does, however, have some use.
(1) It is a way to facilitate the meaningful (and rote) learning of certain motor skills and techniques specific to the chemistry laboratory.
(2) It can also be used to facilitate the meaningful learning of science *concepts*. While students are learning motor skills and techniques, they could simultaneously be reflecting on (and learning meaningfully) any underlying chemistry concepts that are relevant to the activity. This second use, however, is not specific to learning in the laboratory and could be achieved through lectures and/or tutorial sessions which, in many cases, are cheaper, and less time consuming. It was argued, nevertheless, that lab activities may be more effective than lectures and demonstrations because they force students to engage in an activity and thus are more likely to form 'episodes' (White, 1996) in a student's mind (see section 6.2.5.1).

A type of lab session which, although similar to the verification lab session in many respects, does not verify any concepts to students in the laboratory, was identified. It was decided to call it a 'procedural' lab session because students merely follow a procedure (they may also be given some underlying theory explaining the procedure followed). It was also argued that, while

verification lab sessions are a means to making science concepts appear *plausible* to students, the procedural lab session is a means to showing students the *fruitfulness* of science concepts. It was also shown that the arguments pertaining to the meaningful and rote learning of scientific inquiry skills in a verification lab session must hold true for procedural lab sessions as well.

The data from this research shows that the student did learn certain manipulative skills and techniques as well as certain chemistry concepts (eg. percentage by mass) as a result of experiment A6 (which may be classified as a procedural lab session).

- Recommendations:

The following teaching strategy was suggested as an alternative to what is presently the situation in the WITS chemistry department;
First, by means of procedural and verification lab sessions, students could rote learn as many manipulative skills and techniques as necessary. They could then, while still engaging in procedural as well as verification lab sessions, proceed to learn these same manipulative skills and techniques *meaningfully*. At the same time meaningful learning of any underlying *concepts* relevant to the activity should also be facilitated. Once students have learned a sufficient number of manipulative skills, procedures and concepts meaningfully, they then should be introduced to science *inquiry* skills by means of a guided discovery (this, however, need only occur at a post-graduate or third year level). Once science inquiry skills have been *rote* learned (see section 6.2.7 for various teaching strategies) students could be presented with guided inquiry lab sessions where a context of the history and philosophy of science is provided. This will enable students to learn inquiry skills meaningfully. Once students are sufficiently aware of the issues surrounding the scientific method they can be left to do open inquiry lab activities (which would normally occur as PhD or post-doctoral work).

7.2.2.7. Pre-laboratory preparation

- Interpretations:

According to the instructions in the lab manual, there were two important tasks for the student to do by way of pre-lab preparation;
(1) to summarise the aims of the experiment and
(2) to prepare the results section so that the data could simply be filled into it.

The research data collected showed that the student was not aware of what she was supposed to gain from both of the tasks in the pre-lab preparation and that as a result of this, she did not do it properly. (The fact that she didn't make sure that she was doing it properly is very likely due to the fact that it was not assessed - see section 5.2.3.). As a result of her inadequate

preparation, the student spent much time in the laboratory learning concepts that should have been learned during the pre-lab preparation. The 'noise' (Johnstone and Wham, 1982) of the experiment was, thus, increased and she learned less than was intended from her activities in the laboratory.

There appear to be a number of possible reasons why the student did not prepare adequately for the lab session.
(1) The student did not prepare a report sheet properly because, even though students were given *examples* of how to prepare report sheets in the ordinary lab sessions, they were not specifically told how to do it or what the features of a good or bad report sheet are.
(2) The students were aware that the *form* of their report sheet was *not* going to be directly assessed and thus didn't bother to do it properly.
(3) The student didn't prepare an adequate report sheet because she lacked an understanding of the concepts required to do so. The student spent a lot of her time in the laboratory learning what were for her new concepts, when in fact it may have been assumed by the designer of the experiment and the lab manual that she would have known these concepts prior to her entry into the laboratory.
(4) The demonstrator revealed that she did not expect the students to understand the theory or the calculations prior to their entry into the laboratory. She had, thus, made it usual practice to explain all theory to the students in her pre-lab talk. The student, therefore, may have deemed it unnecessary to take steps to ensure that she understood everything prior to her entry into the laboratory.
(5) The student may not have been aware of the purpose of the pre-lab preparation.

- Recommendations

(1) Stimulate the students to do the pre-lab preparation by assessing it adequately (see section 6.3.2.). Assessing pre-lab preparation will also help to ensure that students (i) determine exactly what is required of them and (ii) take steps to do it acceptably.

(2) If it is desired that students learn new theory or revise theory that should have been learned before they enter the laboratory, then specific conceptual questions (with references to the relevant learning goals and/or pages in the course textbook) should be set. Steyn et al (1999) suggest an interactive multimedia computer program making use of text, graphics and video images be developed to support the laboratory experience. This tool can be extremely useful at a pre-lab preparation level (see section 6.3.2. for its advantages).

(3) In the case of quantitative lab sessions, as is the case for experiment A6, specific pre-lab calculation exercises would do the job of familiarising students with the data transformations

just as well (if not better) than the task of preparing a report sheet that is just waiting for the data. A number of problems with regard to the preparation of a report sheet were also identified, (see section 6.3.2). Students could also be shown in the lab manual how to transform the data to be collected and be required to *copy it out* prior to their entry into the laboratory.

(4) The purpose of the task of summarising the scientific aims was to ensure that students had an overall idea of the underlying theory and procedure before they entered the laboratory. Nevertheless, even if the student had done this task correctly, it could have been done without understanding any of the underlying theory or procedure. This is because the aim of the experiment was simply stated in its title. For a procedural lab session such as this one, it is recommended that the scientific aim(s) of the experiment specifically be given and explained to the students. This should be done by interspersing them in the text of the manual (rather than simply listing them at the beginning or end of an experiment - see section 6.3.2) because it helps to reduce the 'noise' of the experiment (Johnstone & Wham, 1982). Specific pre-lab calculations exercises or reading tasks could be given to students to familiarise them with the underlying theory and procedure.

(5) The *demonstrator* should be made aware of what is required of the students by way of pre-lab preparation. In doing this, (s)he could deal appropriately with those who have not prepared adequately rather than simply giving the whole class the solution.

7.3. Strengths and Limitations of the research

7.3.1. Strengths

The strength of this research lies in the validity of its results. Quantitative research, when used to investigate factors that affect learning, presupposes a relationship between a *predetermined* factor and its consequences for the post-lab test results of the control and experimental groups. This means, therefore, that if not *all* extraneous factors are controlled, the results of the research will be invalid. This research, however, made no attempt to *control* any of the factors that affected the learning, and thus no relationship between the student's responses and her meanings was *presupposed*[81]. The analysis of the student's answers to the pre- and post-lab tests are based on (1) the students own explanations of her meanings where they are given, (2) the description of the lab session, (3) the student's submitted lab report and (4) the pre- and

[81] Obviously the researcher was expecting to find certain factors before the lab session (otherwise how could decisions have been made about which observations to record in the field notes and which to leave out). Nevertheless, the student's responses in the post-lab test were not *automatically* explained *without* referring back to the all other data sources in order to validate the explanation.

post-lab interviews. This ensured a greater degree of validity in the explanations given for the students actions.

Also, since most of the information mentioned above is provided in this report, other researchers can make up their own minds about the extent to which this researcher's interpretations accurately portray the student's actual meanings.

7.3.2. Limitations

Firstly the extent to which the presence of the researcher caused the student's actions in the laboratory to be different from what they normally are, was not conclusively determined. Another researcher with different qualities (eg. someone perhaps much older, more domineering, of another sex etc.) may have caused the student (and all other parties involved) to display different behaviours in the same setting. A few times in the description, the researcher noted actions that seemed to indicate the effect of his presence, but these instances were only those that the researcher deemed sufficiently atypical to make a note of. The extent to which he was familiar with (1) the setting and (2) the student would have determined his ability to notice these instances. Having been a demonstrator to the first year chemistry majors two years prior to 1999, abnormalities in the *setting* would easily have been noticed. Limitations occurring because of the presence of an observer, therefore, resulted from the researcher's unfamiliarity with the student, who was a complete stranger to him.

One other limitation of this research involves the generalisablity of the results. Since this research was only based on the study of *one* student during *one* lab session, it is unlikely to be representative of the entire population. Nevertheless, the researcher did go to great lengths to (1) ensure the selection of a sufficiently 'typical' student and lab session, as well as (2) provide a 'thick' description of the context of the results for the reader to make reasoned judgements about the extent to which they stand as a 'working hypothesis' in other settings[82]. These two precautions mean that the results may still be applicable to parties in other settings - despite the uniqueness of the sample.

The degree to which results may be regarded as a working hypothesis in other settings could have been enhanced, however, if the researcher had chosen to study two or three 'typical' cases. In this way he could have checked whether his hypotheses about (1) *what* factors affected the

---

[82]Even with these precautions, the concept of a 'typical' South African university student is problematic considering the diversity of backgrounds of the population of our country. Nevertheless, the provision of a 'thick' description, allows the reader to make a reasoned judgement about the extent to which the findings from this student would be applicable to students in his/her own particular setting.

student and (2) *how* they affected her in this lab session, rang true in other in other cases. Hypotheses that didn't stand up to this sort of falsification could then have been adapted to fit all the cases studied. The more cases studied, the more credibility the hypotheses put forward would have held. With no opportunity to falsify the hypotheses put forward, the generalisablity of the results is limited to a certain extent.

7.4. Possible avenues for further research

The second limitation mentioned above, is not inherent in the methodological approach of the research. The findings of this research, therefore, could be extended by looking at more undergraduate students in different settings. One could begin by looking at students engaged in other chem (1) major additional labs and then proceed to other undergraduate courses (eg. CHEM 200, organic chemistry) in order to determine the extent to which the findings from this research hold in these settings. The greater the number of lab sessions investigated, the greater our knowledge and understanding of the factors that affect meaningful learning in the undergraduate laboratories at WITS will be. As the number of cases studied expands to other universities and even other countries, the closer the education community would come to a universal theoretical model for learning in the laboratory.

Also, since the data confirmed the hypotheses put forward in section 5.2 about how the *context* and the *type* of lab activity affects learning, it would be interesting to investigate them further. As was noted in section 5.2.6, there is reason to believe that WITS chemistry honours students are *rote* learning scientific inquiry skills. It would be interesting to determine the extent to which this assertion is true. It would also be interesting to study, in a manner similar to this research, what factors are affecting the typical postgraduate student at WITS as they learn how to 'do' science (ie. science inquiry skills).

An additional prospect for further research that was brought to light (section 6.2.8) was to identify scientific *manipulative skills and techniques* that are commonly learned incorrectly by undergraduate students. This research, however, could not be conducted in the way that research to identify misconceptions in scientific *concepts* is usually carried out. The reason for this is because any research that involves the measurement of *practical skills* in the laboratory means that the researcher will face the methodological challenge of valid measurement vs. generalisability (see section 1.4.5.).

Another avenue for further research would be to implement the recommendations put forward here and then conduct research, of the same lab session as was investigated here, in years to

come. How the recommendations put forward had affected the factors that affected meaningful learning identified in this study could then be determined.

One further avenue of possible research relates to recent work by White (1996). Based on his paper 'The link between laboratory and learning', it was argued that the extent to which laboratory work is more *memorable* and *outstanding* than lectures, tutorials and demonstrations, is the extent to which it is better able to cause meaningful learning to occur (section 6.2.5.1.). It may be useful to explore what sorts of experiments are the most effective in actively engaging students as they conduct lab work and how the formation of 'episodes' (White, op. cit.) may be optimised.

7.5. Conclusion

In an extensive review of the literature on laboratory work, Hofstein (1991) summed up his findings by stating;

> "It is true that research has failed to show simplistic relationships between experiences in the laboratory and student learning in science" (p. 212).

This research, instead of presupposing a relationship between a predetermined factor and its effects on student learning, has described the learning experience in the laboratory. In doing so, the researcher was able to identify and gain insight into the factors that affected meaningful learning in the laboratory as the student actually experienced them.

Many of the factors identified in this way indicated an urgent need to clearly articulate the *learning* aims of individual laboratory sessions as well as laboratory courses as a whole. This is because decisions about how best to facilitate meaningful learning in the laboratory, depend to a large extent on *what* science educators wish their students to learn meaningfully. Simply 'doing' practical work will not necessarily cause students to realise every aim put forward. Explicit attention needs to be paid to the *context* and the *type* of practical work that the students engage in, as well as;

(1) the role of the demonstrator as perceived by the demonstrator.
(2) the method of assessment.
(3) the amount of time available to the student to conduct the experiment.
(4) the *learning* aims of the experiment as perceived by the student.
(5) the pre-laboratory preparation exercises.

Some have proposed that the learning aims of laboratory activity should be to "expose the student to critical thinking, planning, analyses and synthesis and should develop a sense of the integrity of the data" (Lagowski, 1990) rather than simply the "illustration of it's [science's] principles, ... the mastery of finger skills, and ... the invention of new procedures" (Pickering, 1985).

Clearly there are different opinions as to *why* practical work in science education should be carried out. But whatever our aims are, how best to facilitate them is the more important challenge. The researcher is of the opinion that both the general learning aims for laboratory work mentioned above should be accommodated. It would be naive, however, to propose that they both should be realised *at the same time* or *in any sequence*. This research has not so much disputed *why* practical work should be conducted in undergraduate chemistry courses, but rather how best to facilitate the realisation of the *different* aims that most science educators earnestly desire to see.

References

Aboderin, O. A. & Thomas, M., (1996). An Evaluation of the Influence of Behavioural Objectives on Nigerian Students' Cognitive Achievement in Biology. *Research in Science & Technological Education* 14 (2) 193-204

Anderson, G. J. (1976). *The Experience of Science: A New Perspective for Laboratory Teaching*. Teachers College Press: New York, Columbia University

Atkin, M. (1968). Behavioural objectives in curriculum design : a cautionary note. *The Science Teacher*. 35 (5) 27-30.

Ausubel, D. P. (1963). *The Psychology of Meaningful Verbal learning*. New York : Grune and Straton

Ausubel, D. P. (1968). *Educational Psychology : A Cognitive View*. New York : Holt, Rinehart and Winston

Barnes, L. W. (1967). The development of a student checklist to determine laboratory practices in high school biology. In Lee, A. E. (Ed.) *Research and Curriculum Development in Science Education* Vol. 1. Austin, TX, University of Texas.

Bates, G.R. (1978). The role of the laboratory in secondary school science programs. In Rowe, M.B. (Ed). *What research says to the science teacher*. Chpt. 1, p. 55-82

Ben-Zvi, R, Eylon, B, Silberstein, J, (1988). Theories, principles and laws. *Education in Chemistry*. 25:89-92

Bertrand, A. & Cebula, J. P. (1980). *Tests, Measurement and Evaluation : A Developmental Approach*. Philippines : Addison-Wesley Publishing Company Inc.

Bradley, J.D., & Gerrans, G., C., & Long, G.C., (1990). Views of some secondary school science teachers and student teachers about chemical equilibrium. *South African Journal of Education*. 10:3-12

Cervellati, R, Montushci, A, Perugini, D, Grimellini-Tomasini, N, & Balandi, B. (1982). Investigation of secondary school students' understanding of the mole concept in Italy. *Journal of Chemical Education*. 59 : 852-6

Chalmers, A. F. (1982). *What is this Thing called Science* (2nd edition). Hackett Publishing Company : Indianapolis, Cambridge

Chen, H. H. (1980). *Relevance of Gowin's Structure of Knowledge and Ausubel's Learning Theory to Methods for Improving Physics Laboratory Instruction.* Master's Thesis, Cornell University. In Novak, J. D. & Gowin, D. B. (1984). *Learning how to Learn.* Cambridge : Cambridge University Press

Cohen, I. (1987). Various Strategies for the Teaching of the Topics Chemical Energy and Chemical Equilibrium : Development, Implementation and Evaluation. *Unpublished, PhD dissertation.* Rehovot : The Weizmann Institute of Science.

Eggleston, J. F. et. al. (1976). *The Process and Product of Science Teaching.* London : Macmillan Education.

Farrell, J.J., Moog, R.S. & Spencer, J.N. (1999). A guided inquiry general chemistry course. *Journal of Chemical Education.* 76 (4) 570-4

Fensham, P. J., Gunstone, R. F. & White, R. T. (1994). Part 1. Science content and constructivist view of learning and teaching. In Fensham, P. J., Gunstone, R. F. & White, R. T. (Eds) *The Context of Science, a Constructivist Approach to its Teaching and Learning.* London: The Falmer Press

Frith, D.S. & Macintosh H. G. (1984). *A Teacher's Guide to Assessment.* Cheltenham : Stanley Thornes (Publishers) Ltd.

Ganiel, U. & Hofstein, A. (1982). Objective and continuous assessment of student performance in the physics laboratory. *Science Education* 66 (4) 581-91

Gott, R. & Duggan, S. (1996). Practical work : It's role in the understanding of evidence in science education. *International Journal of Science Education* 18 (7) 791-806

Grobman, H. (1970). *Developmental Curriculum Projects : Decision, Points and Process.* Itasca, IL : Peacock Publishers

Gronlund, N.E. (1976), *Measurement and evaluation in teaching.* (3rd edition), MacMillan Publishing Company : Canada

Gunstone, R. F. (1994). The importance of specific science content in the enhancement of metacognition. In Fensham, P. J., Gunstone, R. F. & White, R. T. (Eds) *The Context of Science, a Constructivist Approach to its Teaching and Learning*. London: The Falmer Press

Guskey T. R. (1994). What you assess may not be what you get. *Educational Leadership* 51 (6) 51-54.

Hackling, M.W. & Garnett, P.J. (1985). Misconceptions of chemical equilibrium. *European Journal of Science Education*. 7:205-214

Haladyna, T. M., Nolen S. B. & Haas N. S. (1991). Raising standardised achievement test scores and the origins of test score pollution. *Educational Researcher* 20 (5) 2-7

Halliday, D. & Resnick R. (1988). *Fundamentals of Physics*. (3rd edtion) John Wiley and Sons : New York

Hammersley, M. & Atkinson, P. (1983). *Ethnography: Principles in Practice*. Tavistock Publications : New York

Herron, M. D. (1971). The nature of scientific enquiry. *School Review* 79 : 171-212

Hodson, D. (1982). Is there a scientific method ? *Education in Chemistry* 7 : 112-116

Hofstein, A. & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Review of Educational Research*. 52 (2) 201-217

Hofstein, A. (1991). Practical work in science education II. In Fensham, P. (Ed) (1991). *Development and Dilemmas in Science Education* London: Falmer Press. p. 189-217.

Hudson, B. (Contributing Ed.) (1973). *Assessment techniques: An introduction*. Butler and Tanner Ltd. : Great Britain, p. 18.

Johnstone, A. H. (1993). Why is science difficult ? Things are not always what they seem. In Edwards, D., Scanlan, E. & West, D. (1993). *Teaching, Learning and Assessment in Science Education*. London : Paul Chapman.

Johnstone, A. H. (1997). Chemistry teaching - Science or Alchemy ? *Journal of Chemical Education* 74 (3) 262-268

Johnstone, A. H. & Letton, K. M. (1988). Is practical work practicable ? *Journal of College Science Teaching* 18 (3) 190-192.

Johnstone, A. H. & Wham, A. J. B. (1982). The demands of practical work. *Education in Chemistry* 19 (3) 71-73.

Kahn, M. (1990). Paradigm lost: The importance of practical work in school science from a developing country perspective. *Studies in Science Education* 18:127-136

Klainin, S. (1991). Practical Work in Science Education I. In Fensham, P. (Ed) (1991). *Development and Dilemmas in Science Education* London : Falmer Press, p. 169-188.

Knamiller, G. W. & O-saki, K. M. (1995). Tanzanian teachers' understanding of the science embedded in traditional technologies : A study to inform teacher education. *Research in Science and Technological Education.* 13 (1) 77-88

Lagowski, J.J. (1990). Editorial. *Journal of Chemical Education.* 67(3). In Beasley, W. (1991) Matching laboratory learning goals to evaluation of student performance. *Journal of Chemical Education.* 68 (7) 590-591.

Lunetta, V. N. & Hofstein, A. (1980). The science lab : a new look at goals and practice. *Unpublished manuscript* Iowa City, University of Iowa. In Fensham, P. (Ed) (1991) *Development and Dilemmas in Science Education* London: Falmer Press, p. 207

Lunetta, V. N. & Tamir, P. (1979). Matching lab activities with teaching goals. *The Science Teacher* 46:22-24

Matthews, M. R. (1994). *Science Teaching : The Role of the History and Philosophy of Science*. London : Routledge

Maxwell, J. A. (1992). Understanding and validity in qualitative research. *Harvard Educational Review* 62 (3) 279-300.

McComas, W. F. (1997). The laboratory environment : An ecological perspective *Science Education International* 8 (2) 12-16

Miller, S. M. (1952). The participant observer and 'over-rapport'. *American Sociological Review*. 17 : 97-9

Miller, G. A. (1956). The magical number seven, plus or minus two : Some limits on our capacity for processing information. *Psychological Review* 63 : 81-97

Novak, J. D. (1984). Application of advances in learning theory and philosophy of science to the improvement of chemistry teaching. *Journal of Chemical Education* 61 (7) 607-612

Novak, J. D. & Gowin, D. B. (1984). *Learning how to Learn.* Cambridge : Cambridge University Press

Okebukola, P. A. (1986). Cooperative learning and students' attitude to laboratory work. *School Science and Mathematics* 86 (7) 582-590

Olsen, T. P., Hewson, P. W. & Lyons, L. (1996). Preordained science and student autonomy : the nature of laboratory tasks in physics classrooms. *International Journal of Science Education* 18 (7) 755-790

Palladino, G. F. & Figgens C. E. (1983). Preparing for laboratory work. *Education in Chemistry*. November : 212-213

Parlett, M., & Hamilton, D., (1972). *Evaluation as illumination: a new approach to the study of innovatory programmes.* Occasional Paper 9, Centre for Research. In The Educational Sciences, University of Edinburgh. In Hamilton, D., Jenkins, D., King, C., MacDonald, B., & Parlett, M., (Ed) (1977) *Beyond the numbers game: a reader in educational evaluation.* London, New York, Johannesburg, Dublin, Melbourne & Delhi: MacMillan Education Ltd.

Parsons, N., Sage, D. & Vokins, M. (1991). The assessment of practical skills for GCSE. *School Science Review* 73 (263) 105.

Pavelich, M. J. & Abraham R. M. (1979). An inquiry format laboratory program for general chemistry. *Journal of Chemical Education* 56 (2) 100-103

Pella, M. O. (1961). The laboratory and science teaching. *The Science Teacher* 28 : 20-31

Piaget, J. (1926). *The Language and Thought of the Child* (translated by Marjorie and Ruth Gabain). London : Routledge and Kegan Paul

Piaget, J. (1929). *The Child's Conception of the World* (translated by Joan and Andrew Tomlinson). London : Kegan Paul, Trench, Taubner & Company

Pickering, M. (1985). Lab is a puzzle, not an illustration. *Journal of Chemical Education*. 62 (10) 874-875

Pickering, M. (1992). High school laboratory without lab manuals. *Journal of Chemical Education* 69 (2) 150

Posner, G. J. & Gertzog, W. A. (1982). The clinical interview and the measurement of conceptual change. *Science Education* 66 (2) 195-209

Posner, G., Strike, K., Hewson, P. & Gertzog, W. (1982). Accomodation of a scientific conception : Towards a theory of conceptual change. *Science Education*. 66 (2) 211-227

Ramsey, G.A. & Howe, R.W. (1969). An analysis of research in instructional procedure in secondary school science: Part II. *The Science Teacher* 36 (4) 72-81

Rollnick, M., Zwane, S., Staskun, M., Lotz, S. & Green, G. (1998). Finding a connection between pre-lab preparation, successful laboratory experiences and writing of reports. *Unpublished* University of the Witwatersrand, Chemistry Department

Romey, W. D. (1968). *Inquiry Techniques for teaching Science*, Englewood Cliffs, NJ, Prentice Hall in Fensham, P. (Ed) (1991) *Development and Dilemmas in Science Education* London : Falmer Press, p. 191.

Roth, W. (1998). Starting small with uncertainty: toward a neurocomputational account of knowing and learning in school science laboratories. *International Journal of Science Education*. 20 (9) 1089-1105

Roychoudhury, A. & Roth, A., (1996). Interactions in an open-inquiry physics laboratory. *International Journal of Science Education* 18 (4) 423-445

Schofield, J. W., (1993). Increasing the generalisablity of qualitative research. In Hammersley, M., (Ed.) (1993). *Educational Research: Current Issues* Paul Chapman Publishing Ltd: London

Shephard L. A. (1989). Why we need better assessments. *Educational Leadership* 46 (7) 4-9.

Shephard L. A. (1990). Inflated test score gains : Is the problem old norms or teaching to the test ? *Educational Measurement: Issues and Practice* 6 (3) 33-42.

Shymanski, J.A., Penick, J. E., Kelsey, L. J. & Foster, G. W. (1976). *Science Laboratory Interaction Category (SLIC) - teacher*. Iowa City : University of Iowa

Steyn, M. M. de V, du Toit, C.J. & Lachmann, G. (1999) The implementation of a multimedia program for first year university chemistry practicals. *South African Journal of Chemistry* 52 (4) 120 - 126

Tamir, P. (1972). The practical mode : A distinct mode of performance. *Journal of Biological Education* 6:175-182

Turner, G. (1983). The hidden curriculum of examinations. In Hammersley, M. & Hargreaves, A. (Eds) (1983) *Curriculum Practice : Some Sociological Case Studies*. The Falmer Press : Sussex

Wolcott H., F., (1988). Ethnographic research in education. In Jager, R. M (Ed) *Complementary Methods for Research in Education*. Washington, DC : American Educational Association, p. 187-206

White, R. T. (1996). The link between the laboratory and learning. *International Journal of Science Education* 18:761-773

APPENDIX A

Survey of two typical students

Student questionnaire General information
Chemistry (I) major

- Name [redacted]
- Student no. [redacted]
- What school did you go to ?
  Potchefstroom Girls High
- How old are you ?
  19
- Is this your first year out of school ? Yes (No)
- If no what did you do before you came to WITS ?
  Sport overseas
- Is this the first tertiary institution you have ever gone to ? (Yes) No
- If yes, which university/college/other was it ?
- Is this your first year of chemistry at university ? (Yes) No
- Have you ever done any additional lab courses ? Yes (No)
- What is your first language ?
  English
- Have you ever done any special courses when comes to lab work ? (Please specify)
  No
- Have you done any special work that involved lab work ? (Please specify)
  No
- Did you win any science prizes at school or else where ? (Please specify)
  No

Student questionnaire General information

Chemistry (I) major



- Name [redacted]
- Student no. [redacted]
- What school did you go to ?
  DAVID MAMA HIGH SCHOOL
- How old are you ?
  17 years
- Is this your first year out of school ? ~~Yes~~ No
- If no what did you do before you came to WITS ?
  .....
- Is this the first tertiary institution you have ever gone to ? ~~Yes~~ No
- If yes, which university/college/other was it ?
  .....
- Is this your first year of chemistry at university ? ~~Yes~~ No
- Have you ever done any additional lab courses ? Yes ~~No~~
- What is your first language ?
  XHOSA
- Have you ever done any special courses when comes to lab work ? (Please specify)
  NO
- Have you done any special work that involved lab work ? (Please specify)
  FACILITATING DURING THE YEAR OF SCIENCE AN TECHNOLOGY EXHIBITION
- Did you win any science prizes at school or else where ? (Please specify)
  FACILITATION CERTIFICATE

APPENDIX B

(1) Pre- and Post-lab tests

(2) The Chemistry Department's learning aims for experiment A6

Pre-lab test.

COMPREHENSION TEST

1) A chemist took an amount of ammonium ferrous sulphate (MW = 392.17 g/mol) and dissolved it in water. She then added $BaCl_2$ (MW = 208.2 g/mol) to the solution and collected all the barium sulphate (MW = 233.37 g/mol) precipitate that formed ($BaSO_4$).

$$BaCl_2 + SO_4^{2-} \rightarrow BaSO_4\downarrow + 2Cl^-$$

(a) calculate what she found to be the percentage by mass of sulphate in ammonium ferrous sulphate by using the following information;

Mass of ammonium ferrous sulphate = 0.3000 g
Mass of $BaSO_4$ obtained = 0.1002 g

100 g → Mass obtain [1] = 1 mol SO_4^{2-} [2]

[6] Mass origi = 1 mol $BaSO_4$ [3]

$\frac{0,1002}{0,3}$ [4]

= 33,4 % [5]

= 33,4 g of 100 g Sulphate
[7] [8]

(b) Using your answer to (a) calculate the percentage purity of ammonium ferrous sulphate.

M = 392,17 [9]

m = 0,3 [10]

(c) The reaction of barium chloride and sulphate ions mentioned above is specifically chosen in this experiment because it is a reaction that goes to completion. Why is this fact so important if we want to get accurate results ?

(d) The chemist mentioned above wanted to make sure that she got ***all*** the sulphate in the solution to react with the $BaCl_2$ that she added. What steps could she have taken to ensure this.

5) Our chemist tested two small portions of the final dry product by placing them in a test tube each and adding a few rops of ammonium thiocyanate (1%) solution to one and ortho-phenanthroline (1%) to the other. In both cases the mple turned red.

(a) What does this mean ?

The product has acidic prop [11]

(b) What does this tell you about her answers to 1 (a) and (b) above ?

) Before she decanted the liquid, she added agar-agar solution drop wise to the mixture over ten minutes.

(a) What does the word "decant" mean ?

(b) Why did she add agar-agar solution ?

4
(6) After she had transferred all the precipitate to the funnel, she wanted to make sure that it was pure.

(a) Why did she want to make sure that it was pure ? What impurities might have occured in this case?



(b) How would her results have been affected if ~~she~~ the impurities mentioned above were present ?

(c) If there were impurities there, how could she remove them ?

Filtration [12]

extraction [13]

(d) How could she test that they were all gone ?

)

There is one final twist in the story! Before she could weigh the final dry precipitate that she collected in the filter paper, he got rid of the filter paper ensuring that not one grain of the sulphate was lost in the process.

(a) Pick out the equipment that she could have used to do this (naming each piece as you do).

(b) Demonstrate (using the equipment you have picked out) how you would go about doing this, giving reasons why you would do what you are demonstrating and explaining what would be happening to the chemicals as the experiment proceeded. Also emphasise any precautions that you would make to ensure that you got the exact amount of precipitate when you had finished.

Vhat does the phrase "gravimetric analysis" mean ?

SKILLS TEST

1a) Accurately weigh out about 0.3 g of ammonium ferrous sulphate into the beaker provided (report your results in the space provided below)

Beaker = 81,84 g

Beaker + ammonium ferrous sulphate =

81,84
+ 0,3
82,14 g

1b) How confident were you that you knew what you were doing while you were carrying out the above task ? (circle ne option that best describes you)

a. very confident
b) quite confident
c. not so confident
d. not confident at all

2a) Get as much of the solid into this piece of filter paper as you can !

:b) How confident were you that you knew what you were doing while you were carrying out the above this task ?
ircle the option that best describes you)

. very confident
. quite confident
) not so confident
. not confident at all

3a) Wash the precipitate that you have collected with warm water and test the filtrate with a few drops of silver nitrate olution (report what you observe). Continue washing until fresh filtrate no longer show any signs of forming a precipitate.

After the silve nitrate was added there was no change in the colour but the solid precipitate has collected at the bottom of the flask.

3b) How confident were you that you knew what you were doing while you were carrying out the above this task ? circle the option that best describes you)

a. very confident
b. quite confident
c. not so confident
d. not confident at all

4) What sorts of preparations would you suggest our chemist make before she came into the lab ?

Post-lab test

COMPREHENSION TEST

(1) A chemist took an amount of ammonium ferrous sulphate (MW = 392.17 g/mol) and dissolved it in water. She th added $BaCl_2$ (MW = 208.2 g/mol) to the solution and collected all the barium sulphate (MW = 233.37 g/mol) precipitate that formed ($BaSO_4$).

$$BaCl_2 + SO_4^{2-} \rightarrow BaSO_4\downarrow + 2Cl^-$$

(a) calculate what she found to be the percentage by mass of sulphate in ammonium ferrous sulphate by using t following information;

Mass of ammonium ferrous sulphate = 0.3000 g
Mass of $BaSO_4$ obtained = 0.1002 g

1 mol $BaSO_4$ → 1 mol SO_4^{2} [1]
1 mol - 233,37 g/mol [2] → 1 mol SO_4 [3] (32,07)(16×4) 96,07 [6]
∴ 0,001 43 mol [4] → 0,0013 mol SO_4 [5]
begin to write 0 + then changed it to a 3?
0,00043 [7] $n = \frac{m}{M}$ [8]
$m = nM$ [9]
= 0,00043 · 96,07
= 0,0412 g [11]

$\frac{0,0412}{0,3}$ [12]
= 14 % [13]

(b) Using your answer to (a) calculate the percentage purity of ammonium ferrous sulphate.

1 mol A·F·S → 392,17 [14] ⟹ 2 mol SO_4s [15]
0,00153 [16]
[21] $\frac{\text{observed}}{\text{expected}} = \frac{14\%}{14,7}$ [22] = 95,2 % [23] $n = \frac{m}{M}$ [17]
purity $m = nM$ [18]
= 0,147 [19]
= 14,7 % [20]

(c) The reaction of barium chloride and sulphate ions mentioned above is specifically chosen in this experiment because it is a reaction that goes to completion. Why is this fact so important if we want to get accurate results ?

(d) The chemist mentioned above wanted to make sure that she got ***all*** the sulphate in the solution to react wit the $BaCl_2$ that she added. What steps could she have taken to ensure this.

2

(3) Our chemist tested two small portions of the final dry product by placing them in a test tube each and adding a fe drops of ammonium thiocyanate (1%) solution to one and ortho-phenanthroline (1%) to the other. In both cases the sample turned red.

(a) What does this mean ?

(b) What does this tell you about her answers to 1 (a) and (b) above ?

5

(5) Before she decanted the liquid, she added agar-agar solution drop wise to the mixture over ten minutes.

(a) What does the word "decant" mean ?

(b) Why did she add agar-agar solution ?

(6) After she had transferred all the precipitate to the funnel, she wanted to make sure that it was pure.



(a) Why did she want to make sure that it was pure ? What impurities might have occured in this case?

(b) How would her results have been affected if ~~she~~ the impurities mentioned above were present ?

(c) If there were impurities there, how could she remove them ?

(d) How could she test that they were all gone ?

(5)

There was one final twist in the story! Before she could weigh the final dry precipitate that she collected in the filter paper she got rid of the filter paper ensuring that not one grain of the sulphate was lost in the process.

(a) Pick out the equipment that she could have used to do this (naming each piece as you do).

(b) Demonstrate (using the equipment you have picked out) how you would go about doing this, giving reasc why you would do what you are demonstrating and explaining what would be happening to the chemicals as experiment proceeded. Also emphasise any precautions that you would make to ensure that you got the exact amount of precipitate when you had finished.

What does the phrase "gravimetric analysis" mean ?

SKILLS TEST

(1a) Accurately weigh out about 0.3 g of ammonium ferrous sulphate. (report your results in the space provided belc

filter paper = 0,729
filter paper + a.F.S = 1,039

∴ a.m.s = 1,03 - 0,72
= 0,31g

(1b) How confident were you that you knew what you were doing while you were carrying out the above task ? (circ the option that best describes you)

A. very confident
B. quite confident
C. not so confident
D. not confident at all

(2a) Get as much of the solid into this piece of filter paper as you can !

2b) How confident were you that you knew what you were doing while you were carrying out the above this task ? circle the option that best describes you)

A. very confident
B. quite confident
C. not so confident
D. not confident at all



(3a) Wash the precipitate that you have collected with warm water and test the filtrate with a few drops of silver nitrate solution (report what you observe). Continue washing until fresh filtrate no longer show any signs of forming a precipitate.

3b) How confident were you that you knew what you were doing while you were carrying out the above this task ? circle the option that best describes you)

A. very confident
B. quite confident
C. not so confident
D. not confident at all

4) What sorts of preparations would you suggest our chemist make before she came into the lab ?

(2) Learning aims of the chemistry department for lab session A6

No clear learning aims were outlined anywhere for this particular lab session. Thus, in order to determine what the chemistry department wanted the students to learn as a result of experiment A6, an interview was held with the lecturer who was in charge of the lab course (lecturer #2)[83]. This interview was rather a lengthy one, and it has not been included here to conserve space[84]. A summary of the aims set forth in the interview by lecturer #2 is included here, however. Lecturer #2 was given a copy of the lab manual for A6 (appendix D) and asked to reveal to the researcher what she would like the students to learn through their experience the lab session.

2.3.3.1.Concepts

Lecturer #2 wanted the students to learn that;

- one has to choose a reaction that goes to completion to get this experiment to work otherwise one will not get all the sulphate out of solution (lines 41-49).
- the instruction to "accurately weigh out about 2-3 g of ammonium ferrous sulphate" means that the students should;
  (1) add sample to a sample bottle on a rough balance until it is around 0.30 g and they don't have to waste time getting it to 0.3000 g but it must be close to 0.3 g and (2) then weigh it on an accurate balance to get the exact amount (lines 68-106).
- an excess of $BaCl_2$ is added to ensure that we get all the sulphate ions out (lines 133-135).
- they are trying to get the exact amount of sulphate in the solution (ie ***all*** of it). (lines 134-135, 182-189, 190-192).
- the meaning of the word "coagulate" (lines 177-178).
- the purpose of the agar-agar solution in this experiment. (line 180).
- why they need all the sulphate so that they can get an accurate answer and determine the true percentage by mass of sulphate in AFS (lines 190-197).
- the more sulphates one squanders the further ones answer is from the true value (lines 190-192).
- gravimetric analysis is by weight (lines 199-200).
- the more they leave in the beaker, the more inaccurate the answer will be (lines 207-208).

---

[83]The lecturer interviewed did not design the laboratory session, which was in place before she took over these laboratory sessions. Nevertheless she had taken it upon herself to make up a guideline marking scheme (see appendix) for the demonstrators (previously there had been no mark scheme to guide the demonstrators' marking of the lab reports). By doing this, she *must have* consciously (or unconsciously) reappraised the aims of the lab session by deciding what to assess and how many marks to assign to it.

[84]Copies of it may be obtained from the author.

- you wash the precipitate with water in order to get rid of all the Cl^- ions and excess barium chloride so that the precipitate will only consist of barium sulphate (lines 216-218, 235-236).
- if Cl^- ions are still in there then the weight of barium sulphate will appear to be higher than what it really is (line 238).
- silver nitrate + $Cl^- \rightarrow$ cloudy solution (ie. a precipitate) (lines 243-245).
- if the solution stays clear after the addition of silver nitrate, then they have washed all the chloride ions out and the precipitate is pure (lines 247-249).
- a gravimetric analysis is a kind of quantitative chemical analysis involving weighing as the sole method of measurement (lines 269).
- they use the crucible to dry the filter paper by heating the crucible to get rid of the water and then dry the precipitate and then burn off the paper (lines 314-315, 323).
- the above procedure is to get clean, pure, dried barium sulphate (lines 322).
- there is a connection between carbonisation, ashless filter paper and all the paper is going to disappear as carbon dioxide and water (lines 324-326)
- the crucible is reheated and reweighed to improve the accuracy and precision of the results - not simply to practice the technique (lines 341-343).
- this is a quantitative experiment (line 375).
- the purpose for the ashless filter paper is to burn it away and get accurate results. (line 384).
- what is occurring in the crucible is as follows;
  (1) water is being driven off (line 389).
  (2) and then the filter paper (line 390).
  (3) pure barium sulphate is left (line 390).
- ferrous ions = Fe^{2+} (line 401).
- ferric ions = Fe^{3+} (line 401).
- the ferrous ions come from the AFS, while the ferric ions come from the Fe^{2+} ions that have undergone aerial oxidation (line 401).
- how to calculate the percentage by mass of sulphate in AFS from the experimental results and the calculation for the percentage purity from this (lines 420-423).
- one needs to consider whether or not one takes the waters of hydration in the formula of AFS into account when you are calculating the percentage purity in this particular case. (lines 432-444).

- the Fe impurities affect the percentage by mass of SO_4 ions by increasing the weight recorded for the sulphate. This in turn makes the sample appear to be less pure than what it really is[85] (lines 446-461).
- there is a difference between the actual and theoretical mass and what this difference is, and how it can be applied to give us the percentage by mass and the percentage purity in this experiment (lines 585-579).
- a higher/lower percentage mass than expected => high amount contamination (lines 573-576).
- in doing gravimetric analyses they should appreciate that they have to have all the product and nothing else, and that is why they test for impurities.

2.3.3.2. Skills

Lecturer #1 wanted the students to learn the following skills or techniques;

- heating the crucible (line 278).
- washing the precipitate (line 280).
- getting all the precipitate out of the beaker with a rubber 'bung'[86] (lines 279, 281).
- washing the precipitate all around the top and not allowing the water level to come too near the top. This ensures that you don't lose any barium sulphate onto the glass filter funnel (lines 282-283).
- work well to get ***all*** the precipitate out of the beaker into the filter paper when filtering (ie. use a wash bottle to get as much precipitate out before using a policeman) (lines 479-480).
- testing the filtrate for chloride ions with silver nitrate. (lines 500-501).
- ensuring that the weight of barium sulphate is accurate by reheating and reweighing the crucible (lines 508-515).
- testing the residue in the crucible for iron ions (lines 517-525).
- reporting their observations from the testing of the residue in the most comprehensive way possible. Eg.;

  Fe^{2+} + ammonium thiocyanate => observation

  Fe^{3+} + ortho phenanthroline => observation (lines 540-552).
- make a conclusion for the practical on the basis of the results (lines 560-579).
- attention given to significant figures (line 616).

---

[85]This is incorrect the presence of iron ions actually decreases the recorded weight of the barium sulphate because Fe^{2+} ions can replace barium ions in the crystal lattice. Since iron has a lower molar mass than barium, the sample will be lighter that it would have been had no iron impurities been present. The sample, therefore, appears to be less pure than what it really is. Nevertheless, it is definitely one of the chemistry department's learning aims for the experiment because lecturer #2 specifically included it in the assessment of the lab report.

[86]This word was actually used by the lecturer. (She is most likely referring to a glass rod with a small length of rubber tubing on the end.

- attention given to units (line 618).
- write ordered, organised lab reports so that it is intelligible to the reader (line 629).
- write in ink when they hand in a report (line 630-631).
- write their results straight onto the report sheet not on "tacky" bits of paper (eg. a spare piece of filter paper) (lines 639-648).
- students should come to the lab prepared with a research book and places for masses, observations or calculations with the aim of filling them in during the lab. They should therefore ensure that they have an idea of how much space they should leave for each calculation (lines 655-670).
- the students make *tables* for themselves to fill in results during the lab (lines 677-683).
- care in not breaking delicate equipment (eg. crucible and lid) (lines 688-701).
- the students should clean up their apparatus (lines 721-738).
- students should learn to manage their time in the lab efficiently (ie. time management skills) (lines 739-749). They should;

  (1) arrive on time (line 743).

  (2) get started immediately (line 744).

2.3.3.3. Attitudes

- students should see the value in the labs (line 812).
- students should want to get an accurate answer (ie. accuracy is good) (lines 205-206).

APPENDIX C

(1) A copy of experiment A6 from the lab manual
(2) A copy of the lab manual's instructions for pre-lab preparation

INTRODUCTION

READ THIS BEFORE ARRIVING FOR THE FIRST LABORATORY SESSION

In the first semester you will undertake extended investigations into two substances: an organic compound, aspirin, and an inorganic compound, ammonium ferrous sulphate. The general outline of the investigations are as follows:

1. Synthesis This is the procedure whereby a substance is made from simpler starting materials.

2. Purification Since it is virtually inevitable that a new substance which is synthesised from starting materials will be contaminated by the starting materials and/or products of (unwanted) side reactions, purification procedures are designed to obtain an optimum purity of the desired product.

3. Qualitative investigations Various chemical and physical tests are conducted on the substance to verify that it is indeed the substance one set out to make.

4. Quantitative investigations The central question to be answered here is "How pure is the substance made"?

These investigations closely parallel the work of research chemists, as you will come to appreciate as you pursue a study of Chemistry through University.

LABORATORY RULES

Safety and behaviour rules as outlined in the Lab Manual for the Ordinary Lab Course are applicable.

PRE–LAB REPORTS

In contrast to the ordinary lab course, you will be required to prepare a pre–lab report BEFORE you arrive in the laboratory. You demonstrator will mark this, and only when he/she is satisfied with your pre–lab report will you be allowed to

commence with the experiment. Should you fail to produce one, you will be asked to leave the laboratory, and will be marked absent for that session. Obviously, you will obtain zero marks for that session.

RECALL THAT YOU ARE OBLIGED TO ATTEND AND COMPLETE SATISFACTORILY 80% OF ALL ADD. LAB. SESSIONS OTHERWISE YOU MAY BE REFUSED A D.P. CERTIFICATE AND HENCE WILL BE DISQUALIFIED FROM SITTING THE FINAL EXAMINATION IN THIS COURSE.

PREPARE A PRE–LAB REPORT

The Pre–Lab Report consists of:

a) A cover sheet, fully completed. It is particularly important to record your Group Number, and your Locker Number

b) The main body of the report.

c) A blue backing sheet.

The main body of the report is to be written on ruled A4 paper and consists of:

1. Experiment Number

2. Heading (Experiment name).

3. INTRODUCTION in which you summarise briefly the aim(s) of the experiment, perhaps mentioning the technique(s) which will be used.

4. PROCEDURE. It is not necessary to write out the entire procedure in the experiment. You need only refer to the page numbers in the lab manual. It is advisable to leave sufficient space to write any changes to the procedure given that might have become necessary during the course of the experiment.

5. RESULTS. This is the most important section of the pre–lab report. You must provide space, usually in table form, for recording all results you obtain in the lab. Hence, when actually doing the experiment, you need only fill in the blank spaces you have created for yourself in the pre–lab report.

4. Record the measured conductance of the equivolume mixture of 0,002M ferrous sulphate and 0,002M ammonium sulphate and of the 0,001M ammonium ferrous sulphate solution. Compare and interpret the results.

EXPERIMENT A6

DETERMINATION OF THE PERCENTAGE BY MASS OF SULPHATE IN THE SAMPLE OF AMMONIUM FERROUS SULPHATE BY GRAVIMETRIC ANALYSIS

The form and purity of precipitate obtained when mixing reactants is strongly influenced by the conditions employed. In a gravimetric analysis where a precipitate is to be quantitatively collected in high purity, the proper choice of conditions is vital. In this experiment the sulphate in the sample of ammonium ferrous sulphate is precipiteated as barium sulphate, the essential reaction involved being:

$$Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4(\downarrow)$$

Under the specified conditions a pure precipitate, which is quite readily filtered, is obtained.

Procedure

Accurately weigh out about 0.3 g of the sample of ammonium ferrous sulphate and transfer to a 400 ml beaker. Dissolve the solid in distilled water, add $HC\ell$ (0,5 ml, 11 M concentration) and dilute the mixture with distilled water (200 ml). Heat the solution just to boiling and then add dropwise using a clear dropper, warm barium chloride solution (10 ml, 5%). Stir constantly during the addition.

Remove the beaker from the heat and allow the precipitate to settle for a minute or two. Add a few drops more of the barium chloride solution and see whether or not any more precipitate forms. If it does, add a further 3 ml barium chloride solution dropwise, and test again. Repeat the operation until a small excess of barium chloride is indicated.

Treat the hot mixture with agar–agar solution (10 ml) to help coagulate the precipitate. This solution should be added dropwise over a period of some minutes. Allow the mixture to stand for 10 to 15 minutes.

Now collect the precipitate using the special ashless filter paper provided, taking great care to ensure <u>all</u> the precipitate is collected. First decant most of the liquid

through the filter, retaining the precipitate in the beaker; then wash the precipitate into the bottom of the filter cone using hot distilled water (your plastic squeeze-bottle may be heated up in a beaker of boiling water).

Dislodge any fragments of precipitate that adhere to the beaker with the aid of a glass rod having a short length of rubber tubing on the end (sometimes called "a policeman"). Use further quantities of hot distilled water to wash the filter paper and precipitate: wash from all around the top and never allow the water level in the filter paper cone to come near the top. Continue washing until a few drops of fresh filtrate no longer show any sign of forming a precipitate when tested with a drop or two of silver nitrate solution (the test is for Cl^- originating with the $BaCl_2$ solution).

In the meantime prepare your porcelain crucible and lid by first thoroughly cleaning them and then heating them to red heat for 15 – 20 minutes whilst supported in a pipeclay triangle. Use the crucible tongs to place the crucible and lid in a desiccator and when cool, take them out and weigh them accurately together.

Now fold the moist filter paper cone around the precipitate and place it, point down, into the crucible. Place the crucible, inclined, in the pipeclay triangle and partially cover the crucible with the lid: the lid should then be resting partly on the crucible and partly on the triangle. Place the Bunsen burner with a very small but not smokey, yellow flame under the crucible and lid. When steam no longer escapes, the crucible contents will be dry and the flame may be increased slightly so as to slowly carbonise the paper. Do not allow the paper to inflame or else fine particles of precipitate may be scattered out. (If it should inflame temporarily put the lid on, using the crucible tongs.) When carbonisation is complete and vapours no longer are evolved (about 20 min) gradually increase the flame to full strength. The carbon will slowly burn away (about 45 minutes). When ignition is complete stop heating, and after 1 or 2 minutes transfer the crucible and lid to the desiccator to cool. Accurately weigh the crucible, lid and contents. Re-heat for 15 minutes, cool and re-weigh. Repeat the cycle until successive weighings differ by less than 5 mg.

Finally, test the residue in the crucible for the presence of ferrous and ferric ions. For this purpose scrape a little of the residue into each of two clean test tubes.

Ensure the sample taken is finely-powdered. To one portion add a few drops of ammonium thiocyanate solution (1%) [a red colour indicates Fe(III)] and to the other portion add a few drops of ortho-phenanthroline solution (0,1%) [a red colour indicates Fe(II)]. Allow the mixture to stand for a few minutes and report what you observe.

Report

1. Record masses observed.

2. From the mass of $BaSO_4$ obtained deduce the mass of sulphate present in the original mass of ammonium ferrous sulphate sample. Hence deduce the percentage by mass of sulphate in the sample. Compare the observed result with that expected for ammonium ferrous sulphate and express the comparison as a percentage purity.

3. One of the problems that arises if unsuitable conditions of precipitation are used is that foreign cations and/or anions may be incorporated in the precipitate. In the case of precipitating the sulphate in ammonium ferrous sulphate, the iron may be incorporated in the barium sulphate precipitate. The iron may be present in the expected ferrous (iron(II)) state or, due to aerial oxidation, in the ferric (iron(III)) state. What did your qualitative tests indicate about the presence of iron in your $BaSO_4$? What kind of error will arise in a percentage sulphate result if ferrous and/or ferric iron is present in the $BaSO_4$ precipitate? Will it give too high or too low a figure? Explain your conclusion.

For example:

Table 2

Titration of M NaOH with M HCl.

	Titration 1	Titration 2	Average
Initial burette reading /ml			–
Final burette reading /ml			–
Titre /ml			–
Average titre	–	–	

6. DISCUSSION AND CONCLUSION. Leave space to discuss the implications of your results once you have performed the experiment.

7. QUESTIONS If required, leave space to answer the questions posed at the end of the experiment in the lab manual.

The report may be completed at home, but must be handed in by 1:30 pm on the FRIDAY following the Monday lab session. If Friday is a public holiday, then the due date is the THURSDAY. Reports should be posted in the pigeon holes marked "MONDAY AFTERNOON" outside the Wilkinson Lab on the ground floor of the Chemistry building.

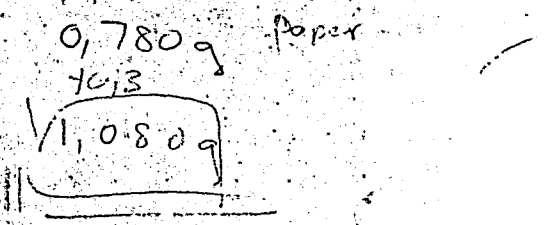
TIME MANAGEMENT

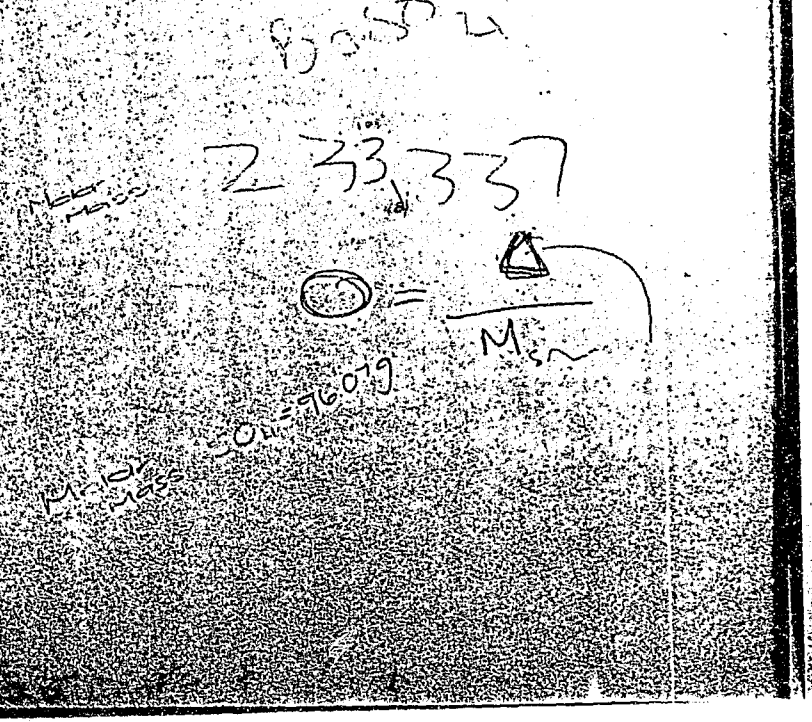
The amount of work to be done in the $2^1/_2$ hours allocated for each laboratory session makes it imperative that you organise your time properly. Don't expect your demonstrator to do this for you. Hence you should never be sitting around watching something come to the boil, or waiting for a product to crystallise. While this is going on, you should be doing another part of the experiment. The laboratory will be locked promptly at the end of the session and if you have not completed all the work, this will be to your disadvantage in that you will obviously obtain lower marks for your efforts.

APPENDIX D

(1) A copy of the student's writings in her lab manual during the lab
(2) A copy of the student's marked lab report for the experiment

4. Record the measured conductance of the equivolume mixture of 0,002M ferrous sulphate and 0,002M ammonium sulphate and of the 0,001M ammonium ferrous sulphate solution. Compare and interpret the results.





EXPERIMENT A6
DETERMINATION OF THE PERCENTAGE BY MASS OF SULPHATE IN THE SAMPLE OF AMMONIUM FERROUS SULPHATE BY GRAVIMETRIC ANALYSIS

The form and purity of precipitate obtained when mixing reactants is strongly influenced by the conditions employed. In a gravimetric analysis where a precipitate is to be quantitatively collected in high purity, the proper choice of conditions is vital. In this experiment the sulphate in the sample of ammonium ferrous sulphate is precipiteated as barium sulphate, the essential reaction involved being:

$$Ba^{2+} + SO_4^{2-} \longrightarrow BaSO_4(1)$$

Under the specified conditions a pure precipitate, which is quite readily filtered, is obtained.

Procedure

Accurately weigh out about 0.3 g of the sample of ammonium ferrous sulphate and transfer to a 400 ml beaker. Dissolve the solid in distilled water, add HCℓ (0,5 ml, 11 M concentration) and dilute the mixture with distilled water (200 ml). Heat the solution just to boiling and then add dropwise using a clean dropper, warm barium chloride solution (10 ml, 5%). Stir constantly during the addition.

Remove the beaker from the heat and allow the precipitate to settle for a minute or two. Add a few drops more of the barium chloride solution and see whether or not any more precipitate forms. If it does, add a further 3 ml barium chloride solution dropwise, and test again. Repeat the operation until a small excess of barium chloride is indicated.

Treat the hot mixture with agar–agar solution (10 ml) to help coagulate the precipitate. This solution should be added dropwise over a period of some minutes. Allow the mixture to stand for 10 to 15 minutes.

Now collect the precipitate using the special ashless filter paper provided, taking great care to ensure all the precipitate is collected. First decant most of the liquid

through the filter, retaining the precipitate in the beaker; then wash the precipitate into the bottom of the filter cone using hot distilled water (your plastic squeeze–bottle may be heated up in a beaker of boiling water).

Dislodge any fragments of precipitate that adhere to the beaker with the aid of a glass rod having a short length of rubber tubing on the end (sometimes called "a policeman"). Use further quantities of hot distilled water to wash the filter paper and precipitate: wash from all around the top and never allow the water level in the filter paper cone to come near the top. Continue washing until a few drops of fresh filtrate no longer show any sign of forming a precipitate when tested with a drop or two of silver nitrate solution (the test is for Cl^- originating with the $BaCl_2$ solution).

In the meantime prepare your porcelain crucible and lid by first thoroughly cleaning them and then heating them to red heat for 15 – 20 minutes whilst supported in a pipeclay triangle. Use the crucible tongs to place the crucible and lid in a desiccator and when cool, take them out and weigh them accurately together.

Fold the moist filter paper cone around the precipitate and place it, point down, into the crucible. Place the crucible, inclined, in the pipeclay triangle and partly cover the crucible with the lid: the lid should then be resting partly on the crucible and partly on the triangle. Place the Bunsen burner with a very small but hot, yellow flame under the crucible and lid. When steam no longer escapes, the crucible contents will be dry and the flame may be increased slightly so as to slowly carbonise the paper. Do not allow the paper to inflame or else fine particles of precipitate may be scattered out. (If it should inflame temporarily put the lid on, using the crucible tongs.) When carbonisation is complete and vapours no longer are evolved (about 20 min) gradually increase the flame to full strength. The carbon will slowly burn away (about 45 minutes). When ignition is complete stop heating, and after 1 or 2 minutes transfer the crucible and lid to the desiccator to cool. Accurately weigh the crucible, lid and contents. Re–heat for 15 minutes, cool and re–weigh. Repeat the cycle until successive weighings differ by less than 5 mg.

Finally, test the residue in the crucible for the presence of ferrous and ferric ions. For this purpose scrape a little of the residue into each of two clean test tubes.

Ensure the sample taken is finely–powdered. To one portion add a few drops of ammonium thiocyanate solution (1%) [a red colour indicates Fe(III)] and to the other portion add a few drops of ortho–phenanthroline solution (0,1%) [a red colour indicates Fe(II)]. Allow the mixture to stand for a few minutes and report what you observe.

$n = \frac{m}{M}$

Report

1. Record masses observed.

2. From the mass of $BaSO_4$ obtained deduce the mass of sulphate present in the original mass of ammonium ferrous sulphate sample. Hence deduce the percentage by mass of sulphate in the sample. Compare the observed result with that expected for ammonium ferrous sulphate and express the comparison as a percentage purity.

3. One of the problems that arises if unsuitable conditions of precipitation are used is that foreign cations and/or anions may be incorporated in the precipitate. In the case of precipitating the sulphate in ammonium ferrous sulphate, the iron may be incorporated in the barium sulphate precipitate. The iron may be present in the expected ferrous (iron(II)) state or, due to aerial oxidation, in the ferric (iron(III)) state. What did your qualitative tests indicate about the presence of iron in your $BaSO_4$? What kind of error will arise in a percentage sulphate result if ferrous and/or ferric iron is present in the $BaSO_4$ precipitate? Will it give too high or too low a figure? Explain your conclusion.

C Burnell Group A Demonst: Gill
Locker 10 9907957A

Experiment A6: Determination of the % by mass of sulphate in the sample of ammonium ferrous sulphate by gravimetric analysis

7/0

Intro:

Form & purity of precipitate obtained when mixing reactants is strongly influenced by the conditions employed.

Procedure:

- Accurately weigh out ± 0,3g of ammonium ferrous sulphate and place in 400ml beaker.
- Dissolve in distilled water, add HCl (0,5ml; 11M con & dilute mixture with distilled H_2O.
- Heat solution & add barium chloride (10ml; 5%
- Allow precipitate to cool & settle ⇒ Treat sol. with agai-agar to coagulate precip. Stand 10-15m
- Now collect precipitate using filter paper.
- Prepare porcelain crucible & lid. Place filter pap into crucible ⇒ Carbonisation occurs.
- Test residue for presence of ferrous & ferric ions etc.

Report

- Mass of filter paper = 0,780g
- Mass of filter paper + ammonium ferrous sulphate = 1,115g

∴ Mass of ammonium ferrous sulphate = 1,115g − 0,780g = 0,335g ✓ 30,1299

- Mass HCl = 0,300g
- Volume $BaSO_4$ = 10,00ml
- Mass crucible + lid = 29,724g
- Mass cruc. + lid + $BaSO_4$ = 30,100g ⇒ Mass $BaSO_4$ = 0,376g ✓

(4/6)

2. a) Mass SO_4 present:

$$n\,BaSO_4 = \frac{m}{M} = \frac{0,376\,g}{233,37\,g/mol} = 0,0016\,mol$$

$$m_{SO_4} = nM = (0,0016)(96,07) = 0,155\,g$$

$$\%\,SO_4 \text{ in sample} = \frac{\text{mass } SO_4}{\text{Mass ammonium ferrous sulphate}} \times 100 = \frac{0,155\,g}{0,335\,g} \times 100 = 0,462\% \times 100 = 46,2\%$$

Comparison:

Experimental

As we can see the expected percentage ~~purity~~ SO_4 is 49,0% and the observed percentage SO_4 is 46,2% this shows a 94,3% purity which indicates that the experiment was very accurately conducted. ⇒ Also that the ammonium ferrous sulphate contained very little impurities!

Theoretical

$$\text{expected } \%\,SO_4 = \frac{\text{theoretical } SO_4 \text{ ma}}{\text{Mass am. fer. sul}} = \frac{0,164\,g}{0,335\,g} = 48,96\% \approx 49,0$$

Calculation?

$$\%\,\text{Purity} = \frac{\text{observed}}{\text{expected}} \times 100 = \frac{46,2}{49,0} \times 100 = 94,3\% \quad \left(\frac{8}{10}\right)$$

3. a) Using both the ammonium thiocyanate sol and orthophenanthroline by adding them to the powdered $BaSO_4$ indicated no change in the colour which means that no Fe(III) or Fe(II) ions where present in ~~our~~ my solution of $BaSO_4$ precip. $\frac{4}{4}$

b) If these tests indicated a presence of $Fe^{2+/3+}$ (with a blue colour) these ions would by added to our final mass of SO_4 present after burning. This would affect the overall experimental % of SO_4 present in sample and ultimately will affect

176; cont:
the overall percentage purity (How?)

c) If the mass is then heavier the percentage of ~~%a~~ ~~ions~~ SO_4^{2+} ions in sample would be much larger, than the actual mass of sulphate and this too large value will affect the overall percentage purity of the observed mass (in %) over expected mass (in %) (2/2)
This value would be incorrect, how? because you cannot obtain an over 100% percentage purity recovery and therefore it is crucial to ensu that when doing the filtration of $BaSO_4$ precip. Conclusion that the precip is continually wash until no Fe^{2+}, Fe^{3+} ions are present. (1/1)

- Also to ensure the accuracy of the experimen the crucible must be effectively heated and clea to ensure that to water isn't weighed.
- While heating the soiled filter paper in crucible the lid must be slightly off to get rid of carbon present in crucible and vapour must be able to evaporate.

All these factors effect the final mass of SO_4 ions present - How?

APPENDIX E

A copy of the model answers prepared by lecturer #2

The following interchange took place between the researcher and the demonstrator regarding the mark sheet given below;

RESEARCHER:	Okay. So you have already assessed the students and I have got the Lab Manual here if you want to look through it. ... if you could just briefly give me an outline of how you allocated the marks in the - for the lab - for this lab report.
DEMONSTRATOR 1:	We were given a marking scheme for it.
RESEARCHER:	Is it?
DEMONSTRATOR 1:	Yes.
RESEARCHER:	Oh okay, so then we don't have to go through it then -if you stuck to the ...
DEMONSTRATOR 1:	Ja, I did.
RESEARCHER:	Okay.
DEMONSTRATOR 1:	Except I changed it a little bit because they didn't have much time to do the three - so if they had done 2, I gave them 6 out of 6 - then 4 out of 6 and if they only did 1 then I gave them 4 out of 6.

DEMONSTRATOR NOTES – CHEM 117 – EXPERIMENT A6

ANALYSIS OF SULPHATE IN AMMONIUM FERROUS SULPHATE

1) Students should heat and cool the sample of $BaSO_4$ at least 3 times to get values to within 5 mg. They should have a table similar to the one below on their *Report Sheet* when they arrive at the laboratory.

After heating and cooling number:	Mass /g
1	
2	
3 etc.	

Assign 6 marks here – 2 for every weighing - if they have only 1 mass then award 2 marks! **(6 marks)**

2) **Calculations for the amount of sulphate in *ammonium ferrous sulphate*:**

Mass $(NH_4)_2Fe(SO_4)_2.6H_2O$ = 0.3000 g

Amount $(NH_4)_2Fe(SO_4)_2.6H_2O$ = 0.3000 g / 392.126 g mol^{-1} = 7.650×10^{-4} mol

Theoretical amount of sulphate = 1.530×10^{-3} mol

Mass of sulphate expected = 1.530×10^{-3} mol x 96.06 g mol^{-1} = 0.1470 g

Mass of heated and cooled $BaSO_4$ = Y

Amount of $BaSO_4$ = Y / 233.40 g mol^{-1}

= actual amount of sulphate

Actual mass of sulphate = Y x 96.06 g mol^{-1}

$$\text{Therefore, \% Purity of } (NH_4)_2Fe(SO_4)_2.6H_2O = \frac{\text{actual amount of } SO_4}{\text{theoretical amount } SO_4} \times \frac{100}{1}$$

(Can also do the calculation using the actual and theoretical masses of the sulphate)

Award 10 marks for clear layout and correct calculation of % sulphate (using either the mass or the amount of sulphate) **(10 Marks)**

If Fe^{2+} or Fe^{3+} is present in the sample, then not all the mass of the heated and dried sample is due to barium sulphate i.e. the actual mass of sulphate will be less and so the percentage purity will be less than that calculated. **(4 marks)**

3) Table for tests for Ferrous and Ferric ions

	Observations
Test for Fe^{2+} ions	
Test for Fe^{3+} ions	

Award 2 marks for each observation from each test = } **4 marks.**

Comment on results of tests: **3 marks**

4) Discussion of Results. **3 marks**

Total for the practical = 20 Convert this mark to /10

25

DEMONSTRATOR NOTES – CHEM 117 – EXPERIMENT A6

ANALYSIS OF SULPHATE IN AMMONIUM FERROUS SULPHATE

1) Students should heat and cool the sample of $BaSO_4$ at least 3 times to get values to within 5 mg. They should have a table similar to the one below on their Report Sheet when they arrive at the laboratory.

After heating and cooling number:	Mass /g
1	
2	
3 etc.	

Assign 6 marks here – 2 for every weighing - if they have only 1 mass then award 2 marks! **(6 marks)**

2) **Calculations for the amount of sulphate in ammonium ferrous sulphate:**

Mass $(NH_4)_2Fe(SO_4)_2.6H_2O$ = 0.3000 g

Amount $(NH_4)_2Fe(SO_4)_2.6H_2O$ = 0.3000 g / 392.126 g mol^{-1} = 7.650×10^{-4} mol

Theoretical amount of sulphate = 1.530×10^{-3} mol

Mass of sulphate expected = 1.530×10^{-3} mol x 96.06 g mol^{-1} = 0.1470 g

Mass of heated and cooled $BaSO_4$ = Y

Amount of $BaSO_4$ = Y / 233.40 g mol^{-1}

= actual amount of sulphate

Actual mass of sulphate = Y x 96.06 g mol^{-1}

Therefore, % Purity of $(NH_4)_2Fe(SO_4)_2.6H_2O$ = $\frac{\text{actual amount of } SO_4}{\text{theoretical amount } SO_4} \times \frac{100}{1}$

(Can also do the calculation using the actual and theoretical masses of the sulphate)

Award 10 marks for clear layout and correct calculation of % sulphate (using either the mass or the amount of sulphate) **(10 Marks)**

If Fe^{2+} or Fe^{3+} is present in the sample, then not all the mass of the heated and dried sample is due to barium sulphate i.e. the actual mass of sulphate will be less and so the percentage purity will be less than that calculated. **(4 marks)**

3) Table for tests for Ferrous and Ferric ions

	Observations
Test for Fe^{2+} ions	
Test for Fe^{3+} ions	

Award 2 marks for each observation from each test = **4 marks.**

Comment on results of tests: **3 marks**

4) Discussion of Results. **3 marks**

Total for the practical = 30 Convert the mark to /10

24
25

Author Gunter C E
Name of thesis Practical Work In University Chemistry: Aims And Outcomes Gunter C E 2000

PUBLISHER:
University of the Witwatersrand, Johannesburg
©2013

LEGAL NOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed, or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page) for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.