Science and Mathematics Education Centre

DEVELOPMENT AND APPLICATION OF A DIAGNOSTIC INSTRUMENT TO EVALUATE SECONDARY STUDENTS' CONCEPTIONS OF QUALITATIVE ANALYSIS

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ABSTRACT

The primary purpose of this study was to develop a two-tier multiple choice diagnostic instrument to assess Singapore Grade 10 students' (15 to 17 years old) understanding and alternative conceptions of qualitative analysis. Additional and related purposes were to determine whether more advanced chemistry students, for example, junior college (Grade 11 and 12) students, undergraduates and graduate trainee-teachers have a better understanding of basic qualitative analysis than secondary students, and to develop appropriate teaching strategies and materials on qualitative analysis based on the findings of this study and a review of the literature on practical work.

The results from the administration of the diagnostic instrument showed that Singapore Grade 10 students had many alternative conceptions related to qualitative analysis, and these were grouped under the headings of 'Displacement', 'Redox', 'Dissolution', 'Addition of acid' and 'Heating'. The cross-age study showed that the more advanced chemistry students generally had a better understanding of basic qualitative analysis but had similar alternative conceptions as the Grade 10 students. However, the alternative conceptions identified were consistently held by only a small number of students across all contexts examined in the diagnostic instrument, suggesting that a number of students either had more than one conception for a particular concept or no conceptions at all. The results from the trial of the qualitative analysis teaching package indicated that the teaching package was feasible. Teachers involved in the trial found it structured and comprehensive, and the students who experienced the teaching package performed better on the diagnostic instrument than a comparison group.

The study recommends that better ways of conducting qualitative analysis practical work are required, and using the teaching package may be a step in this direction. The study also raises questions about the value of teaching qualitative analysis in secondary schools when important reactions involved in qualitative

analysis are omitted from the syllabus, and when there is little incentive and time in the school curriculum for learners to understand what they are doing in qualitative analysis.

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LIST OF ABBREVIATIONS

A-level	Singapore-Cambridge General Certificate of Education Advance Level
JC	Junior college
MLI	Modified Laboratory Instruction
O-level	Singapore-Cambridge General Certificate of Education Ordinary Level
PGDE	Postgraduate Diploma in Education
QADI	Qualitative Analysis Diagnostic Instrument
QATP	Qualitative Analysis Teaching Package
STS	Science-Technology-Society

NOMENCLATURE

In this thesis, the terms 'sulphur', 'sulphate' and 'sulphuric' were used instead of 'sulfur', 'sulfate' and 'sulfuric' which are prescribed by the International Union of Pure and Applied Chemistry and the Royal Society of Chemistry. This is because the terms 'sulphur', 'sulphate' and 'sulphuric' are used in the General Certificate of Education Ordinary and Advance Levels chemistry examinations in Singapore, and in all chemistry texts approved by the Ministry of Education, Singapore, for use in Singapore schools.

CHAPTER ONE

INTRODUCTION

THE PROBLEM

This study addresses the problem of how to diagnose secondary students' (14 to 17 years old) understanding and alternative conceptions of qualitative analysis using a pencil and paper test, whether more advanced chemistry students have a better understanding of basic qualitative analysis, and how to develop appropriate teaching strategies and materials on qualitative analysis based on the findings of this study and a review of the literature on practical work.

CONTEXT OF THE STUDY

In Singapore, students start their formal chemical education when they are 14 to 16 years old, in Grade 9. They will study chemistry for two years before they sit for the Singapore-Cambridge General Certificate of Education Ordinary Level (O-level) Chemistry examinations at the end of Grade 10. The chemistry examinations consist of three papers, two theory and one practical. In their two years of study, the students will be taught the basic concepts of chemistry such as the kinetic theory of matter, atomic structure, chemical bonding, stoichiometry and chemical calculations, kinetics, energetics, oxidation-reduction, electrochemistry, as well as introductory inorganic and organic chemistry. They will also acquire basic laboratory skills as they carry out simple experiments on rates of reaction and heat of reaction, as well as volumetric analysis and qualitative analysis in their laboratory sessions.

The topic, qualitative analysis, is an important component of the O-level chemistry course in Singapore. Questions on qualitative analysis can appear in both the theory and practical papers. In practical qualitative analysis, students are expected to carry out experiments on an unknown sample, either in solution or the solid form. The unknown sample can contain a single compound or a mixture of compounds. Based on their observations obtained in following the procedures given in the question paper, students have to make inferences about the nature and/or identity of unknown substances present (possible ions are given in Appendix A). Marks are awarded based on written reports that the students submit; the actual laboratory performance of the student during the practical examination is not assessed. In the theory papers, students can be given qualitative analysis data, in multiple-choice or structured questions, to interpret and upon which to make inferences.

To carry out qualitative analysis experiments successfully, students need to be proficient in handling apparatus and reagents, know how to carry out the experiments, and know what to look out for in the experiments. They also need to be able to record their observations properly and interpret their results appropriately. Thus, practical qualitative analysis involves manipulative, observational, recording and inferential skills. To understand the experiments that they carry out, the reactions that occur, and the results that they obtain, students need to understand and apply concepts from other chemistry topics such as 'Acids, Bases and Salts', 'Oxidation and Reduction', 'Reactivity of Metals' and 'Periodicity'. Consequently, students may experience cognitive overload (Johnstone & Wham, 1982) as a result of the considerable mental and physical demands of qualitative analysis practical work, making qualitative analysis a difficult topic to master.

Many chemistry teachers in Singapore feel that their students do not understand what they are doing in the qualitative analysis practical sessions. Teachers frequently complain that students adopt a recipe-approach, cannot carry out the experimental procedures properly, and do not understand the purpose of the experimental procedures. They find that students seldom think for themselves, and often resort to asking teachers for help in conducting the experiments, recording observations, and making sense of their observations. An example of students' lack of understanding of qualitative analysis can be seen in the Reports on the November 1994 and November 1997 Examinations (University of Cambridge Local Examinations Syndicate (UCLES, 1995; 1998) where the examiners stated that in procedures which involved the addition of aqueous ammonia to the unknown samples, many students wasted time testing for ammonia gas which, not surprisingly, they were unable to find.

Unfortunately, or fortunately in their case, students can score well in their qualitative analysis practical examinations with little understanding of what they are doing. Chemistry teachers want their students to learn qualitative analysis in a meaningful way, that is, to understand why they are carrying out certain procedures, and to know what reactions are involved and why certain results are obtained. However, many teachers in Singapore face a dilemma – should they teach for understanding or for results? Secondary schools are ranked in Singapore based on their Grade 10 students' performance in the O-level examinations, and this has made principals and teachers very concerned about the performance of their students. The qualitative analysis questions in the O-level examinations are quite similar year after year, so extensive drill and practice of past years' examination questions can prepare students adequately for the examinations. Subsequently, teaching by drill and practice is common in schools because it often leads to good results under the current assessment system – knowing how to answer past years' examination questions and memorising facts become more important than understanding the content. The following comment by a teacher succinctly describes the situation.

> Because of the ranking, we're really very focussed, which I find is unhealthy. We get the results but students actually learn less. It's true, we do get better results but students learn less.

Goh, Toh and Chia (1987), in their study of the effect of laboratory instruction on students' achievement in qualitative analysis, highlighted this drill and practice nature of the qualitative analysis laboratory sessions in Singapore schools. The following comment of a teacher illustrates what is usually practised in the laboratory.

> We have to effectively drill them paper after paper to get them used to certain questions and the format of the examination. So we do a lot of past years' examination questions just to gear them towards the requirements of the examination. We gear them towards writing the 'correct' observations and this will give them the marks. In fact if they follow whatever we tell them to do, they'll do well.

Chemistry teachers would ensure that their students have ample practice doing what is required in the examinations, know what results to expect from carrying out certain procedures, and learn how to write the 'standard' answers expected by the examiners. This is an example of Woolnough's (1991) assertion that the assessment procedure affects the way practical work is carried out.

Until recently, students were allowed to bring into the examination laboratories, any reference material they wanted, and the examination paper also came with a data sheet (Appendix A) describing tests and outcomes of tests for the various ions stated in the syllabus (Appendix B). This approach allows students to match the results that they obtained during the experiments with their reference material or data sheet to determine the reactions that had taken place or the identity of the ions present. Thus, many students felt that it was unnecessary to understand what they were doing because they could refer to their reference material during the examinations. This situation showed in their practical sessions as the following comment by a teacher illustrates.

> When we try to explain this and that, they don't want to listen. They give the excuse that they can bring in their textbooks, handbooks and worksheets that they had previously done in class.

From 1999 onwards, students are not allowed to bring in any reference material, but are still given the data sheet. The intention is that students will have the incentive to understand the procedures and reactions involved in qualitative analysis.

In summary, the actual practice of qualitative analysis falls short of the outcomes envisaged, that is, the mastery of process skills, and the integration and application of practical and theoretical knowledge learned in the chemistry course. Therefore, it is no surprise that qualitative analysis does not seem to be meaningful to many students; it is something that they have to do to pass the examinations. For students, getting the required results, knowing how to write 'standard' observations and answers, and being able to match their results with the reference material or data sheet given are all that matters as these will lead to good marks (Tan, Goh, & Chia, 1999).

PURPOSE OF THE STUDY

As discussed in the preceding section, the present O-level chemistry practical assessment system rewards a drill and practice approach to qualitative analysis. However, in 2004, a new practical assessment system will be introduced in Singapore which stresses on mastery of process skills and understanding of the theory involved in the experiments. Thus, there is a need for the content framework of qualitative analysis to be defined to guide the development of teaching approaches which stress the understanding of the procedures and theory involved in qualitative analysis as well as the mastery of required process skills. There is also a need to develop new instruments to assess students' knowledge of qualitative analysis and mastery of process skills.

The objectives of the study are to:

1. Identify the concepts and propositional knowledge necessary for secondary chemistry students to understand the topic of qualitative analysis.

2. Analyse two approved chemistry textbooks and two practical workbooks used by secondary chemistry students, to compare the concepts and propositional knowledge present in the textbooks and workbooks with the concepts and propositional knowledge identified in the study.
3. Identify secondary chemistry students' alternative conceptions in qualitative analysis.
4. Develop a two-tier multiple choice diagnostic instrument consistent with the identified concepts, propositional knowledge and known student alternative conceptions related to qualitative analysis.
5. Measure secondary chemistry students' understanding of the concepts and propositional knowledge related to qualitative analysis through the use of the two-tier multiple choice diagnostic instrument developed.
6. Measure junior college students', undergraduates' and graduate trainee-teachers' understanding of the concepts and propositional knowledge related to qualitative analysis through the use of the two-tier multiple choice diagnostic instrument developed.
7. Design a teaching package to help secondary students understand the procedures and reactions involved in qualitative analysis, as well as, acquire the process skills required in qualitative analysis.
8. Evaluate the impact of the teaching package on secondary chemistry students' understanding of the concepts and propositional knowledge related to qualitative analysis through the use of the two-tier multiple choice diagnostic instrument developed.

RATIONALE OF THE STUDY

Qualitative analysis is a difficult topic for students to learn as it involves both process skills as well as the understanding of many chemistry concepts (Goh, Toh, & Chia, 1987; Tsoi, 1994). Goh, Toh and Chia (1987) studied the questions on how students can be adequately equipped with essential science process skills in qualitative analysis, and how these process skills can be correctly assessed during science practical work. They developed a schema, the Modified Laboratory Instruction (MLI), for improving the mastery of process skills, and found that students who had experienced the MLI schema generally did better in a practical test and a pencil-and-paper alternative-to-practical-test than those who were taught using traditional methods. These students also showed more positive attitude toward laboratory work, as well as greater confidence in their own manipulation of laboratory apparatus. Similar results were obtained by Tsoi (1994) who extended the study of MLI to include computer-assisted instruction.

Apart from the above two mentioned studies, no other studies on secondary qualitative analysis were encountered in the literature. Therefore, there is a need for more research in this area, and as Garnett, Garnett and Hackling (1995) suggest, a list of conceptual and propositional knowledge statements to clarify the knowledge base will provide a sound starting point. Thus, intially this study seeks to identify the conceptual and propositional knowledge that a student needs to learn qualitative analysis.

Textbooks are the main sources of information for teachers and students. Two chemistry textbooks which have been approved by the Ministry of Education, Singapore, for use in secondary schools, were analysed to compare the concepts and propositional knowledge on qualitative analysis present in the books to that identified by the study. The purpose of this analysis is to identify inconsistencies or shortcomings, if any, of the textbooks when used to teach or learn qualitative analysis. Two practical workbooks which are commonly used in schools were analysed in a similar manner.

Students who cannot learn in a meaningful way tend to resort to rote learning the concepts (Peterson, 1986). If teachers are to assist students in learning a topic meaningfully, they need to be familiar with, and know how to test, the level of students' understanding of the topic and be able to identify the students' possible alternative conceptions (Peterson, 1986). Theory questions on qualitative analysis, such as those in the O-level examinations, mainly test the recall of facts.

The practical questions are not much better because once the students are familiar with the qualitative analysis experiments, they can produce the required reports, and score high marks, with little understanding of qualitative analysis. As the understanding of procedures and chemical concepts involved in experiments is important in the new practical assessment system, to be able to diagnose their students' understanding, teachers need better tools such as concept mapping (Novak, 1996; Novak & Gowin, 1984), interviews (Carr, 1996; Osborne & Gilbert, 1980) and multiple choice diagnostic instruments (Treagust, 1986, 1988, 1995). As multiple choice diagnostic instruments are more readily administered and scored than the other methods (Peterson, Treagust, & Garnett, 1989; Taber, 1999a; Tan & Treagust, 1999), they are particularly useful for classroom teachers. Since there is no such multiple choice diagnostic instrument available for teachers to determine their students' understanding of qualitative analysis, the study seeks to address this need by developing such an instrument.

Birk and Kurtz (1999) point out that although many published studies showed alternative conceptions at all levels of education, the authors did not look at the retention of specific alternative conceptions over time. They contend that testing students of different chemistry experience may show if a particular course provided the necessary information to overcome earlier alternative conceptions. Thus, the study also seeks to determine the understanding of qualitative analysis of junior college (Grade 11 and 12) students (16 to 19 years old), undergraduates taking chemistry as a subject and graduate trainee-teachers who are being trained to teach chemistry to examine whether the more advanced chemistry students understood O-level qualitative analysis better than the secondary students.

Based on this author's personal teaching experience and conversations with secondary chemistry teachers, this author believes that there is a lack of teaching material which enables teachers to teach, and students to learn, qualitative analysis in a meaningful manner. The textbooks, workbooks and handbooks used by the students seldom, if ever, link together the concepts required for the understanding of qualitative analysis. These resources also rarely highlight the process skills and metacognitive strategies required for carrying out the experiments, and fail to systematically help students to develop the necessary skills and strategies. Thus there is a need to develop a teaching package which emphasises understanding of the reactions and concepts involved in qualitative analysis, and the systematic development of the necessary process skills and metacognitive strategies. The final part of this research addresses this need with the development of a teaching package on qualitative analysis.

SIGNIFICANCE OF THE STUDY

In his speech entitled 'Shaping Our Future: Thinking Schools, Learning Nation', at the opening of the 7th International Conference on Thinking on 2 June 1997, the Prime Minister of Singapore, Mr Goh Chok Tong, stressed the need for schools to develop future generations of thinking and committed citizens, capable of making good decisions to keep Singapore vibrant and successful in the future. The Ministry of Education of Singapore recognises that much of the learning in school is rote learning and examination-oriented. Thus, it is undertaking a fundamental review of its curriculum and assessment system to see how it can better develop the critical and creative thinking, and learning skills which are required for the future.

Students in Singapore have problems in understanding and doing qualitative analysis concepts (Goh et al., 1987). Students are often unsure of what they are doing in the laboratory and will approach teachers for help without making the effort to think for themselves. By spelling out the concepts and propositional statements in qualitative analysis, teachers and students will be made more aware of what is required for the meaningful learning of qualitative analysis. With this awareness, teachers can deliberately highlight the critical factors in the qualitative analysis experiments (Tasker & Freyberg, 1985), why certain procedures need to be carried out and what outcomes can be expected. Students also will be alerted to the concepts behind what they do in the laboratory and be better informed to understand the experiments.

The diagnostic instrument to be developed will allow teachers to assess their students' understanding of the concepts and propositional statements, and identify any alternative conceptions. Duit, Treagust, and Mansfield (1996) state that investigating students' conceptions not only reveals important insights into students' ways of thinking and understanding, but can also help teachers to see their own views in totally new ways that can result in major reconstruction of their science knowledge or their conviction of how this knowledge should be presented in class. Teachers also can assess and clarify their own understanding of qualitative analysis using the instrument; they may even discover that they do not fully understand certain concepts involved or that they have unknowingly taught their own alternative conceptions to their students. As a result, diagnostic instruments allow teachers to gain a greater insight in the topics, the learning processes of their students and their own teaching methodology. The teachers are likely to be more receptive and willing to try or develop alternative teaching strategies if they find that their present methods are inadequate in addressing students' difficulties. Thus, the quality of teaching and learning would be raised as teachers would be teaching for the understanding of concepts, and not merely for the acquisition of facts (Peterson, Treagust, & Garnett, 1989).

Curriculum planners who have access to the results of diagnostic tests will be more aware of students' alternative conceptions. They can use the information in the development of curriculum materials such as textbooks, workbooks and multimedia instructional software, thereby enabling students to better understand concepts and minimise their alternative conceptions. The teaching package on qualitative analysis to be developed in this study is a step in this direction as it will emphasise understanding, and be based on the findings of the analysis of two textbooks and two workbooks on qualitative analysis, the results from the administration of the diagnostic instrument, as well as, the findings of selected studies in the literature on practical work.

RESEARCH QUESTIONS

Eight research questions which are being considered in this study of the understanding and conceptions of qualitative analysis of secondary students are related to the eight objectives.

1. What are the concepts and propositional knowledge statements necessary for secondary chemistry students to understand the topic of qualitative analysis?
2. Are the concepts and propositional knowledge present in the two approved chemistry textbooks and two practical workbooks used by secondary chemistry students consistent with the concepts and propositional knowledge identified in the study?
3. What do secondary chemistry students understand about the concepts and propositional knowledge related to qualitative analysis?
4. What are the difficulties in developing a diagnostic test consistent with the identified concepts, propositional knowledge and known student alternative conceptions related to qualitative analysis?
5. What is the extent of secondary chemistry students' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as identified through the use of a diagnostic test?
6. What is the extent of junior college students', undergraduates' and graduate trainee-teachers' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as identified through the use of a diagnostic test?
7. How can a teaching package be designed to help students understand the procedures and reactions involved in qualitative analysis, as well as, acquire the process skills and thinking required in qualitative analysis?
8. What is the impact of the teaching package on secondary chemistry students' understanding of the concepts and propositional knowledge

related to qualitative analysis as determined through the administration of the diagnostic test?

LIMITATIONS OF THE STUDY

One major limitation of the study is the examination-oriented teaching of qualitative analysis. The drill and practice nature of the qualitative analysis laboratory sessions in many Singapore schools does not foster the understanding of the procedures and reactions involved in qualitative analysis. Thus, students may find the items in the diagnostic instrument difficult as they may not have thought much about or understood the procedures and reactions involved. Another major limitation is that some teachers may not have taught their students all the reactions involved in the O-level qualitative analysis. For example, students are expected to test for sulphur dioxide in the qualitative analysis experiments but the acid-sulphate(IV) reaction and the thermal decomposition of sulphate(IV) salts which result in the formation of sulphur dioxide are not included in the O-level Chemistry 5070 (pure chemistry) syllabus. Though these ‘extra’ reactions are within the ability of the students to understand and are common in the experiments that they do, teachers, especially if they have lower achieving students, may not teach these reactions because the students will not be asked to answer questions on them in the examinations. This will affect the study as students may not be able to answer some questions, not because they do not understand the reactions involved, but because they have little or no knowledge of the reactions.

Students may not understand or may misinterpret the questions and options in the two-tier multiple choice diagnostic instrument, and since they have little recourse for clarification, this may affect the validity and reliability of the test. Students guessing of answers will also affect validity and reliability of the test. The limited number of distracters that can be given a question also means that only the most common alternative are likely to be diagnosed (Taber, 1999a).

The results and conclusions generated in this study refer specifically to the sample groups involved in the study. Generalisation of the findings to all secondary and junior college chemistry students, undergraduates taking chemistry as a subject and chemistry teachers in Singapore must be considered with caution due to the nature and the limited size of the samples. The effects of the students' learning styles, the attitudes of the students towards the learning of chemistry, the classroom climate, as well as, the effects of the different teachers who taught the students, their teaching and management styles, on the findings are also unknown.

The trial of the qualitative analysis teaching package developed in this study is not intended to do more than to indicate its feasibility. Thus, within the constraints of this study, the requirement is to demonstrate whether it is possible to increase students' understanding of the conceptions and propositional knowledge related to qualitative analysis using the teaching package. Extensive trials of the teaching package focussing on its effects on students' understanding and performance in qualitative analysis practical sessions, students' attitude towards the practical sessions, the acquisition of process skills such as manipulative, observational and inferential skills, and the acquisition of metacognitive strategies required in qualitative analysis can be the focus of future studies.

METHODOLOGY

In this study, five procedures were used to limit and specify the subject content related to qualitative analysis. They were the extraction of parts of the O-level pure chemistry syllabus relevant to qualitative analysis, the development of a concept map, the identification of propositional knowledge statements and facts on qualitative analysis, and the relating of the propositional knowledge statements to the concept map. The extract of the syllabus, concept map, list of propositional statements and list of facts were reviewed by three tertiary chemistry professors and four experienced secondary school chemistry teachers for accuracy and relevance.

The literature was reviewed to determine students' knowledge and alternative conceptions in topics related to qualitative analysis. In 1998, semi-structured interviews of Grade 10 students (15 to 17 years old) were conducted to explore their understanding of qualitative analysis. A trial free response test on qualitative analysis, designed using the data collected from the interviews, was administered to undergraduate and graduate trainee-teachers in a Singapore university to determine their understanding and problems in qualitative analysis. Identified student conceptual difficulties and alternative conceptions from the two sources were used to develop the second version of the free response test. This free response test was administered to Grade 10 students in the first half of 1999, and the data collected was used to develop the first version of the two-tier multiple choice diagnostic instrument. Further studies resulted in the second, and subsequently, the third and final version of the diagnostic instrument, the 'Qualitative Analysis Diagnostic Instrument' (QADI). The QADI was administered to 915 Grade 10 students from 11 secondary schools, 360 Grade 11 and 12 students from 3 junior colleges, 38 undergraduate and 56 graduate trainee-teachers from one university in the second half of 1999. The results obtained were analysed and the alternative conceptions on qualitative analysis that the students had were identified.

Based on the literature on practical work and qualitative analysis reviewed, and the results from the development of the diagnostic instrument, a teaching package for O-level qualitative analysis was developed and a pilot study was carried out in a secondary school in November 1999 to determine its feasibility. Teachers involved in the trial of the teaching package were interviewed and the QADI was administered to the students involved to determine their understanding of qualitative analysis as measured by the QADI.

OUTLINE OF THE STUDY

To clarify the scope of this study, a brief description outlining the content of the remaining chapters of the project is given.

The literature review in Chapter 2 establishes the theoretical and methodological framework for the study. Chapter 3 provides the propositional knowledge statements and concept maps for knowledge base. The content of two secondary chemistry textbooks and two workbooks on qualitative analysis is analysed in Chapter 4. The first study using laboratory observations and interviews with students is described in Chapter 5. The development of the two-tier multiple choice diagnostic instrument is described in Chapter 6. The results following the administration of the final version of the diagnostic instrument to secondary chemistry students are given in Chapter 7, together with the interpretation of the results. Chapter 8 describes the administration of the diagnostic instrument to junior college students, undergraduates and graduate trainee-teachers, the results obtained, the discussion and implication of the results. The development of the teaching package on qualitative analysis is explained in Chapter 9, together with the pilot study to determine its feasibility. Finally, the conclusions, recommendations, and discussion of the limitations of the whole study are presented in Chapter 10.

SUMMARY

The main purpose of this study is to develop a written diagnostic instrument which could be used to determine secondary students' understanding, as well as, identify alternative conceptions, in qualitative analysis following instruction in the topic and practice in the laboratory. This is to enable teachers and curriculum writers to be aware of students' alternative conceptions so that they can develop appropriate teaching strategies and materials to help students better understand qualitative analysis. An additional purpose of this study is to develop a teaching package on qualitative analysis based on the findings of this study and on selected literature on practical work, and to do a pilot study on the teaching package to determine its feasibility in helping students understand the procedures and reactions involved in qualitative analysis.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

The literature review serves to provide a theoretical and methodological framework for this study on the development of a two-tier multiple choice diagnostic instrument to measure secondary students' understanding and alternative conceptions of qualitative analysis, and a teaching package on qualitative analysis. There are six main sections in this literature review. The first section describes selected learning theories relevant to the study. The nature of alternative conceptions and studies of alternative conceptions in science, particularly in chemistry, are discussed in the second and third sections, respectively. The fourth section outlines some methodologies for determining alternative conceptions. The fifth section reviews the role and nature of practical work in relation to qualitative analysis and the studies done on qualitative analysis. Finally, the role and analysis of textbooks are described in the sixth section.

LEARNING

This section describes theories of learning which are relevant to this study. Theories of learning help in the understanding of how students learn and understand concepts in science, and provide the framework for developing instructional materials and strategies.

> Science instruction, from the elementary school to the university level, is frequently disappointing as far as promoting students' understanding of science is concerned. Students are often in full

> command of science terminology and, for example, might be able to provide the names of animals and plants, to write down the Schroedinger equation without any difficulties, or to provide key examples when presented with formulas. However, there very often is no deep understanding behind the facade of knowledge. (Duit & Treagust, 1995, p. 46)

How people acquire knowledge and derive meaning has been of great interest to many philosophers and scientists. Two early theories put forth to explain the acquisition of knowledge by human beings were empiricism, espoused by Aristotle, and nativism or apriorism, espoused by Plato and later by Chomsky (Lawson, 1994). Lawson (1994) describes empiricism as the doctrine that all knowledge is derived through keen observation of the world, whereas in nativism, knowledge is said to unfurl from within the individual. He believes that knowledge acquisition "appears to involve a complex interaction among sensory impressions, properties of the organism's developing brain, and the organism's behaviour in a dynamic and changing environment" (p. 132).

Cognitive developmentalists such as Piaget believe that learners move through different stages of cognitive development at different ages, and hence can handle, most successfully, the learning tasks which correspond to their stage of development (Adey, 1992). It may not be necessary to wait until a learner's mental faculties are appropriately developed to acquire difficult knowledge; the learner can be subjected to external stimuli to cause mental disequilibrium which could result in the necessary mental reorganisation or equilibration (Piaget, 1977) to enable the learner to incorporate that knowledge into his or her cognitive structures. Adey (1992), however, cautions that there are limits set by the learner's age and complexity of the learning tasks - learning quantum mechanics is difficult even for tertiary students.

Ausubel (1968) defines meaningful learning as relating a learning task in a "nonarbitrary, substantive (non-verbatim) fashion to what the learner already knows" (p. 24). The learning task must be assimilated into the learner's cognitive structure as "an example, elaboration, modification, or qualification" (p. 90) of more established knowledge that the learner already has. The learner, in addition, must want to learn meaningfully and must have the prior knowledge necessary to make the learning task meaningful. The degree of meaningfulness of a learning task varies with learners depending on the adequacy of their relevant prior knowledge (Novak, 1976). Ausubel (1968) believes that meaningful learning is very important as it is the "human mechanism par excellence for acquiring and storing the vast quantity of ideas and information represented by any field of knowledge" (p. 58). He contrasts meaningful learning with rote learning, which he describes as "purely arbitrary associations" (p. 24). Novak (1976) stresses that meaningful-rote learning is a continuum rather than a dichotomy.

Thus, the learner is an active participant and not a dormant recipient in the process of knowledge and meaning acquisition. The learner is responsible for his/her learning (Novak, 1988); firstly, he/she must choose to learn, and secondly, choose to derive meaning from the learning task (Ausubel, 1968). After which, Lawson (1994) elaborates, learners

> (1) must be prompted to engage their previous ways of thinking about the situation to discover how they are inadequate to assimilate the new situation and (2) must then be given ample opportunity to think through the situation to allow the appropriate mental reorganisation (accommodation), which in turn allows successful assimilation of the new situation. (p. 139)

Driver (1995) believes that discussion with peers encourages knowledge construction as it provides "a forum in which previously implicit ideas can be made explicit and available for reflection and checking [as well as] an opportunity for individuals to build on each other's ideas to reach a solution" (p. 394).

The learning task must, of course, be potentially meaningful in the first instance (Ausubel, 1968), that is, the learner must be able relate it with what he or she already knows. The learner's existing knowledge has significant effects on new learning (Driver, 1995; Duit, 1995; Johnstone, 1999; Osborne & Wittrock, 1985, Pintrich, Marx, & Boyle, 1993). The learner's stored knowledge influences the selection of, and the attention given to the various aspects of the learning task. The learner then generates links between the task and what he/she already knows, retrieves information from memory to make sense of the task, tests the validity of the task, and subsumes his/her constructions of the task into his/her depository of knowledge. Osborne and Wittrock (1985) have the same view as Novak (1988) that learners must accept responsibility for their own learning as meaning requires active construction. Osborne and Wittrock recommend instilling in pupils "the view that success or failure in making better sense of experience, and in understanding the ideas of others, is dependent on the pupils' own actions and is not solely attributable to heredity, to teachers and to others" (p. 76). However, students may resist such constructivist learning and regard it as uncalled for because it places a high demand on them "to engage with the ideas in a deep and sustained manner" (Duit & Confrey, 1996, p. 85). Students also feel more comfortable being led to the 'correct answer' instead of exploring ideas (Duit, 1995; Hogan, 1999). On the other hand, it may be that the task is beyond the learner as he/she may not have the cognitive maturity and ability required for the task, or the task may be too difficult and/or abstract (Adey, 1992).

Concepts are acquired early in life, that is, children spontaneously develop theories and explanations for things and phenomena that they encounter in their everyday life (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Novak, 1988; Osborne & Wittrock, 1985). These conceptions are resistant to change because they are coherent, sensible and fit with the students' domain of experience. Some of these conceptions differ from the experts' views due to "children's self-centred and human-centred points of view, their limited experiences and everyday use of language and their interests in mini-theories to explain specific events" (Osborne & Wittrock, 1985, p. 69). In addition to what the learner already knows, Novak (1988) believes that the epistemological commitments of students influence their learning, and that thinking, feeling and acting are integrated. He states that students "with a constructivist commitment also show more capacity for modifying wrong or inadequate conceptions" (Novak, 1988, p. 93), and that "there is a pattern to the feelings expressed, with negative feelings associated with cognitive involvement in essentially rote learning and positive feelings expressed when involvement is meaningful" (p. 95).

Learning as conceptual change (Posner, Strike, Hewson, & Gertzog, 1982) is portrayed as "a process in which a person changes his or her conceptions by capturing new conceptions, restructuring existing conceptions, or exchanging existing conceptions for new conceptions" (Hewson, 1996, p. 132). Hewson (1996) describes status as a measure of a learner's acceptance of, or preference for, an idea, new or old; the more a conception meets the conditions of intelligibility, plausibility and fruitfulness (Posner et. al., 1982), the higher its status. Hewson (1996) argues that the status of new and existing conceptions is important for the learning process. If a student encounters a new conception which is in conflict with an existing conception, the learner will not accept the new conception unless the status of the existing one is lowered, that is, the learner must first have reasons to be dissatisfied with the existing one. Chi, Slotta and de Leeuw (1994) postulate that the entities on earth belong to different ontological categories such as matter, processes and mental states. They believe that the ontological status of the students' conceptions and the scientific concepts determines the difficulty of learning. If the student conception and scientific concept are ontologically compatible, for example, both belong to the matter category, then conceptual change is easy. If they are ontologically distinct, then learning will be difficult. Learning science concepts may pose additional difficulty as many science concepts "embody both matter as well as process entities, so the learner must alternate between these two conceptual categories in trying to understand them" (Chi, et al., 1994, p. 34).

In addition to the cognitive aspects, Pintrich et al. (1993) and Hogan (2000) highlight the importance of the learners' motivational beliefs about themselves and the social aspects of their learning environment in facilitating or hindering conceptual change. Johnstone, Hogg, MacGuire and Raja (1997) commented that students accepted many phenomena as they were, so to them there was no need to think or make a fuss about the phenomena. In addition, if students have their own conceptions, they tend to be indifferent to accepted scientific concepts (Macbeth, 2000). Thus, they need to be motivated, in the first instance, to focus their attention on the scientific concepts before teachers can motivate them to give some thought to the concepts. A belief that the scientific concepts are very complex, also can affect students' learning of the concepts (Huddle, White, & Rogers, 2000). Pintrich et al. (1993) believe that the learners' goal orientation, values, efficacy beliefs, and control beliefs serve as mediators of conceptual change and thus should not be neglected. Tyson, Venville, Harrison and Treagust (1997) proposed the use of a multidimensional framework to interpret learning from ontological (Chi et al., 1994), epistemological (Posner et al., 1982) and social/affective perspectives (Pintrich et al., 1993). This approach will give a more holistic picture of how students perceive "the nature of the thing to be studied" (Tyson et al., 1997, p. 398), "his or her own knowledge of the thing to be studied [and] the social/affective conditions necessary for conceptual change to occur" (p. 399). This multidimensional framework was used by Venville and Treagust (1998) to explore Grade 10 students' conceptions of genes during a ten-week genetics course. They found that there was much overlap and interaction between the ontological and epistemological aspects of learning, and that the various perspectives contributed valuable insights into the process of conceptual change which occurred in the students during the course.

The development of a child is a "balance of aspects of self-development and guidance" (Duit, 1995, p. 274). Children have to personally make sense of what they are learning in science but they need to be initiated into the culture and social institutions of science because they cannot discover these on their own (Driver, 1995; Driver et al., 1994; Osborne, 1996). Teachers need to provide the appropriate experiences with the phenomena concerned and introduce the concepts, theories, models, procedures and language used by the scientific community. The significance of initiation into the world of science was highlighted by Stavy (1994) who found that young children up to the age of five and adults with no formal schooling could not understand the concepts of solid and liquid defined in science even though the children and adults encountered solids and liquids everyday. Rop (1999) highlighted a dark aspect of the culture and social aspects of the school science learning in the United States; the education system sets the standards for competence and as a result, science knowledge becomes "information or skills to be repeated or demonstrated on assignments and tests" (p. 228). Often, teachers teach and students learn content only to obtain good results in examinations (Barrow, 1991, Roth & Roychoudhury, 1994); understanding takes a back seat.

Driver et al. (1994) highlight the similarities between the science ideas constructed by students and the development of scientific ideas and theories; both result from the interaction of individuals with phenomena, and what is known about the phenomena are the constructions of the individuals (Driver, 1995; Duit & Treagust, 1995). The scientific ideas and theories also need to be communicated, discussed and validated before being accepted, resulting "in the scientific community sharing a view of the world involving concepts, models, conventions and procedures" (Driver et al., 1994, p. 6). In addition, ideally science should be seen as being "fallible, self-correcting, and progressive, rather than infallible, always correct, and conservative" (Eltinge & Roberts, 1993, p. 66) and teachers should highlight how scientific ideas are developed and evaluated so that students "can appreciate the 'provisional' nature of science ideas [and] gain confidence in trying and testing ideas" (Driver et al., 1994, p. 7). However, many teachers and students tend to view learning as transferring to memory all the accumulated facts because they are "naive realists in that they view science and mathematics knowledge as a faithful copy of the 'world outside' and not as tentative human construction" (Treagust, Duit & Fraser, 1996, p. 2). Therefore, these students may not accept the responsibility of constructing meaning from the lesson, and teachers with reproductive conceptions of teaching (Koballa, Graber, Coleman, & Kemp, 2000) will continue to 'fill' their students' 'blank minds' with knowledge (Gilbert, Osborne, & Fensham, 1982) without providing their students with opportunities to construct meaning from the lessons.

ALTERNATIVE CONCEPTIONS

This section defines the term 'alternative conception' used in this study and discusses how alternative conceptions arise, their characteristics, and how they influence teaching and learning in science.

> Put simply, to teach a child about science, not only does it help to know something about science, it helps to know something about the child. (Osborne, 1996, p. 68)

Many researchers agree that the most important things that students bring to class are their conceptions (Ausubel, 1968; Driver & Oldham, 1986). Duit and Treagust (1995) define conceptions as "the individual's idiosyncratic mental representations" while concepts are "something firmly defined or widely accepted" (p. 47). Children develop ideas and beliefs about the natural world through their everyday life experiences. These include sensual experiences, language experiences, cultural background, peer groups, mass media as well as formal instruction (Duit & Treagust, 1995). Some of these ideas and beliefs, such as those about light and sight (Driver, 1995) may be similar across cultures as children have very similar personal experience with phenomena.

Andersson (1986a) argues that everyday experiences give rise to the experiential gestalt of causation which often conflicts with scientific thinking. As previously mentioned, students' conceptions are critical to subsequent learning in formal lessons because there is interaction between the new knowledge that the students encounter in class and their existing knowledge. Johnstone (2000) states that when a person tries to store material in long term memory and cannot find existing knowledge with which to link it, he/she may try to 'bend' the knowledge to fit somewhere, and this gives rise to erroneous ideas. When students' existing conceptions differs from those commonly accepted in the disciplines, they are termed as alternative frameworks (Driver & Easley, 1978), misconceptions (Cho, Kahle, & Nordland, 1985; Driver & Easley, 1978), student conceptions (Duit & Treagust, 1995), alternative conceptions (Abimbola, 1988; Hewson, 1981), intuitive beliefs (McCloskey, 1983), intuitive conceptions (Duit, 1995), naive beliefs (Caramazza, McCloskey, & Green, 1981), or children's science (Osborne, Bell & Gilbert, 1983). The terms used depend on the author's views of science (Abimbola, 1988) and of the nature of knowledge (Duit & Treagust, 1995). For example, Duit and Treagust state that alternative frameworks suggest that the students' conceptions are effective in daily life and hence valuable to them, while children's science indicate that students' conceptions are to be taken seriously as they formulate their ideas in a way that is similar to scientists. Abimbola (1988) prefers the use of alternative conceptions to describe the student's ideas and alternative frameworks for the organisation of ideas, while Gilbert and Watts (1983) describe alternative frameworks as "thematic interpretations of data, stylised, mild caricatures of responses made by students" (p. 69). Vosniadou (1994) regards misconceptions to be spontaneous constructions which are often generated on the spot, and not deeply held specific theories. These misconceptions arise as "individuals' attempts to assimilate new information into existing conceptual structures that contain information contrary to the scientific view" (Vosniadou, 1994, p. 45).

In this study, the term alternative conceptions is used to describe student conceptions which differ from scientific concepts. This author agreed with Wandersee, Mintzes and Novak (1994) that the term "confers intellectual respect on the learner who holds those ideas – because it implies that alternative conceptions are contextually valid and rational and can lead to even more fruitful conceptions (e.g., scientific conceptions)" (p. 178). Interest in student conceptions surged with the emergence of constructivism (Osborne, 1996;

Solomon, 1994) which brought along with it "a language with new descriptive power" (Solomon, 1994, p. 6). This language, Solomon argues, transmuted common student mistakes, which was of little appeal to anyone, to something exciting and of great interest.

Students' existing ideas are often strongly held, resistant to traditional teaching and form coherent though mistaken conceptual structures (Driver & Easley, 1978). Students may undergo instruction in a particular science topic, do reasonably well in a test on the topic, and yet, do not change their original ideas pertaining to the topic even if these ideas are in conflict with the scientific concepts they were taught (Fetherstonhaugh & Treagust, 1992). Duit and Treagust (1995) attribute this to students being satisfied with their own conceptions and therefore seeing little value in the new concepts. Another reason they proposed was that students look at the new learning material "through the lenses of their preinstructional conceptions" (p.47) and may find it incomprehensible. Osborne et al. (1983) state that students often misinterpret, modify or reject scientific viewpoints based upon the way they really think about how and why things behave, so it is not surprising that research shows that students may persist almost totally with their existing views (Treagust et al., 1996). When the students' existing knowledge prevails, the science concepts are rejected or there may be misinterpretation of the science concepts to fit or even support their existing knowledge. If the science concepts are accepted, it may be that they are accepted as special cases, exceptions to the rule (Hashweh, 1986), or in isolation from the students' existing knowledge, only to be used in the science classroom (de Posada, 1997; Osborne & Wittrock, 1985) and regurgitated during examinations. Additional years of study can result in students acquiring more technical language but still leave the alternative conceptions unchanged (de Posada, 1997). However, cognitive development over time is important for learning as development of scientific reasoning ability and conceptual change during adolescence has been shown to be linked to brain growth (Kwon & Lawson, 2000).

Thus teachers must be aware that they "cannot assume that what is taught is what is learned" (Driver & Scott, 1996, p. 106). They also need to realise that formal lessons and textbooks can also be sources of alternative conceptions. Alternative conceptions may arise when students are presented with concepts in too few contexts or when concepts presented are beyond their developmental level (Gabel, 1989). Another source of confusion is the different meaning of common words in different subjects and in everyday use. Harrison and Treagust (1996) reported that students were confused between the nucleus of an atom and the nucleus of a cell, and that one student actually drew a cell for an atom. They also found students having alternative conceptions about electron clouds, and cautioned that teachers need to qualify the sense in which they transfer the attributes of the analog to the target. McDermott (1988) suggests that some alternative conceptions may arise from failing to integrate knowledge from different chapters and from concept interference which comprise "situations where the correct application of a conception by students is hindered by their misuse of another concept that they have learned" (p. 539). This occurs when students do not have an adequate conceptual framework to know which concept to apply in a situation. Concept interference may also be due to set effects (Hashweh, 1986) where certain knowledge or conceptions are brought to mind due to strong ties with certain features of a given situation through previous experience.

Teachers need to know their students' alternative conceptions in order to help them lower the status of these conceptions in favour of the accepted science concepts. Unfortunately teachers are often unaware of their students' alternative conceptions (Treagust et al., 1996), which is why Posner et al. (1982) maintain that teachers "should spend a substantial portion of their time diagnosing errors in thinking and identifying moves used by students to resist accommodation" (p. 226). However, Wandersee et al. (1994) contend that the large quantity of research on alternative conceptions, the format in which the studies have been reported, and the lack of access to the published studies make them virtually inaccessible to classroom teachers.

Scott, Asoko, Driver and Emberton (1994), Wittrock (1994) and Ebenezer and Erickson (1996) believe that identifying and understanding student conceptions will advance the design of science teaching. Scott et al. (1994) argue that if the central focus of planing lessons was the comparison of students' conceptions with the accepted views of science, insights into the intellectual demands made on students would be more evident. The information obtained could be used to develop strategies to induce students' dissatisfaction with their alternative conceptions, and give them access to newer and better ideas which are intelligible, plausible and fruitful in offering new interpretations (Hewson, 1981; Posner et al., 1982). Howe (1996) proposed that instead of challenging alternative conceptions directly as wrong or inadequate, one should "accept the student's ideas as a starting point with a view to helping them expand their knowledge, learn to use it more flexibly, apply it to more situations and, eventually, integrate it into a system of broader, more inclusive concepts" (p. 47). Students need to think what the science concepts mean in terms of their experiences of the concepts, and at the same time fit their everyday experiences into the framework learned in school. They need to move "from the abstract to the concrete and from the concrete to the abstract" (Howe, 1994, p. 40). Howe believes that this Vygotskian model would be less confrontational and take into account that "the students need time to get used to and accept new ideas and other ways of understanding phenomena" (p. 50). This issue is supported by Gilbert et al. (1982) and Duit (1995).

A final point is that teachers need to be aware that they also can be the sources of alternative conceptions. Teachers can unwittingly pass their own alternative conceptions to their students, and the way they teach, for instance, using imprecise terminology, can also cause confusion (Banerjee, 1991; Chang, 1999; De Jong, Acampo, & Verdonk, 1995; Gabel, Samuel, & Hunn, 1987; Gilbert et al., 1982; Lawrenz, 1986; Lee, 1999a,b; Lee, Goh, & Chia, 1998; Lenton & Turner, 1999; Lin, Cheng, & Lawrenz, 2000; Quilez & Solaz, 1995; Taylor & Coll, 1997; Wandersee et al., 1994; Willson & Williams, 1996). When teachers have the same alternative conceptions as their students (Wandersee et al., 1994), they think that there is nothing wrong with their students' conceptions. Given the number of students taught over a teaching career, the generation of alternative conceptions can be quite significant. Teachers should realise that textbooks also can contain errors and misleading or conflicting illustrations and statements which can give rise to alternative conceptions (Boo, 1998; Cox, 1996; Dall'Alba et al., 1993; de Posada, 1999; Garnett, Garnett, & Treagust, 1990; Griffiths & Preston, 1992; Sanger & Greenbowe, 1999; Wandersee et al., 1994); textbooks should not be regarded as infallible.

STUDIES OF STUDENT CONCEPTIONS IN CHEMISTRY

Qualitative analysis involves many aspects of chemistry, hence an overview of relevant studies of student conceptions in chemistry is necessary to give a sense of the complexity of students' learning of qualitative analysis in a meaningful manner. Subsequently, the difficulties that students have in learning chemistry, and students' conceptions of the particulate nature of matter, chemical bonding and selected chemical reactions are discussed in this section. The concept of the particulate nature of matter and concepts in chemical bonding are fundamental to the learning of chemistry. Many reactions are involved in qualitative analysis, and knowledge of students' conceptions of relevant chemical reactions is important to this study as it can be used to identify the concepts which students may find difficult in qualitative analysis.

Chemistry is a difficult subject to learn because it involves "abstract and formal explanations of invisible interactions between particles at a molecular level" (Carr, 1984, p.97). In addition, many concepts in chemistry are "notional, semantic, handed down by authority rather than experienced" (Johnstone, 1999, p. 46) and would be inexplicable without the use of analogies or models (Gabel, 1999). Ross and Munby (1991) pointed out that chemistry concepts are so inter-related that students having difficulty in one topic can be expected to have difficulty with others. To engage in chemical reasoning, the student may need to constantly shift between four representational systems (Nakhleh & Krajcik, 1994), the macroscopic, microscopic, symbolic and algebraic, and this causes further difficulties. Johnstone (2000) pointed out that the need to shift between representational systems is “at once the strength of our subject as an intellectual pursuit, and the weakness of our subject when we try to teach it, or more importantly, when beginners (students) try to learn it” (p. 11). He believes that the student may not be able to process and store information in the different representational systems and may “attempt to ‘bend’ or ‘manipulate’ the information into a more tangible form” (p. 11), giving rise to alternative conceptions. Abraham, Grzybowski, Renner and Marek (1992) indicated that the formal operational reasoning required to understand chemistry concepts, to make sense of “the invisible and the untouchable” (Kozma & Russell, 1997, p. 949), but this might be beyond the ability of many secondary students. Gabel and Bunce (1994) noted that according to literature, only 30% to 70% of chemistry students operated on formal level in chemistry, and this implied that many students rely on memorisation strategies to deal with difficult concepts.

Abraham, Williamson and Westbrook (1994) found that both reasoning ability and experience with concepts influence the understanding of chemistry concepts. They suggested a spiral curriculum should be adopted for chemical education, with emphasis on concrete experiences for beginning students. Teachers and textbooks need to simplify abstract concepts and use analogy to make the concepts more ‘real’ to students. Johnstone (1999), however, believes that in doing so, the foundations for alternative conceptions are laid because students may make wrong associations and these are difficult to unlearn as well as interfere in new learning (Taber, 1999b). Johnstone (1999) also believes that students have difficulty with chemistry because “the tangible macro-science (the appearance, state, smell colour etc.) has little obvious link with the micro-science at molecular level” (p. 46). Treagust, Duit and Nieswandt (1999) contend that major learning difficulties arise because the concepts in chemistry, in many ways, contradict intuitive and everyday views of learners. The special language of chemistry also poses problems to the learners (Boo, 1998; Fensham, 1994; Gabel, 1999). Andersson (1986b) stressed that careful choice of language is very important in the teaching of chemistry as students, lacking the appropriate framework, may misinterpret the words of teachers and textbook authors giving rise to alternative conceptions.

There are many studies into student alternative conceptions in chemistry and summaries of such studies can be found in Driver et al. (1994), Gabel and Bunce (1994), Garnett et al. (1995), Nakhleh (1992), Pfundt and Duit (1998). Areas of studies pertinent to qualitative analysis include the particulate nature of matter, bonding, chemical reactions and changes, acids, bases and salts, redox and chemical equilibrium.

Particulate nature of matter

The concept of the particulate nature of matter lays the foundation for the understanding of many chemistry concepts (Abraham et al., 1992; Gabel et al., 1987; Griffiths & Preston, 1992; Haidar & Abraham, 1991; Herron & Nurrenbern, 1999; Nakhleh, 1992; Nakhleh & Samarapungavan, 1999; Williamson & Abraham, 1995). However, Abraham et al. (1994) found that students at all levels tended not to use atomic and molecular explanations for chemical phenomena. Tsaparlis (1997) argues that "(i) the inability of most or many students to employ formal operations; (ii) the lack of proper knowledge corpus which is a prerequisite for meaningful learning; (iii) the absence of the relevant conceptions from long-term memory" (p. 924) made particulate nature of matter difficult for students to learn. This position is in agreement with Abraham et al. (1992) who stated that students avoided using such explanations because they did not understand them well enough, and this might be linked to students' inability to build mental models that illustrate particulate behaviour (Williamson & Abraham, 1995). It is not surprising that students have problems understanding the particulate nature of matter as "students have to take their existence on faith and build up knowledge structures of molecules and molecular behaviour without having direct experience with molecules" (Fellows, 1994, p. 988).

Basic terms such as particle, elements, compounds, mixtures, as well as atoms, ions and molecules are also not well understood and differentiated (Ayas & Demirbas, 1997; de Posada, 1997; Driver et al., 1994; Fensham, 1994; Gabel et al., 1987; Gilbert et al., 1982; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Mitchell & Gunstone, 1984; Nakhleh & Krajcik, 1994; Taber, 1996). Yarroch (1985) and Lythcott (1990) found that students had little understanding of the coefficients and subscripts in chemical formulae though they could balance chemical equations. For example, Yarroch (1985) discovered that students drew three hydrogen molecules as six linked circles, while Lythcott (1990) found drawings of water molecules as a collection of unlinked circles representing hydrogen atoms or molecules and oxygen atoms. The experimental context (McDermott, 1988) is very important and must not be neglected; Gabel (1989) cautions that kinetic molecular theory must not be presented "in lieu of the macroscopic phenomenon that forms the basis for the theory" (p. 729), and Ahtee and Varjola (1998) contend that students need to experience different chemical phenomena in order to "realise the variety for which a general explanation in the form of atom theory applies" (p. 315). However, students need instruction to "help them develop the link between the macroscopic observations in the laboratory and the microscopic models that chemist used to explain them" (Haidar & Abraham, 1991, p. 932).

Novak and Musonda (1991), Lee et al. (1993), Leisten (1995) and Skamp (1999) contend that the basic concepts involved in particulate nature of matter can be even taught to primary-aged students using appropriate strategies such as concrete representations of particles, hands-on activities and role playing. They believe that the upper primary students are very keen to learn science, and are capable of understanding some basic concepts. However, Stavy (1994) argues that students below sixth grade already have difficulties in understanding the macroscopic physical attributes of solids and liquids, and recommends that they should be given time to learn these physical attributes before being introduced to the particulate nature of matter. Nakhleh and Samarapungavan (1999) suggest that the understanding of the nature of matter requires "acts of imagination" (p. 801) and young students may be able to grasp basic concepts if appropriately taught. Reynolds and Brosnan (2000) also argue that in the teaching of science "an important part of what we require of students is an act of the imagination" (p. 61). Nakhleh and Samarapungavan (1999) state that the difficulties that children face have less to do with developmental constraints on their cognitive abilities than with the ontological shifts that are required to switch from a macroscopic to a microscopic view of matter.

Many students from junior high to university level believed that matter exists as a continuous medium rather than as an aggregation of particles, and that atoms and molecules have macroscopic properties such as expanding when heated and having the colour of the substance (Andersson, 1990; Fensham, 1994; Garnett et al., 1995; Hill, 1988; Lee et al., 1993; Nakhleh, 1992; Novak & Musonda, 1991; Reynolds & Brosnan, 2000). de Posada (1997), and Nakhleh and Samarapungavan (1999) suggest that students find the atomic model more applicable to gases or liquids than to solids because it seems to contradict their everyday experiences of solids, for example, many solids are hard, cannot be compressed, and particles in solids cannot be observed. However, other studies found that many students did not accept that particles in the gaseous phase had empty space between them, and believed that gas molecules are arranged in an orderly manner (Garnett et al., 1995; Nakhleh, 1992; Williamson and Abraham, 1995). Novick and Nussbaum (1978) believe that emphasis on the bulk properties of gases such as the weight of gases and the pressure they exert made it difficult for students to accept the idea of empty space in their particle model. Harrison and Treagust (1996) reported that some students believed the particles which made up nonliving things were atoms but particles which made up living things were cells; these students did not realise that cells were made of atoms as well.

Abraham et al. (1994) found that few students understood the energy changes involved in phase changes, for example, the melting of ice and the boiling of water. Many students believed that "the ice or the cold water from ice prevented the water's temperature from rising (cold balanced the warm)" (Abraham et al., 1994, p. 162). Studies have also shown that students had difficulty in explaining the evaporation, boiling and condensation, and were confused about conservation of matter during phase changes as well as the size, shape, weight, spacing and bonding of molecules in the different phases (Bar & Travis, 1991; Benson, Wittrock & Baur, 1993; Chang, 1999; Fensham, 1994; Griffiths & Preston, 1992; Hatzinikita & Koulaidis, 1997; Lee et al., 1993; Nakhleh, 1992; Novak & Musonda, 1991; Osborne & Cosgrove, 1983; Pereira & Pestana, 1991; Skamp, 1999; Stavy, 1990). Many students believed that water had changed into air when it evaporated, that air reacted with cold surfaces to form water upon condensation, and that bubbles formed by boiling water were made of air, oxygen or hydrogen. Hill (1988) and Andersson (1990) suggest that illustrations in science textbook may be responsible for alternative conceptions involving spacing between particles, for example, the extent of expansion by solids when heated is greatly exaggerated and the decrease in density when a liquid changes to a gas is under-represented. Ahtee and Varjola (1998) found that nearly 20% of the 7th and 8th graders and 10% of senior secondary school students in their study considered change of state and dissolving to be chemical changes. They suggested that this was because students were introduced to many reactions which involved 'change of state' such as the formation of precipitate or gas, and perhaps, disappearance of solids.

Studies have shown that students have difficulty in understanding dissolution (Buell & Bradley, 1972; Lee et al., 1993; Longden, Black, & Solomon, 1991; Nusirjan & Fensham, 1987). Butts and Smith (1987) reported that a survey of 266 Year 12 chemistry students showed that 30% of them considered concepts relating to dissolution processes and precipitation were difficult. They believe that many students do not understand the actual process of aqueous dissolution and the role of the polar water molecule in the process. Boo (1994) also reported that A-level students do not see water as playing a significant role in dissolution, and that the concept of ion-solvent interaction is largely unknown or unclear. Some students believed that there are ionic bonds between the cations and anions in solution as this fitted well with their conception of 'ionic molecules'. This is shown by their belief that that sodium chloride exists as discrete pairs of Na^+ and Cl^- units in aqueous sodium chloride (Boo, 1998). Others thought that when sodium chloride is dissolved, ionic bonds are broken resulting in the positive charge on the sodium ions being neutralised by the gain of electrons from the chloride ions. These findings supported the assertion made by Butts and Smith (1987) that students "generally had a better conception of the structure of a solid than they did of the corresponding aqueous solution, especially in the case of sodium chloride" (p. 199). Abraham et al. (1994) found several alternative conceptions on dissolution such as the idea that sugar particles floated or sank to the bottom of a beaker instead of being evenly mixed, and that sugar changed chemically into a new substance or decompose into its ions or elements. Students also have difficulty differentiating between dissolving and melting, especially if heat is used to accelerate dissolution, and between dissolving and reaction (Abraham, et al, 1992; Driver et al., 1994; Ebenezer & Erickson, 1996; Fellows, 1994; Fensham, 1994; Prieto, Blanco & Rodriguez, 1989).

Bonding

Although intermediate classes of bonding do exist (Laing, 1993), students in secondary school are only taught that there are three distinct categories of bonding, covalent, ionic and metallic. Even with this simplification, students have great difficulty understanding chemical bonding. Previous research has identified a range of difficulties with understanding ionic bonding (Butts & Smith, 1987; Boo, 1998). Taber (1994) found that many students believed that the atomic electronic configuration determines the number of ionic bonds formed, for example, a sodium atom could only donate one electron, so it could form only one bond. Students thought that in sodium chloride, the chloride was bonded to the specific sodium atom that donated an electron to it, and also was attracted to a further five sodium ions, but just by forces and not bonds. Taber (1997) believed that the students adopted a molecular framework for ionic bonding because they saw sodium chloride as a molecular solid similar to iodine, consisting of discrete units, each unit made up of a sodium ion and a chloride ion. Taber (1998a, 1999b) argues that students' use of the octet rule forms the basis of an alternative conceptual framework for understanding chemical bonding. He believes that this octet rule framework explains why students see bond types as a dichotomy, believe in ionic molecules and "consider 'proper bonds' and 'just forces' to be ontologically distinct rather than just different in magnitude" (Taber, 1998a, p. 606). It is likely that these alternative conceptions arise due to similar methods of teaching and/or presentation of content in textbooks (Taber, 1997; Tan & Treagust, 1999) as students only encounter ideas about bonding during formal instruction.

Studies on students' understanding of covalent bonding and molecular structure have been conducted by Peterson, et al. (1989), Peterson and Treagust, (1989), Goh, Khoo, and Chia (1993), Taber (1998a), Birk and Kurtz (1999), and Tan and Treagust (1999). Students had difficulties understanding bond polarity, shape of molecules, polarity of molecules, intermolecular forces, octet rule, lattices, delocalisation of electrons and the electrical conductivity of graphite. For example, Peterson and Treagust (1989) found that students believed that equal sharing of the electron pair occurs in all covalent bonds and did not consider the influence of electronegativity and the resultant unequal sharing of the electron pair on bond polarity.

de Prosada (1997) and Taber (1998a) found that Grades 10 to 12 had vague conceptions of metallic bonding and how metals conduct electricity. For example, some students thought that an electrical current in metals was produced by the movement of atoms or ions, while others thought that atoms in metals transferred electricity from one atom to another. In addition, Coll (2000, Jun) found that few Grade 12 students, undergraduates and postgraduates were able to explain bonding in alloys and malleability of metals.

Peterson et al. (1989) suggested that the students' alternative conceptions in bonding was due to the student's lack of distinction of meaning of the same words used in a chemistry context and in everyday English speech. Another reason given was the emphasis of teachers and students, due to time and syllabus constraints, on the acquisition of facts rather than the comprehension of concepts. de Prosada (1997) suggested that the lack of understanding of bonding could be due to the way it was presented in textbooks. He found that Spanish textbooks practically only define metallic bonding with very little explanation, and had confusing diagrams such as those which showed inaccurate proportion of sizes between electrons and other particles. Since students had difficulty in relating the macroscopic properties of metals with the explanations at the microscopic level, they often resorted to rote learning. Birk and Kurtz (1999) also believe that beginning students of chemistry might actually have very little or no understanding at all about bonding rather than having extensive alternative conceptions. They suggested that these beginners, for example, high school students, might not be intellectually prepared to deal with such abstract topics, or had poor learning experiences.

Chemical reactions

The study of chemical reactions is important to the study of chemistry (Boo, 1998). However, studies have shown that students have difficulties understanding the different types of chemical reactions, mainly because what happens in a chemical reaction cannot be seen. For example, Mitchell and Gunstone (1984) reported that very few students saw atoms as immutable; some students saw atoms coalescing into molecules when combined, some thought that "atoms decomposed as a corpse decayed" (p. 82), while others believed that chemical energy involved the destruction of atoms according to $E = mc^2$.

Andersson (1986b, 1990) classified students' understanding of physical and chemical changes under five categories.

1. It is just like that: No explanation is given at all.
2. Displacement: A substance appears at a given place because it has been displaced from elsewhere.
3. Modification: What appears to be a new substance is in actual fact the same substance as before.
4. Transmutation: A given substance is transformed into a new one.
5. Chemical interaction: The original substance can interact with another one to form a new substance.

Andersson (1986b), Ben-Zvi, Eylon and Silberstein (1987), Hesse and Anderson (1992), and Ahtee and Varjola (1998) found that many students cannot understand the interactive nature of a chemical reaction, the concept of atoms rearranging and yet retaining their identity. This explains why the original substances disappear and new products appear, as well as why the original substances can be regained. Ahtee and Varjola (1998) believe that understanding chemical reactions requires the ability to differentiate among concepts such as element, compound, and mixture, and atom and molecule. Watson, Prieto and Dillon (1997) reported that students made no mention of atomic or molecular particles in their explanation of chemical reaction; "students tend to explain chemical phenomena using mostly visual criteria related to macroscopic properties" (Gabel & Bunce, 1994, p. 308). Mitchell and Gunstone (1984) found that none of the students they interviewed called for chemical equations in discussing chemical changes. Yarroch (1985), Ben-Zvi et al. (1987), and Hesse and Anderson (1992) found that students did not have a sound understanding of what chemical equations represent. This may be due to their "lack of understanding of the particulate nature of matter and their inability to visualise the dynamic process of a reaction on a particulate level" (Garnett et al., 1995, p. 80). Ben-Zvi et al. (1987) commented that reading chemical equations was difficult because students needed to know the structure of the reagents and products, how they exist at reaction conditions, the kinetics and energetics of the reactions, and the quantitative aspect of the reactions. Hesse and Anderson (1992) believe that to explain chemical change, students need to have knowledge of chemical properties of the substances involved and basic chemical theories such as the particulate nature of matter. They also need to be able to carry out conservation reasoning and understand what constitutes an acceptable explanation in chemistry. Ribeiro, Pereira and Maskill (1990) found perceptually dominated thinking guided students' understanding of the word reaction; if the students did not see a new substance being formed, they tended not to refer to the change as a reaction.

Boo (1994) pointed out that defining chemical change as 'one in which a new substance is formed' is problematic as students struggle with what constitutes a new substance. She found that the criteria to judge whether a new substance is formed, for example, evolution of heat, new properties, bond making/breaking, reversibility/irreversibility, were not as straightforward as they seemed. This caused students great difficulty and led to some students concluding that any change involving 'chemicals' is a chemical change. Palmer and Treagust (1996) concurred that the concept of physical and chemical change has no satisfactory definition. Brosnan (1999) feels that problems arise because it is not indicated whether macro-level substances or micro-level substances are being referred to. When a mixture of solid lead(II) nitrate(V), solid potassium iodide and water is heated, a new substance, lead(II) iodide, is produced at the macro-level but there is no change at the micro-level as the same four types of ions exist. This is unlike the combustion of hydrogen in water where a new substance is formed at both the molecular- and macro-levels. Brosnan (1999) suggests that one solution is to decide more precisely "which level determines whether a new 'chemical entity' is made" (p. 56). However, using changes at the macro-level would mean that the dissolution of all ionic substances would be termed as chemical changes while using changes at the micro-level would result in double decomposition reactions being described as physical changes. In the end, Brosnan questions the need to worry about definitions or the distinction between physical and chemical changes. Instead, he proposes students should be helped to understand that some changes simply involve the rearrangement of micro particles while others involve changes in these micro particles themselves.

Combustion

Studies on student ideas of combustion have been carried out by Barker and Millar (1999), Boo (1998), Prieto, Watson and Dillon (1992), Rahayu and Tytler (1999), Stavy (1994), and Watson, Prieto, and Dillon (1995, 1997). Meheut, Saltiel and Tiberghien (1985) found that observations made by 11 to 12 year old students led the students to make incorrect interpretations on conservation of chemical elements in combustion reactions. The students believed that transformation of substances during combustion involved substances separately instead of involving interactions between several substances. Thus they had difficulty with the ideas that candle wax, alcohol and metals could undergo combustion instead of merely melting or vaporising, that oxygen was involved in combustion, or that water be produced during combustion without being present in the original material. Similar findings were reported by BouJaoude (1991) who indicated that the students' ideas on burning were fragmented, inconsistent and task specific, and Boo (1994) attributed the students' ideas to their everyday experience – the experiential gestalt of causation (Andersson, 1986a). Watson et al. (1997) suggest students are unable to explain combustion as a chemical reaction because they have not yet reached the cognitive development that will allow the necessary formal operational thinking. However, Abraham et al. (1994), and Boo and Toh (1998) reported that even college students had difficulty in explaining combustion; they used a more extensive vocabulary, but often inappropriately, indicating the lack of understanding of the terms. To improve students' understanding of combustion, Ross (1991) and Prieto et al. (1992) stress the need for lessons to emphasise the involvement of gases in combustion as students tend to consider only perceptible substances in the reactions and ignore the invisible gases. Watson et al. (1995) reported that practical work on combustion seemed to alter students' perception of the important features of a combustion reaction, but failed to have an impact on their understanding of combustion; the knowledge gained from practical work was not explicitly used to develop concepts on combustion.

Acids, bases and salts

Nakhleh and Krajcik (1994) deem the topic acids, bases and pH particularly challenging because "the student must possess a deep understanding of atoms, molecules, ions and chemical reactions" (p. 1078). Hand and Treagust (1988) reported that Year-10 students had five major alternative conceptions on acids and bases; an acid eats material away or burns people, testing for acids involve eating something away, neutralisation is the breakdown of an acid, the difference between strong and weak acids is that strong acids eat material faster than a weak acid, and a base is something which makes up an acid. Zoller (1990), and Ross and Munby (1991) found that students had difficulties understanding pH, and Nakhleh and Krajcik (1994) discovered that students had little understanding of the role of indicators. Zoller (1990) believes that the term, pH, "is used and/or manipulated by students in a 'mechanical' or technical' sense, without a real grasp and understanding of the conception" (p. 1058). Another related student difficulty reported by Zoller (1990) and Schmidt (1991, 1997) was the hydrolysis of salts in aqueous solution; many students believe that salts formed in neutralisation reactions are neutral. Wilson (1998) also found that many Year-12 students were unable to relate the properties of acids and bases to the concept of chemical equilibrium. Carr (1984) and Schmidt (1991) believe that student difficulties in acids and bases arise because students are confused about the models of acids and bases used in teaching rather than from a conflict between their preconceptions and the scientific view. Carr (1984) maintains that students will be confused if the transition from one model to another is not "carefully sign-posted" (p. 99). Fensham and Kass (1988) pointed out that students were confused or misled by features of models in chemistry which were not the purpose of the model to portray. Thus, teachers need to indicate when a new model is introduced, how the new model is different from the previous one and why the new model works better than the previous one. As meanings of some terms, for example, neutralisation, change with the model used, teachers also need to explicitly explain the use of the terms.

Butts and Smith (1987) found that few students could relate the formation of a precipitate when aqueous sodium chloride was added to aqueous silver nitrate(V) to the low solubility of silver chloride. A few students also believed that silver chloride could not be an ionic compound since it does not dissolve in water. Boo (1994, 1998) found that students thought that in a reaction between sodium chloride and lead(II) nitrate(V), the driving force of the reaction was the difference in reactivity between the sodium and lead as sodium is more reactive than lead and displaces it from lead(II) nitrate(V). They did not understand that double decomposition did not involve displacement of a less reactive substance by a more reactive one. Barker and Millar (1999) found that students believed there would be an increase in mass in a precipitation reaction because solids were heavier than liquids, while others believed that the mass would decrease because gases were produced in precipitation reactions.

Redox

Many students find redox difficult and are confused with the existence of four different models of redox (Harrison & Treagust, 1998). Thus, they often resort to rote learning and application of concepts and algorithms (Garnett et al., 1990). Student difficulties in understanding redox include the interdependence of oxidation and reduction processes, the concept of relative strength of oxidising and reducing agents, the concept of oxidation number, as well as the classification of reactions as examples of redox reactions and the balancing of complex redox equations (De Jong et al., 1995; Garnett & Treagust, 1992).

Ringnes (1995) believes that the way redox is taught in school does not promote understanding because students are taught four different definitions of redox, the chemical terms used are in conflict with their everyday usage, and the historical development of the concepts are seldom given. As in the case of acids and bases, students are taught several models of redox, in this case, the oxygen, hydrogen, electron and oxidation number models, and this gives rise to confusion over the use of various models. For example, the use of the oxygen and hydrogen model cannot explain why sodium reacting with chlorine forming sodium chloride is considered as a redox reaction, and the use of the electron model is rather limited as the transfer of electrons is not reflected in the overall reaction. Ringnes (1995), Herron (1975), Sisler and VanderWerf (1980), and Garnett et al. (1990) believe that the oxidation number model helps students most in understanding and identifying redox reactions. However, De Jong et al. (1995) argue that the concept of oxidation number is difficult to teach, and recommend that teachers omit teaching the concept of oxidation number as "core electrochemical concepts and procedures can be taught without oxidation numbers" (p. 1109). Davis (1991), however, contend that hydrogen ions involved in the reaction between iron(II) and manganate(VII) ions could be considered as being oxidised using the oxygen model, reduced using the electron model but neither oxidised nor reduced, which is the case, using the oxidation number model. Thus, by not teaching the oxidation number model as De Jong et al. (1995) suggested, a great deal of confusion would arise. However Davies (1991) agrees with De Jong et al. that abstract ideas are involved in the oxidation number model, making it difficult for teaching and learning at junior levels.

As the historical development of the terms used are seldom given, this gives rise to confusion with the everyday use of the terms. For example, "to reduce means to gain (electrons), contrasting to decrease in everyday language [and] oxidations need not comprise reactions with oxygen" (Ringnes, 1995, p.77). Schmidt (1997) reported that many students misled by the 'ox' in 'redox' into thinking that oxygen must be involved in any redox reactions. Linguistic complexity such as 'the oxidant is reduced' and the 'reductant is oxidised' also appeared to cause student confusion (De Jong et al., 1995). Davies (1991) and Ringnes (1995) believe that the concepts in redox should be given a "thorough linguistic, historical and chemical presentation" (Ringnes, 1995, p. 77). All the models should be taught because, as Davies (1991) argues, "each model has its own utilitarian value in providing the simplest explanation of certain reactions" (p. 137). However, the advantages and limitations of the various models should be highlighted as well as the areas where the models overlap and where they are in conflict.

Chemical equilibrium

Chemical equilibrium is a difficult topic because it includes numerous other complex chemical concepts such as stoichiometric relationship, solubility and concentration (Gabel & Bunce, 1994). Studies have shown that there are many alternative conceptions on chemical equilibrium (Banerjee, 1991; Garnett et al., 1995; Gorodetsky & Gussarsky, 1986; Hackling & Garnett, 1985; Quilez & Solaz, 1995; Voska & Heikkinen, 2000). Some alternative conceptions that students have are that chemical equilibrium is static in nature or involves oscillating behaviour, that reversible reactions go to completion, that the forward reactions increases with time, and that the forward reaction rate always equals the reverse reaction rate. Other alternative conceptions determined include that the equilibrium constant changes when concentration of components or volume of gases is altered, that when the forward rate of reaction is increased, the reverse rate of reaction is decreased, that a catalyst will only speed up the forward reaction, and that Le Chatelier's principle applies to heterogeneous systems without considering the phases of the components in the system.

Tyson, Treagust and Bucat (1999) believe that student difficulties arise because of the content of chemical equilibrium is "abstract, has a high degree of linkage with other content areas in chemistry, and is highly sophisticated in that interpretation required of terminology and concepts is very specific" (p. 557). In addition, Van Driel, de Vos and Verloop (1999) maintain the introduction of chemical equilibrium requires students to revise their previous understanding of chemical reactions as being one-way and proceeding to completion; they now also have to consider reversibility of chemical reactions and the possibility that reactions do not proceed to completion. Ahtee and Varjola (1998) believed that the conflict between what was taught initially and later could cause great confusion to students. Another source of student confusion pointed out by Quilez and Solaz (1995) was that the studies on student conceptions and difficulties in chemical equilibrium were ignored by authors of general chemistry texts and by teachers. For example, many authors and teachers still promoted the use of Le Chatelier's principle as an infallible rule despite its shortcomings.

METHODOLOGIES FOR INVESTIGATING STUDENT CONCEPTIONS

The section discusses selected methodologies used in this study to define the content framework and investigate students' conceptions in qualitative analysis. Concept mapping is used in Chapter 3 to define the content framework of O-level qualitative analysis. It is not used to investigate students' conception in this study because this author found, when he previously taught qualitative analysis, that students drew flowcharts of how ions were identified instead of concept maps. To investigate students' conceptions of qualitative analysis in this study, interviews and written tests were used. Interviews were used to collect data (described in Chapter 5) which were used to develop a two-tier multiple diagnostic instrument on qualitative analysis (described in Chapter 6). The diagnostic instrument was administered to Grade 10 and junior college students, undergraduates and graduate trainee-teachers to determine their understanding of qualitative analysis, and the results obtained are discussed in Chapters 7 and 8.

Yarroch (1985), and Gabel and Bunce (1994) believes that the ability of a student to choose the correct answer or solve a problem does not indicate that the student has understood the concepts involved; more information is required to determine the nature of the knowledge that a student possesses. A variety of methods have been used to investigate students' understanding of concepts. These methods include clinical interviews, multiple choice tests, concept mapping, sorting tasks, student drawings, and open-ended questions. The nature and uses of clinical interviews, multiple choice tests and concept mapping are discussed in the following sections.

Duit (1995), Duit et al. (1996), and Johnson and Gott (1996) warn that what researchers call students' conceptions are actually their own conceptions about the students' conceptions. Thus the researcher has to be aware of the pitfalls of investigating students' conceptions. For example, students' responses can be misinterpreted as their perspectives may be different from the researchers. Another danger is that researchers may read too much into the students' responses and come up with interpretations which are far from the students' own ideas. Thirdly, the students' conceptions may be created by the study and not brought to light, that is, the students may never have thought about the concept or phenomena before but had to invent something to answer the question or perform the task required by the researcher. Fourthly, students might give responses which they think the researcher expects and which are not their actual ideas. In addition, any data collected cannot be considered as "students' unchanging views" (Duit et al., 1996, p. 21), but only as instances of conceptions at a given moment in time as construction and reconstruction of conceptions are ever on-going. Johnson and Gott (1996) proposes the creation of a "neutral ground [in which] a largely (but never completely) undistorted communication takes place between the child and researcher" (p. 565). They believe that to develop a neutral ground, the tasks given must be neutral, interpretation must proceed in the neutral ground and that triangulation must be a priority.

The level of understanding of a given concept and the range of contexts in which the concept is expected to be used also must be specified in a study and agreed upon by the researchers and the teachers of the students involved (Hashweh, 1986). These specifications prevent the testing of any concept if it was not taught to the students, or if it was not the aim of the course to foster understanding of the concept at the level tested.

Concept mapping

Concept maps are intended to represent meaningful relationships between concepts in the form of propositions (Novak & Gowin, 1984). Propositions are two or more concepts linked by words describing the relationships between the concepts. Thus a concept map is a kind of visual map showing the relationships between the meanings of concepts in proposition. Novak and Gowin (1984) state that concept maps should be hierarchical, that is, the more general, more inclusive concepts should be at the top of the map with progressively more specific and less inclusive concepts arranged below. Related concepts are then linked by words describing their relationships. The number of valid concepts and propositions will indicate the amount of scientifically acceptable knowledge that a student has, the number of branching and hierarchies indicate the degree of conceptual differentiation and subsumption, while the number of cross-links suggest conceptual integration or cohesion (Markham & Mintzes, 1994).

Concept mapping is a skill which has to be learned. Novak and Gowin (1984) give the procedures for teaching students of various ages concept mapping. Students must be taught how to extract specific concepts from printed or oral material and identify relationships among the concepts before writing them down in the form of concept maps. Students' language ability is important for concept mapping as without the appropriate vocabulary, the students may not be able to express their ideas logically (Kinchin, 2000). The maps must then be evaluated and redrawn, a few times if necessary, to correct errors, increase their meaningfulness and tidy them up. Thus a considerable amount of time will be taken up before the students are able to submit reasonable concept maps. However, students may not be willing to spend the time and effort necessary to produce well-constructed concept maps, especially if they are not worth the credit given (Markow & Lonning, 1998). The analysis of the students' concept maps if the maps are extensive, will also be time consuming as one has to look out for all the important concepts to determine if any are missing, and examine all the links and linking words to determine if they are valid.

Interviews

Interview methods, for example, interview about instances and interview about events (Carr, 1996; Osborne & Gilbert, 1980; White & Gunstone, 1992), are very useful for exposing the nature of students' understanding and possible alternative conceptions. An interview about an instance is a deep probe of the student's understanding of a single concept (White & Gunstone, 1992). It is a conversation that an expert has with one student, focussed by initial questions about situations represented in a series of line diagrams that checks not only whether the student can recognise the presence of the concept in specific instances, but also whether the student can explain his or her decision. The quality of the student's understanding can be determined by his or her explanation. Interviews about events are similar probes though the emphasis is now on the student's interpretation of a natural phenomenon or social occurrence and his or her ability to explain it (White & Gunstone, 1992). Interviews also can involve the manipulation of concrete objects (Lazarowitz & Tamir, 1994; White & Gunstone, 1992), and students can be asked to explain the outcomes of their manipulations, for example, the results obtained when two chemical reagents are mixed.

Interviews can be structured, semi-structured or unstructured. In a structured interview, a series of questions, called a protocol, is prepared prior to the interview, and the interviewer has to follow rigidly the series of questions. In a semi-structured interview, the interviewer also follows a sequence of questions prepared beforehand, but he or she is allowed to probe the interviewee's answers with additional questions. In an unstructured interview, the interviewer asks open-ended questions, and based on the response given by the interviewee, more specific follow-up questions are asked to probe any point of interest. Carr (1996) believes that unstructured interviews are difficult to sustain and are confrontational for interviewees, so the interviewer must have a set of questions in mind for use when necessary.

Interviews are highly flexible because they allow the interviewer to change his or her mode of questioning when required; the interviewer can rephrase the questions if the interviewee does not understand the questions, and he or she can probe any response to obtain clarification and elaboration from the interviewee. Thus the interview allows the interviewer to probe the interviewee's ideas in as much detail as desired (Taber, 1998b). The interview situation also allows the interviewee to ask questions, for example, to clarify perceived or actual ambiguities before attempting to answer a question (Osborne & Gilbert, 1980). An advantage that interviews have over written answers is that students "cannot easily ignore a question and give no answer, or omit to give a reason for an answer, or simply produce an answer by guessing" (Osborne & Gilbert, 1980, p. 318). However, as Duit et al. (1996) point out, much experience is needed to carry out interviews effectively and much background knowledge is needed to make valid interpretations of students' responses. Thus classroom teachers are not likely to conduct individual interviews, especially they have limited time and high enrolments (Treagust, 1995). In addition, many teachers are not trained to prepare for and conduct interviews, record and transcribe interview data, or to interpret findings (Fensham, Garrard & West, 1981). Teachers also may have difficulty in "moving from Socratic teaching, where they helped individuals understand the ideas being probed, to noncuing, probing interviewing" (Novak & Musonda, 1991, p. 124), may turn interviews into an oral examination instead of encouraging dialogue (Osborne & Gilbert, 1980), or may have difficulty in refraining from comment or teaching when the student says something wrong (White & Gunstone, 1992). In addition, if the interviewer is also the teacher of the interviewee, the interviewee may be reluctant to voice negative opinions (Markow & Lonning, 1998).

Multiple choice tests

Multiple choice tests have been used for measuring students' understanding of concepts as they enable a large number of students to be sampled in a given amount of time as compared to time consuming interviews. These tests are also easy to administer and score, and the results obtained are also easily processed and analysed (Peterson et al., 1989; Taber, 1999a; Tan & Treagust, 1999). Researchers such as Doran (1972), Halloun and Hestenes (1985), Peterson, Treagust and Garnett (1989), Tamir (1971), Taber (1997, 1999a), and Voska and Heikkinen (2000) have used multiple choice tests to determine students' conceptions in science. However, there are problems associated with the pencil-and-paper tests. For example, multiple choice tests "make some demands on the reading/comprehension skills of the respondents" (Taber, 1999a, p. 99), and students do not "always perceive and interpret test statements in the way that test designers intend" (Hodson, 1993, p. 97). Since they have little recourse for clarification, misunderstandings do occur and this affects the validity and reliability of the tests. Bar and Travis (1991) warned that students could be induced to choose distractors that appear 'scientific'; they conducted a study of phase changes using three formats, an oral test, multiple choice questions and open-ended written questions, and found that the apparently more scientific alternative conceptions detected in the multiple choice questions were rarely brought up in the two other test formats. Taber (1999a) cautioned that only the most common alternatives were likely to be diagnosed as the test writer, based on previous research, would have to leave out the less common ones to avoid too many distractors.

Students' test-wiseness skills may affect the validity and reliability of the test (Towns & Robinson, 1993). Strategies such as time-management, error avoidance, checking responses and elimination of incorrect answers do not damage the validity and reliability of a test while strategies that take "advantage of consistent idiosyncrasies of the test constructor such as grammatical agreement, length of response, location of response, and previous emphases of the test constructor" (Towns & Robinson, 1993, p. 710) do. Guessing, when students do not know the answer, is also a problem in multiple choice tests. However, Tamir (1990) expressed his opinion that if a test consisted of cognitively high level items, students should be advised to attempt all items, diagnostic instrument, the propositional knowledge is to be specified clearly. The items in the instrument are to be developed based on known student conceptions, student-drawn concept maps and responses from students to interviews and free response items. This methodology has been used to develop diagnostic tests on photosynthesis and respiration (Haslam & Treagust, 1987), and diffusion and osmosis (Odom & Barrow, 1995) in biology; in chemistry, diagnostic instruments were developed for covalent bonding (Peterson, 1986; Peterson & Treagust, 1989; Peterson et al., 1989), chemical bonding (Tan, 1994; Tan & Treagust, 1999), and chemical equilibrium (Tyson et al., 1999). The instrument on covalent bonding bonding (Peterson, 1986; Peterson & Treagust, 1989; Peterson et al, 1989) was used by Goh et al. (1993) in a cross-cultural comparison between Australian and Singaporean students, and in a cross-age study by Birk and Kurtz (1999) to determine the retention of specific misconception over time, as well as the extent to which students consistently hold misconceptions.

Voska and Heikkinen (2000) noted that two-tier tests had the disadvantage of detecting far fewer conceptions than students may actually possess within a content domain and that a multiple choice test in which students had to supply their reasons for their choices could detect more alternative conceptions. They, however, did also acknowledge that the use of such approach within large classes was not feasible, and that the teacher's analysis and interpretation of results might be fraught with errors without formal training and without the benefit of information from student interviews. Thus the selection of a multiple choice test with free response justification or a two-tier multiple choice test depends on the goal of the researcher or teacher in using the test.

QUALITATIVE ANALYSIS

In Singapore, the topic, qualitative analysis, is tested mainly in the practical paper of the O-level pure chemistry examinations; a few questions also may appear in the theory papers. The syllabus for pure chemistry (UCLES, 1996) spells out the requirements for practical work; for qualitative analysis, students are required to follow a sequence of instructions, select and use techniques, apparatus and reagents, make and record observations, and interpret as well as evaluate observations and experimental results. In addition, to understand the purpose of the procedures and to interpret and evaluate their results, students need to apply what they have learn in topics such as 'Acids, Bases and Salts', 'Oxidation and Reduction', 'Reactivity of Metals' and 'Periodicity'.

Zubrick (1992) and Zieger (1993) believe that traditional 'wet chemistry' qualitative analysis is still relevant in the age of powerful modern computer-controlled analytical instruments because students learn process skills as well as carry out many of the reactions that they learn in their lessons and textbooks. Practical sessions are ideal for bringing the macroscopic, microscopic and representational aspects of chemistry together (Johnstone, 1999). Thus qualitative analysis is very relevant and important to a chemistry course as it strengthens the students' understanding of chemistry (Cooley & Williams, 1999).

This section discusses the possible reasons why students find qualitative analysis difficult, as well as, selected studies on practical work which could help in the development of instructional materials and procedures to help students understand the concepts involved in qualitative analysis, and master the process skills and strategies required in qualitative analysis practical work.

Reasons why qualitative analysis is difficult

From this author's own teaching experience and the experiences of teachers with whom the author worked in Singapore schools, students find qualitative analysis one of the most difficult topics in their chemistry course. Students' difficulties may arise from not knowing explicitly what is required in qualitative analysis, the content of qualitative analysis, the lack of motivation, cognitive overloading and the lack of mastery of the required process skills.

Not knowing what is required

Many teachers find that upper secondary chemistry students frequently do not understand what they are doing in the qualitative analysis laboratory sessions. The students do not seem to see the links between what they have learnt in class and what they do in practical work. This lack of understanding was also highlighted by the O-level chemistry examiners in various reports (UCLES, 1994; 1995; 1997; 1998). Students frequently do not think for themselves and seem unaware of what they should be doing in the laboratory sessions (Berry, Mulhall, Gunstone, & Loughran, 1999). If students do not have the theory to guide their experiments, it is likely that they will not know what to think about and what to take note of in the experiments (Hodson, 1992). However, teachers assume they do, and thus, seldom emphasise or make explicit the purpose of and the theory behind the procedures (Tasker & Freyberg, 1985). In 1983, Novak, Gowin and Johansen (1983) argue that school learning involves "ritualistic use of procedural elements, without understanding the interplay between conceptual and methodological elements" (p. 629), and it appears that the situation still exist today as Domin (1999a,b) contend that many laboratory activities still are designed to facilitate the development of lower-order cognitive skills such as rote learning and algorithmic problem solving. The typical qualitative analysis experiment is no different, so it seems unreasonable for teachers to expect students to 'think qualitative analysis' when teachers do not make explicit what students should think about in the first place, and do not design worksheets for such a purpose.

McDermott (1988) contends that one of the causes of students' lack of understanding of chemistry is the failure to integrate knowledge. This is seen in qualitative analysis where students either cannot or do not know that they have to make extensive links between theory and practical work. Tasker and Freyberg (1985) pointed out that lessons were frequently seen by students as isolated events with no connections to the previous lessons or topics. In the laboratory, students tend to view each experiment as a single event, unrelated to other experiments or content knowledge that they have learned because they lack appropriate frameworks that could guide their investigations (Berry et al., 1999; Duit & Treagust, 1995; Gunstone, 1991). This is shown in qualitative analysis in the inability of students to use knowledge from topics such as 'Acids, Bases and Salts', 'Oxidation and Reduction', 'Reactivity of Metals' and 'Periodicity' to make sense of the experiments. The students act as though they never encountered the concepts before, as though each lesson is "encapsulated into a separate episode that has no relationship to anything that came before or that comes afterward" (Costa, 1991, p. 104).

Reif and Larkin (1991) believe that students view science knowledge "predominantly as a valuable collection of facts and formulas, rather than as a conceptual structure enabling numerous predictions" (p. 740). Hence their goal is to memorise facts and formulas rather than "learn a few basic principles and reasoning methods enabling many diverse inferences" (p. 740). The secondary school students have an instrumental understanding (Skemp, 1976) of qualitative analysis; they know how to test for the various cations, anions and gases but not the reactions involved. Reif and Larkin (1991) also believe that students do not fully perceive the need to organise their science knowledge in a "globally coherent and logically consistent" (p. 747) manner because such organisation is not required for their everyday life knowledge. Students may have the facts but do not know how to organise and link them together, or think that it is important to do so, hence it is not surprising that they have difficulty in applying their facts and formulas.

Tasker and Freyberg (1985), and Fensham and Kass (1988) also pointed out that discrepancies in intent would lead to discrepancies in action. Students' actions are governed by the purpose they established for an activity. Since the tasks in the practical work are often not clearly defined, students must often define the tasks for themselves and provide their own goals and structure (Pintrich et al. 1993). However, left to themselves, they have "difficulty establishing any meaningful overall purpose [in the experiments, so] their purpose and actions degenerate to simply following instructions" (Tasker & Freyberg, 1985, p. 72); the tasks of assembling apparatus and making required observations or measurements become the focus of student action (Gunstone, 1991). These actions result in qualitative analysis being reduced to a mechanical level which has little intellectual involvement. Another consequence of lack of direction in experiments is that the student's aim becomes "one of guessing what the teacher wants from an activity or 'getting the right answer'" (Tasker & Freyberg, 1985, p. 74). The 'right' answer becomes the goal, undermining the importance of the processes leading to the answer, resulting in little cognitive involvement (Pintrich et al., 1993). Students also will be more inclined to ignore discrepant results, give up easily or ask the teacher for help rather than solve any problems encountered (Berry et al., 1999)

Content of qualitative analysis

Another reason why students find qualitative analysis difficult could be the content of qualitative analysis. White (1994) described several properties of science content that influenced how the content should be taught and learned. These are openness to common experience, abstraction, complexity, presence of alternative models with explanatory power, presence of common words, mix of types of knowledge, demonstrable versus arbitrary, social acceptance, extent of links and emotive power. Students do not encounter qualitative analysis in normal everyday life, only in the laboratory, so they have virtually no conception of it. The concepts behind the procedures in qualitative analysis and the reactions that occur are abstract, complex and extensively linked to other concepts. For example, Fensham (1994) pointed out that students found what happened when substances were heated confusing because the substance could dehydrate, decompose, change its state, or undergo a combination of the processes. Qualitative analysis also involves a mix of knowledge and skills such as propositional and procedural knowledge, and manipulative and inferential skills. Thus it is not surprising that students find qualitative analysis very demanding and difficult.

Motivation to understand

Pintrich et al. (1993) state that students' motivational beliefs about themselves, and their learning contexts could facilitate or hinder conceptual change learning. In Singapore, it seems that the goal of many students is to obtain good results rather than understand what they are learning. Thus the goal of students in qualitative analysis is mainly to do well in the practical examination paper, contributing to the student's overall grade in chemistry. This "backwash effect of examinations" (Skemp, 1976, p. 24) works against the aim of understanding what one learns – especially if understanding is not essential for doing well in the examinations! Goh et al. (1987) highlighted that 'drill and practice' in qualitative analysis practical work was pervasive in schools to prepare students for the practical examinations as good results can be obtained by 'training' to do the experiments and writing the 'right' answers. This 'drill and practice' practical work demands little cognitive effort but pays off handsomely in terms of results. Since there is no incentive for students to spend time and effort understanding qualitative analysis concepts they tend to follow instructions without much thought and little useful learning is likely to occur (White, 1991). Thus, it can be seen that the "assessment procedures distort and narrow instruction" (Treagust, 1995, p. 327) in qualitative analysis.

In addition, the performance goal may be embraced and reinforced by the teachers and school administrators themselves. Teachers may concentrate more on doing past years' examination questions and on writing 'model' answers rather than on enhancing students' thinking and understanding. School administrators, mindful of the school's position in the school performance league table, most likely encourage and reward such teaching and learning activities which enhance examination results. So, it can be seen that the goal orientation beliefs (Pintrich et al., 1993) of the students, teachers and schools may work against the meaningful learning of qualitative analysis. Rop (1999) describes the situation aptly by stating that "there are significant sociocultural incentives and pressures that support traditional school performances than for deep understandings of chemistry" (p. 222). Novak (1996) also commented that "many factors in this school milieu conspire against practices that would encourage meaningful learning" (p. 38).

As mentioned previously, Treagust et al. (1996) suggested that many students held a passive view of learning, so the need to think constantly and actively did not count as "legitimate work in school" (p. 3). Students also may not have a sense of efficacy as a thinker; "they perceive thinking as hard work and recoil from situations that demand 'too much' of it" (Costa, 1991, p. 105). Tsai (1999) found that the students' epistemological views of science affected their learning in school laboratory activities. Students with empiricist views of science placed greater emphasis in the 'doing' rather than the 'meaning' or 'understanding' of practical work. Tsai suggested that the "typical cookbook-like laboratory activities may misguide students' epistemological views about science" (p. 671). These may be additional reasons why qualitative analysis is reduced to a mechanical level with little intellectual involvement, a situation with which students are more familiar and comfortable. This low cognitive level learning also rewards them with good grades, so there is no apparent need to think about and understand what they are doing in qualitative analysis. Since students might not make any attempt at thinking and understanding as they are not needed to score good grades, the assessment system should be changed to make it more consistent with constructivist goals (Gunstone, 1994).

Overloading

Nakhleh and Krajcik (1994) contend that a laboratory experiment is "a complex learning environment, and students may become so overwhelmed with the task at hand that they literally have no memory space left with which to think conceptually" (p. 1095). Similarly, Johnstone and Wham (1982) describe practical work in general as having too much 'noise' and argue that students' working memory is bombarded with information of various kinds, such as, written and verbal instructions, new manipulative skills, unfamiliar labelling of reagents, and inputs from the experiment itself. In addition, the students have to recall manipulative skills and background theory, and associate names for apparatus and reagents. Thus, practical sessions seem to consist of "an avalanche of things to do and little time is left for thought" (Johnstone, 1999, p. 46), a situation which is exacerbated when there are time constraints (Johnstone & Letton, 1991). What has been described so far is true for qualitative analysis. Students need to read instructions, carry them out, prepare additional tests, observe, record and interpret their results, as well as, being mindful of the time left to complete the experiments and their reports. The resulting overloading of the working memory leaves "no space for thought and organisation and so faulty (or even no) learning takes place" (Johnstone, 1984, p. 847).

Lack of mastery of required skills

Another complaint of teachers is that students do not know how to carry out the procedures in qualitative analysis experiments properly. Unfortunately, many teachers do not spend time in helping students develop such procedural skills. Consistent with this situation, Herron (1996) commented:

> We seldom make deliberate efforts to teach laboratory skills that, much to our chagrin, students have never learned. By teaching, I do not mean telling students what to do or performing a quick

> demonstration in front of the class. I mean carefully prepared lessons, with clear statements of expectation, feedback to individual students so that they can correct errors, and evaluation at the end of instruction to be sure that the lesson is learned. I am talking about doing what any good coach would do in teaching a psychomotor skill. (p. 20)

Woolnough and Allsop (1985) also stressed the need for students to develop practical scientific skills and techniques. Hodson (1990) succinctly summed up the situation by stating that "It is not that practical work is necessary in order to provide children with certain laboratory skills. Rather, it is that certain skills are necessary if children are to engage successfully in practical work". (p. 36)

In qualitative analysis, teachers need to explicitly teach students skills such as how to dissolve substances, add reagents, test gases, and heat substances, as well as how to make valid observations and inferences (Gunstone, 1991). They also need to ensure that their students practise and master these skills. Goh et al. (1987, 1989) found that many students lack mastery of process skills in qualitative analysis, so, it would seem that this aspect of qualitative analysis had been neglected. Bekalo and Welford (1999) believed that teachers might not have sufficient training and guidance in conducting practical work. Thus teachers might not know what to teach or how to teach during the practical sessions.

Teaching and learning qualitative analysis

A number of reasons have been provided for the students' apparent inability to learn qualitative analysis meaningfully. These include lack of understanding of the purpose and critical features of the experiments (Tasker & Freyberg, 1985), lack of appropriate frameworks (Duit & Treagust, 1995), lack of cognitive strategies (Gunstone, 1994; Wittrock, 1994), the content of qualitative analysis

(White, 1994), motivational beliefs and learning contextual factors (Pintrich et al., 1993), passive view of learning (Treagust et al., 1996), overloading (Johnstone & Wham, 1982; Nakhleh and Krajcik, 1994) and lack of mastery of process skills (Goh et al, 1987, 1989; Herron, 1996). Selected studies related to practical work are reviewed in this section to provide a theoretical framework for the development of an instructional package on qualitative analysis.

Woolnough and Allsop (1985) offered some suggestions which could improve the teaching and learning of qualitative analysis. Firstly, they believe that tacit knowledge is important; students should gain first hand knowledge of the materials and "a feel for the phenomena" (p. 34) involved in qualitative analysis. This instinctive knowledge will help students to "build up personal constructs" (p. 35) which will help them in "acquiring theoretical understanding of the underlying concepts later" (p. 46). Hodson (1992, 1993) and Lazarowitz and Tamir (1994) agree with Woolnough and Allsop. Hodson (1992, 1993) claims that familiarisation of the physical world precedes making sense of it, and Gabel (1999) believes if students are unfamiliar with the materials used in chemistry instruction, learning becomes abstract and conceptual understanding is hindered.

Woolnough and Allsop (1985) gave examples of 'experiences' in their book (p. 59), those relevant to qualitative analysis include studying chemical changes with colour changes, precipitate formation and gas evolution. Costa (1991) contends that students should use all senses to learn as "those whose sensory pathways are open and alert absorb more information from the environment than those whose pathways are oblivious to sensory stimuli (p. 105). Barrow (1991) believes that students need to be exposed to reagents and the transformation of the reagents to make them "part of the body of experience that can be drawn automatically, when higher level thoughts are processed" (p. 453). White (1991) also considers 'episodes' or the recollection of events important to illuminate knowledge and make it more comprehensible. In the introductory sessions, students should spend some time experiencing relevant phenomena, thinking and discussing about them. The teacher could then introduce the theory behind the phenomena, and students should be better able to construct meaning from what the teacher says after experiencing the phenomena, thinking and talking about them. This method is similar to the orientation, elicitation of ideas and restructuring of ideas sequences in the constructivist teaching sequence outlined by Driver and Oldham (1986) to draw students "inside the problem" (Driver & Scott, 1996, p. 100).

The teacher also can use Vee heuristics (Novak et al., 1983) in laboratory instruction to make explicit the relevant concepts and theories involved in the experiments. In the case of qualitative analysis, students should have studied the relevant content knowledge before they started on the series of experiments, so the task of the teacher is to help students make the links (McDermott, 1988) between the content knowledge that they have already learned and what they are doing in the experiments. This should help students understand the rationale behind the procedures and reagents used in the experiment (Gabel, 1999), something on which current practice places insufficient emphasis (Novak et al., 1983; Osborne, 1993). Another advantage of explicitly linking what is taught in classroom to what is done in the laboratory is the enhancement of students' attitudes towards chemistry (Wong & Fraser, 1996). Fensham, Gunstone and White (1994), and Berry et al. (1999) believe that better learning occurs when students understand why they need to make links between what they learned and then actively seek these links for themselves. However, students may not know where to start, or may not even know that they have to make links, so, the teacher has to bring it to their attention. Unfortunately, teachers seldom show how the topics fit together (Bodner, 1992).

Woolnough and Allsop (1985) also advocate 'exercises' to develop practical skills and techniques as well as 'investigations' to allow students opportunities to act as scientists. Hodson (1990) believes that students are often put in situations where "their inadequate skill level acts as a considerable barrier to learning" (p. 36). Exercises on the process skills required in qualitative analysis should be designed for its own sake as it would be difficult for students to cope if they try to master certain skills and, at the same time, attend to other aspects of the experiments (Hodson, 1990; Woolnough & Allsop, 1985). The skills required in qualitative analysis include how to add reagents to unknown samples, how to heat samples, how to determine whether a precipitate is formed, and how to test for gases. White (1991) contends that repeated practice creates knowledge of procedure and precautions, thus teaching one how to behave in the laboratory. However, Herron (1996) believes that teachers often neglect to teach laboratory skills.

Investigations must be the "heart of practical work [as it gives the students practice and opportunity to] develop competence, in working like a real problem-solving scientist" (Woolnough & Allsop, 1985, p.51) and to reflect on what they are doing (White, 1991). Driver and Oldham (1986) believe that investigations or what they call the 'application phase' in their constructivist teaching sequence consolidates and reinforces new learning by "extending the contexts within which they are seen to be useful" (p. 118). Marzano and Pickering (1991) contend that ultimately learning must involve the meaningful use of knowledge and that science inquiry is very suited for this purpose. So after students have experienced all the relevant phenomena and mastered the manipulative skills required, they can be given unknown samples to determine the cations and anions present without being given instructions on what to do. This forces them mentally active (Shiland, 1999) and engage in higher order thinking in order to plan their own experiments (Domin, 1999a,b). Cooley and Williams (1999) reported that students who had to plan the qualitative analysis experiments themselves stated that they enjoyed the experiments and learned much from them. This supports Hodson's (1990, 1993) beliefs that older students will be motivated by practical work if the tasks focussed on the conceptual aspects of the experiments and students are allowed to design the procedure to be adopted. Thus, conducting investigations paves a way of developing conceptual understanding. To make qualitative analysis more relevant and interesting to students, 'real life or practical' experiments can be given to students (Hodson, 1992). For example, Vincent (1999) described how qualitative analysis was used to uncover the Piltdown Man hoax, and how a similar laboratory experiment can be given to students to simulate the Piltdown Man investigations. However, Berry et al. (1999) caution that open investigations may not lead to improved learning as once students have done their planning, they may proceed with minimal engagement in the task, that is, without considering the quality of their data and how it relates to the procedures they have chosen.

Goh et al., (1987, 1989) developed a schema, the Modified Laboratory Instruction (MLI), for improving the mastery of process skills. This schema involves the systematic building up and the formative monitoring of students' manipulative and process skills, assisting students to comprehend the meaning and purpose of each instructional procedure, and the use of Piagetian-based worksheets. Emphasis is also placed on mental preparation (Beasley, 1985), the cause of wrong results and the process of getting correct ones. Goh et al. (1987, 1989) found that students with MLI experiences generally did better in a practical test and a pencil-and-paper alternative-to-practical-test than those who were taught using traditional methods. These students also showed more positive attitude toward laboratory work, as well as greater confidence in their own manipulation of laboratory apparatus. Similar results were obtained by Tsoi (1994), who extended the study of MLI to include computer-assisted instruction.

Costa (1991), Gunstone (1994) and Wittrock (1994) stress the importance of students being conscious of their thought processes. The need to be metacognitive learners (Gunstone, 1994) "who undertake the tasks of monitoring, integrating and extending their own learning" (p. 135) is clearly required in qualitative analysis. Students need to have tactical control (Pintrich et al., 1993), they need to ask questions such as "What is the purpose of this procedure?", "What reaction can possibly occur when I carry out the procedure?", "What do I have to look out for?", "Have I prepared everything that is necessary for this procedure?", "What results can I expect?" and "Does the result make sense to me?". Being able to predict what would happen in experiments is beneficial; Linn and Songer (1991) found that students who actively predicted outcomes and reconciled results in their experiments had greater understanding of the content involved. White and Mitchell (1994) described several studies on training in metacognition and some positive effects it had on students, such as, designing tests of alternative beliefs and a readiness to accept the verdict of those tests. Osborne (1996), however, questions whether all students are capable of metacognitive activity and whether there is a critical age below which children cannot be metacognitive.

One way of teaching metacognitive skills to students is for teachers to show their students the strategies and thinking that they, themselves, would use in carrying out qualitative analysis. Reif and Larkin (1991) state that students have significant learning difficulties in science because they do not know what kinds of cognitive processes are required in science. Thomas and McRobbie (1999) believe that teachers should assist students "in becoming more reflective and metacognitive" (p. 667) by teaching them how to plan, monitor, evaluate and regulate their learning processes. The required cognitive processes in qualitative analysis can be made explicit by the verbalisation, modelling and coaching of appropriate thinking and strategies by the teacher (Pintrich et al., 1993; Volet, 1991). Teachers need to unveil the "experts' normally covert thinking process" (Volet, 1991, p. 321). Firstly, they need to show students how to deduce which reactions are involved in the experiments by interpreting the procedures given in the worksheets. This knowledge is important as the students need to know what to look out for in the reactions, which gases may be liberated, and which reagent and apparatus they need to prepare before carrying out the procedure. Secondly, teachers also need to show their students how they themselves would carry out the experiments by thinking aloud, explaining the steps and precautions they took and the decisions they made. This would show the students the appropriate behaviours required to carry out qualitative analysis successfully. Students also need to practise these strategies and behaviours, reflect on their thinking and receive feedback on their performances in order to internalise the metacognitive strategies successfully (Volet, 1991). Swartz (1991) proposed similar activities in his discussion of ways to infuse critical thinking into content instruction. Including the use of a science writing heuristic suggested by Keys, Hand, Prain and Collins (1999) in qualitative analysis investigations could provide a suitable platform for such activities. Students believe that practical work requires interaction with equipment but minimal thinking, so teachers need to help students to rethink about practical work as "a thinking task supported by laboratory equipment" (Berry et al., 1999, p. 31).

Johnstone and Wham (1982) recommend that the 'signal' of the experiment be enhanced by making the point of the experiment clear, and the 'noise' be suppressed by stating clearly what is preliminary, peripheral and preparatory. They also suggest that manipulative or interpretative skills be taught for their own sake, rather than doing it in experiments where students, at the same time, need to collect data. Once students mastered the required process skills, they can go on 'auto-pilot', freeing memory space for processing information. Johnstone and Letton (1991), and Johnstone (1999) propose the use of 'pre-labs', preparative work before a practical session, so that students will know "what to expect, and can recognise the unusual for what it is" (Johnstone, 1999, p. 47), as well as, participate in the planning of the experiments so that they know "what is essential and what is peripheral and do not clutter their working memory with trivia" (p. 47). McDowell and Waddling (1985), Johnstone and Letton (1991), Dechsri, Jones and Heikkinen (1997), and Bennett (2000) suggest some methods for improving laboratory worksheets to minimise the 'noise' in practical work. These include using simple and precise language, sequencing experimental procedures into numbered steps, using flowcharts, and using clear and uncluttered diagrams to illustrate procedures. All these can be incorporated into the introductory sessions on qualitative analysis to suppress 'noise' and enhance 'signal'.

Teachers, schools and examination boards also need to encourage understanding rather than rote learning, and drill and practice. Students will learn from their schooling which practices and attitudes are viable (Rop, 1999) and they certainly will not be inclined towards learning for understanding if the school system does not reward it or deem it necessary for success. Rop, however, found that some students were interested in chemistry and wanted to have deeper understanding of what they had been taught. These students felt that "success in chemistry class would be both more valuable and more satisfying if it included these deeper understandings" (p. 229). He also noted that parents and school administrators would become upset if teachers concentrate less on preparing students for test and examinations but force the students to think about difficult ideas. Thus parents, school administrators and teachers need to reconsider the aims of schooling and whether students' understanding of what they have learned is as important as getting good results.

ANALYSIS OF TEXTBOOKS

This section discusses selected studies on analysis of textbooks to provide insights into how textbooks and workbooks influence the teaching and learning of qualitative analysis in Singapore, as well as, how to develop instructional material for qualitative analysis.

Textbooks are very important in science education as they are generally the sole source of information on the subject for both teachers and students, and influence the curriculum, coverage of content and teaching approaches (Chiang-Soong & Yager, 1993; De Jong et al., 1995; Eltinge & Roberts, 1993; Sanger & Greenbowe, 1997, 1999). In the United States, teachers used textbooks in excess of 90% of the time, students expected science lessons to be centred around textbooks, and parents expressed concerned if textbooks were not issued and used for assignments (Chiang-Soong & Yager, 1993).

Since textbooks play such a dominant role in school science, they need to be carefully evaluated (Eltinge & Roberts, 1993) so that textbook learning is "meaningful, conceptually integrated, and active" (de Posada, 1999, p. 427). Textbook content should be free from ambiguities and alternative conceptions, should present and explain information, help students to relate new material to that already learnt, and help students to integrate the material presented explicitly in a coherent way. Analysis of textbooks can indicate the procedures, content, sequences and activities that are used in the classroom, trends in science education, and the "pedagogical, psychological, and epistemological positions of textbook authors" (de Posada, 1999, p. 425). Textbooks have been analysed as sources of alternative conceptions (Cho, Kahle & Nordland, 1985; Sanger & Greenbowe, 1999) and for the use of analogy (Curtis & Reigeluth, 1984; Thiele, Venville & Treagust, 1995). They also have been analysed to determine the treatment of topics and concepts (Dall'Alba et al., 1993; de Berg & Treagust, 1993; de Berg & Greive, 1999; de Posada, 1999; Palmer & Treagust, 1996; Shiland, 1997), the treatment of various issues of science literacy and goals of science education (Chiang-Soong & Yager, 1993; Wilkinson, 1999), and how science is portrayed (Eltinge & Roberts, 1993).

Sanger and Greenbowe (1999) analysed 10 college-level chemistry texts for examples of statements or drawings that could lead to alternative conceptions in electrochemistry. They found that many illustrations and statements used in the textbooks could be misinterpreted by students. Examples include the use of vague or misleading terms such as 'ionic charge carriers' and always drawing the anode as the left-hand half-cell. Sanger and Greenbowe (1999) suggest that the extent to which textbooks contain vague, misleading or incorrect material could be used as a basis for textbook selection. Indeed, Cox (1996) reported the replacement of a series of science books in a school because of "an excessive number of needless errors" (p. 23).

Analogy is used in science textbooks to help students understand science concepts. Curtis and Reigeluth (1984) believe that the most effective use of analogies is as an advance organiser to enable students to link new knowledge and as an embedded activator to explain preceding information and introduce subsequent material. Analogies in four biology and ten chemistry textbooks were analysed by Thiele et al. (1995) to determine the nature of the shared analog and target attributes, the presentational format of the analogy, the degree of abstraction of the analog and target, and the extent of mapping. Thiele et al. found that the biology and chemistry textbooks had similar proportions of structural, functional and structural/functional type analogies, but chemistry textbooks had less pictorial but more verbal analogies. Chemistry textbooks also had a higher proportion of concrete analog/abstract target analogies but a lower frequency of concrete analog/concrete target analogies as compared to biology textbooks. Thiele et al. contend that many of the analogies were presented without the provision of overt mapping of attributes; this may lead to the formation of alternative conceptions as students are left to their own interpretations of the mapping of attributes. Thus they recommend that students learn to recognise analogies in textbooks so that they do not assume a one-to-one correspondence between the analogies and reality by being able to distinguish the 'likes' and the 'unlikes' between the analog and target (Treagust, 1993). Harrison and Treagust (1998) reported that nearly every textbook they examined failed to warn readers that analogies or models are "human inventions that break down at some point" (p. 424). de Posada (1999) also contends that the models used to describe metallic bonding in Spanish textbooks are metaphorical in nature and are open to misinterpretation. de Posada believes that this makes students' understanding of metallic bonding difficult, leading to "unreflective and noncritical memorization of the subject matter" (p. 440).

Stinner (1992) highlighted that textbooks tend to emphasise the logical aspects of science topics and concepts, neglecting the evidential and psychological dimensions. Linn and Songer (1991) believe that textbooks focus on isolated facts and definitions, provide abstract and/or incomplete explanations, and cover too much content in too little depth, preventing "construction of integrated understanding" (p. 891). Shiland (1997) analysed the material on quantum mechanics in eight secondary chemistry textbooks for four elements, namely dissatisfaction, intelligibility, plausibility and fruitfulness, associated with a conceptual change model. He found that the four elements were not present in sufficient quantities to encourage students to accept quantum mechanics over the simpler Bohr theory. Fourteen chemistry textbooks used in Australian schools were analysed by de Berg and Treagust (1993) to determine the extent to which qualitative discussion and exercises, as well as qualitative-to-quantitative sequences were used in the textbooks to present material on the properties of gases. They also analysed the nature of the gas law sequences used by textbooks in the presentation of gas properties. They found minimal qualitative treatment of the gas laws and moderate use of a simple-to-complex sequence with no cognitive gaps. de Berg and Treagust suggest that an increase in the use of qualitative exercises and a complex-to-simple sequence could promote greater understanding of gas laws as "patterns of association between the elements of a concept established up and down a knowledge hierarchy help to foster integrative reconciliation, which strengthens understanding" (p. 880). Dall'Alba et al. (1993) also found that textbooks focussed on quantitative treatment of acceleration at the expense of qualitative explanations left students by themselves to "gain a clear idea of the physics involved" (p. 626).

In an analysis of the 11 most frequently used science textbooks in the United States to determine the attention given to science-technology-society (STS) topics, Chiang-Soong and Yager (1993) found little coverage of STS (0.5% to 11.5%) and the coverage decreased with increasing grade level. This pointed out a great discrepancy between the goals for science education with an STS emphasis and the actual coverage of STS content in the textbooks. In an analysis of high school biology textbooks to determine the degree to which science was portrayed as a process of inquiry, Eltinge and Roberts (1993) found that the portrayal of science as a process of inquiry increased from 1956 to 1965 and then declined to its lowest level in 1985. They believed that the decline was due to a shift in the emphasis of goals in science education when science inquiry also lost favour in schools primarily because teachers were generally not educated to present science as inquiry, and facts were easier to teach and to test than the processes in inquiry. They cautioned that the teacher's use of the textbook was a "confounding variable [in their study as] a textbook may a very high level of inquiry, but a teacher could use it in a manner that emphasizes rote learning" (p. 79). Wilkinson (1999) believes that textbook authors write to cover content that appears in examinations; if greater emphasis is placed on other goals of science literacy besides the knowledge of science, then perhaps there will be a corresponding increase in emphasis given to these areas by the authors.

SUMMARY

In the first part of the literature review, the nature of learning was discussed. Next, the nature of alternative conceptions, studies of students' conceptions in chemistry, and methodologies for investigating students' conceptions were described. These provided the theoretical and methodological framework for the development of the two-tier multiple choice diagnostic instrument on qualitative analysis, which is described in Chapters 3, 5 and 6, and the use of the diagnostic instrument to study students' understanding of qualitative analysis, which is described in Chapter 7 and 8. The review of literature on the roles and analyses of textbooks guided the analysis of two textbooks and two workbooks on qualitative analysis, which described in Chapter 4. Finally, the literature on practical work provided reasons why students find qualitative analysis difficult, and guided the development on a teaching package on qualitative analysis, which is described in Chapter 9.

CHAPTER THREE

IDENTIFICATION OF CONCEPTS AND PROPOSITIONAL KNOWLEDGE STATEMENTS

INTRODUCTION

This chapter describes the development of the content framework in response to Research Question 1 which seeks to identify the concepts and propositional knowledge necessary for secondary chemistry students to understand the topic of qualitative analysis. This is the first phase in the development of a multiple choice diagnostic instrument as outlined by Treagust (1986, 1988, 1995). A concept map, a list of propositional knowledge statements and a list of facts were prepared at a level of sophistication appropriate to the understanding required by students who are preparing for the O-level pure chemistry examinations.

IDENTIFICATION OF SUBJECT CONTENT

Five procedures were used to limit and specify the subject content related to the topic, qualitative analysis. They were as follows:

1. Extract the relevant sections of the O-level pure chemistry syllabus for 1999 (UCLES, 1996) pertaining to qualitative analysis,
2. Develop a concept map on qualitative analysis,
3. Identify the propositional knowledge needed to understand the reactions and procedures involved in qualitative analysis,
4. Relate the propositional knowledge to the concept map,
5. Identify the necessary facts required for the understanding of qualitative analysis.

These five steps were necessary to ensure that the content and hence the development of the two-tier multiple choice items was based on the concepts and propositional knowledge which were being taught to the students preparing for the O-level pure chemistry examinations.

The concept map, list of propositional statements and list of facts were reviewed by three tertiary chemistry academics, Dr. Aw, Dr. Chung and Dr. Lim to ensure the accuracy of the material. All tertiary educators and secondary teachers are referred to by pseudonyms in this study. In addition, four senior secondary chemistry teachers, Mrs. Ang, Mrs Boon, Mrs. Chen and Mrs. Deng Lim, also reviewed the concept map, propositional knowledge statements and facts, as well as the extracts of syllabus to ensure that they were appropriate to, and fully met the requirements of, qualitative analysis in O-level pure chemistry.

EXTRACT OF SYLLABUS PERTAINING TO QUALITATIVE ANALYSIS

There is no specific section in the pure chemistry syllabus (UCLES, 1996) on qualitative analysis. Under the 'Scheme of Assessment' section in the syllabus, it is stated that candidates may be asked to carry out exercises based on tests for oxidising and reducing agents as specified in the syllabus, and to identify the ions and gases as specified in the syllabus (Appendix B). In Appendix B, the requirements for redox reactions, and the cations, anions and gases which students are required to be able to identify, are listed, together with the reagents that they are required to use. Students are not required to identify any species not in the list, but they may be required to deduce its properties based on its reactions with the reagents in the various procedures.

However, based on this author's teaching experience, he believed that what was given in Appendix B did not adequately describe the scope of qualitative analysis that secondary students were doing. This author examined the pure chemistry syllabus and extracted all parts of the syllabus that he considered were required for students to understand what they were doing in qualitative analysis (Appendix C). Even then, this author considered that there was still content not included in the syllabus which the students needed to know in order to understand qualitative analysis. The four secondary chemistry teachers agreed that the extract of the syllabus in Appendix C better matched the requirements of qualitative analysis in Chemistry 5070 than the section described in Appendix B. However, Mrs. Ang remarked that there was a lot of content involved, and that she would not incorporate some of the content identified in Appendix C in her lessons on qualitative analysis. Her arguments are elaborated in the section on the concept map.

The main reactions which occur in qualitative analysis are redox, double decomposition, displacement, thermal decomposition and acid/base reactions. These reactions were highlighted in Appendix B, under the sections on 'Redox', 'Acids, Bases and Salts', 'Periodic Table', and 'Metals'. Parts from the topics of 'Hydrogen', 'Nitrogen', 'Sulphur' and 'Organic Chemistry' also were extracted because they were specific examples of reactions which students would encounter in qualitative analysis. For example, in the 1991 O-level practical examinations, students were asked to add alcohol to an unknown sample after acidifying and heating the sample. The reaction involved was redox, specifically the oxidation of ethanol to ethanoic acid; this reaction was mentioned in the syllabus in the section on organic chemistry.

THE CONCEPT MAP

The concept maps in this study were prepared following the procedure described by Novak and Gowin (1984). The arrangement of the concepts is hierarchical with the more general, more-inclusive concepts at the top of the map, and the progressively more specific and less inclusive concepts arranged below. Related concepts are then linked by words describing their relationships.

The first concept map (Appendix D) that this author produced was divided into three main branches – cations, anions and gases – the species that students were required to identify. However, this map did not appropriately address the most essential and inclusive concepts in qualitative analysis, that is, the reactions which occur. These should be placed higher in the hierarchy. Some examples of such reactions are acid-base, acid-salt, double decomposition and redox. Some tests for cations, anions and gases involved the same type of reaction, for example, double decomposition; these seemingly different tests should be grouped under the reaction involved to show that they involved similar concepts. A tertiary chemistry educator, Dr. Aw, also remarked that the concept map was more like a flow chart for carrying out qualitative analysis than a concept map. With these points in mind, the concept map was redrawn and revised several times. The final version of the concept map is given in Figure 3.1.

Positive tests

Only positive tests for the various species were given in Figure 3.1. For example, there was no reaction between calcium ions and aqueous ammonia, so calcium was left out of the concept map even though the negative test gave clues to the identity of the unknown cation. Where gases were evolved, the identification of these gases would indicate the identity of the unknown ions present. When any ions could be positively identified, given the criteria in the syllabus, the ion would be listed as being identified; if not, it would be given as an example. For instance, if a precipitate disappeared when excess sodium hydroxide was added, students would know that the precipitate contained either aluminium or zinc ions but they could not be certain exactly which was present using the sodium hydroxide test; they need to use aqueous ammonia for this purpose.

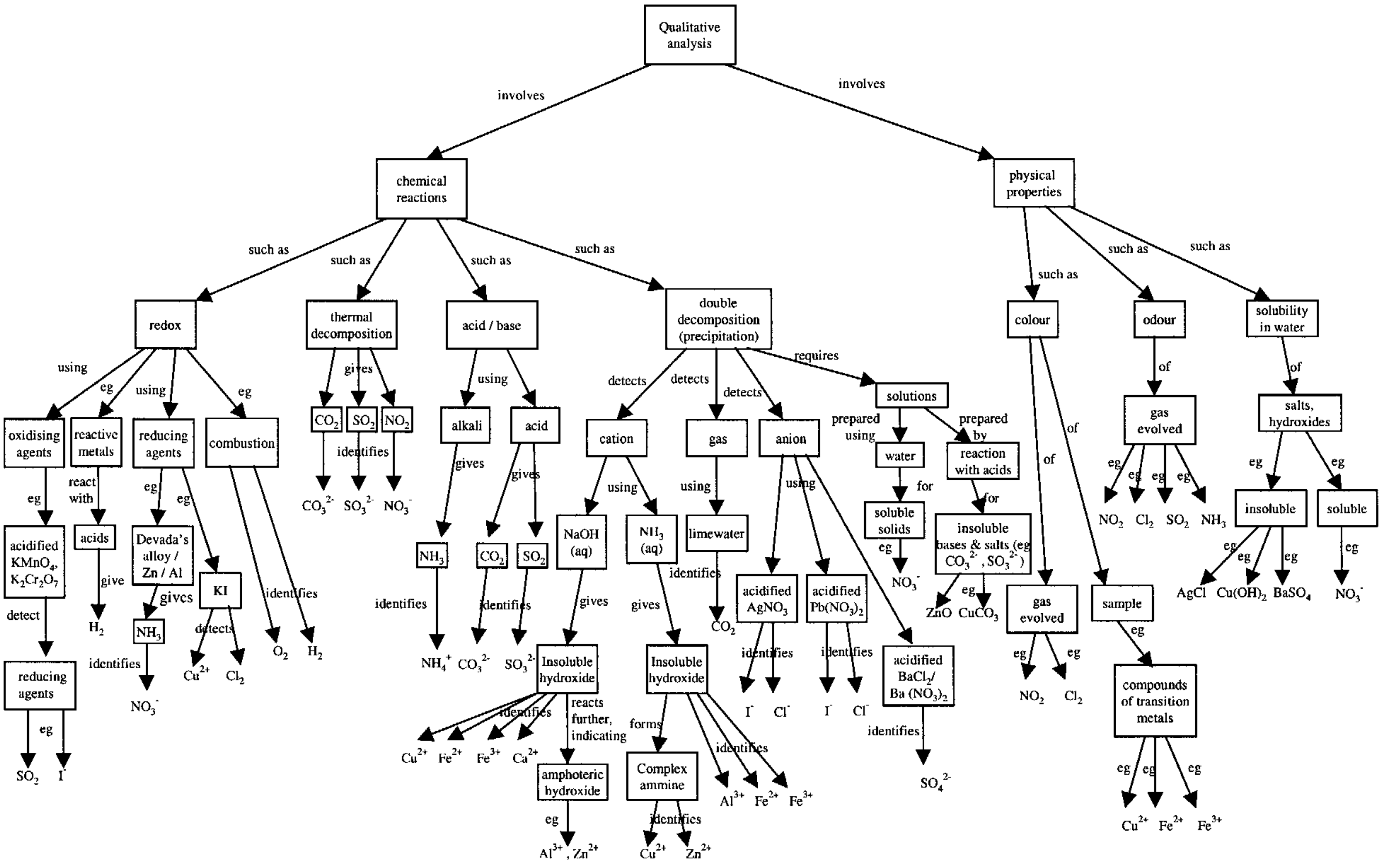

Figure 3.1: Concept map on qualitative analysis

Flame tests

Flame tests, though not in the syllabus, were included in the first version of the concept map because it was assessed in the June 1997 practical examinations. Though students in Singapore take only the October/November O-level examinations, the June examination papers serve as a guide to what questions may be asked in October/November. Thus, from 1997 onwards, many schools in Singapore introduced flame tests. This author believed that because detailed instructions were given on the procedures and for the interpretation of results obtained, the aim of the flame tests in the June 1997 paper was to test students' competence in carrying out the procedures and making observations. Subsequently, flame tests were removed from the concept map because they were considered to be a 'one off' task. Even if flame tests were to appear in an October/November paper, this author expected detailed instructions to be given to the students to perform similar tasks as the June 1997 paper; Mrs. Ang concurred with this opinion.

Precipitation/Double decomposition (Part I)

Mrs. Ang pointed out, in her review of the concept map (Figure 3.1), that her students might not be familiar with the terms 'double decomposition' and 'thermal decomposition' as she used the terms 'precipitation' and 'decomposition by heating' in her teaching. Mrs. Boon also said that she did not teach the term 'double decomposition'. However, Mrs. Chen said that her students were familiar with the two terms. This author believed that it was not significant whether one used the term 'thermal decomposition' or 'decomposition by heat', but the term 'precipitation' merited further discussion. In the first instance, this author considered precipitation reaction as a subset of double decomposition reactions since in secondary school qualitative analysis, double decomposition reactions resulted in the formation of precipitates. Thus this author believed that both terms could be used, with 'precipitation' being more specific, a view with which a tertiary chemistry educator, Dr. Beng, shared. However, another tertiary chemistry educator, Dr. Chung, argued that double decomposition and precipitation reactions were different types of reactions. Double decomposition described reactions which, in his view, involved exchange of partners, while precipitation described reactions in which sparingly soluble salts were formed as solids. He further elaborated that double decomposition usually, if not always, was accompanied by precipitation, but precipitation reactions could encompass non-double decomposition reactions as well. Examples of such precipitation reactions given by Dr. Chung were the precipitation of sulphur when sodium thiosulphate was acidified, and the formation of copper (I) iodide from the reaction between a copper(II) salt and potassium iodide. This author agreed with Dr. Chung's arguments. However, this author also was aware that students might not have been taught the term 'double decomposition', as pointed out by Mrs. Ang and Mrs. Boon, because the term was not listed in the syllabus and did not appear in three approved chemistry textbooks. Students should know that the formation of a precipitate in qualitative analysis usually involved the exchange of ions since they were required to write down equations describing such a reaction, but they were not required to know exceptions to it. Thus this author decided that in this study, he would accept either term to mean the formation of a precipitate resulting from an exchange of ions when aqueous solutions were mixed. As a result, the term 'precipitation' was included in the concept map. In addition, the propositional statement on double decomposition also was modified to include the term.

Content not specified in the syllabus (Part I)

Mrs. Ang also pointed out that there was some content in the concept map, such as the thermal decomposition of nitrate(V) salts and sulphate(IV) salts, which was not specified in the pure chemistry syllabus. This author takes up this issue up later in this section and in the section on propositional statements. In addition, Mrs. Ang remarked that she had never viewed qualitative analysis in the way that it was organised in the concept map. She explained that her school was a typical average government secondary school and the calibre of her students was not academically high. Her students already had problems in following instructions and carrying out the qualitative analysis experiments as they were, and to bring in so much content would be counter-productive as they would not be able to handle it. She believed that too much content would confuse and discourage her students. She remarked that it was unrealistic for her to spend extra time elaborating on the reactions involved because qualitative analysis accounted for only ten percent of the total marks of the chemistry examination. In addition, understanding the reactions was rarely tested in the practical examinations; marks were awarded mainly for the correct observations. She also needed to face reality; her school's ranking in the annually published academic league table was important, and thus she needed to concentrate on the things that would help her students get better results, even at the expense of students not understanding what they were doing.

> I don't have time to teach them everything that they need to know...I can't...I have to focus on achieving results...I get them geared towards achieving a certain grade...I mean it may be wrong, but ultimately what the school wants is good results...so we focus on achieving good grades.

The constraints of time and students' ability, as well as the realities of the examinations, affected the way Mrs. Ang taught qualitative analysis. Qualitative analysis became a mechanical activity, with Mrs. Ang and her students concentrating more on the 'mechanics' of the activity. She tried to ensure that her students could carry out the required procedures and write the 'expected' observations.

> I only gear them towards observations because the O-levels only require them to write the correct observations...so I gear them towards recording the correct observations, how to carry out the tests, how to get marks from the report...so I'm very focussed...I don't have time to explain every detail...what reaction is taking place.

Mrs. Ang admitted that her teaching was focussed on the syllabus and the examinations, and that she would only change her present way of teaching qualitative analysis if the questions in the examinations required greater student understanding of the reactions. This was an example of how the assessment procedures "distort and narrow instruction [and] misrepresent the nature of the subject" (Treagust, 1995, p. 327). It was interesting to note that Mrs. Ang also admitted that many of her students found chemistry at the Singapore-Cambridge General Certificate of Education Advanced Level (A-level) difficult, perhaps due to her 'fault' in following the O-level syllabus too strictly.

Mrs. Boon teaches in the Gifted Education Programme in a top academic ranking independent government secondary school and her students were among the top 5 percent of their cohort in Singapore. When she was asked to express her opinion on the material which was not included in the syllabus, she said that it was part of the chemistry involved in qualitative analysis.

> Sometimes we tell the pupils that this is not in the syllabus...but it is part of the chemistry itself...I'm looking more at the process...how this information is linked and whether it makes sense.

She explained that a teacher might want to bring the material in to explain what was happening in qualitative analysis, but at the same time informed his/her students that the material was not in the syllabus. She said the material was useful in giving students a clearer picture of qualitative analysis, to see how concepts were linked so that they made better sense. When she taught the topic on reactivity of metals, she discussed the stability of compounds such as metal nitrate(V) salts with respect to the reactivity of the metals present in the compounds to give students a more complete picture on reactivity.

> We also discussed a little on their compounds...we say that the more reactive the metal, the more stable its compound...so even though it is not exactly included in the syllabus, we talked about it...otherwise it's

> quite incomplete...we talked about the reactivity of the metals and about their compounds...and what is the relationship?

However, she did add that she could go deeper into a topic or concept because her students were, in general, highly intelligent, and could grasp and understand concepts well.

Mrs. Boon found the concept map very detailed and useful but said that it might be quite complex for her students and that they needed time to understand it.

> As a teacher, I find the concept map very comprehensive and useful because it's like a summary...I would say that this is what we are trying to teach the pupils...that at the end of it, they are able to link all the information together and make sense of what they have been doing. But for the pupils, I don't know whether they have the tenacity...the determination...to look through every bit...I think they will need some time to decipher all the information, but it will help them to piece all the information together...it will take quite some time for them.

Mrs. Boon claimed that a reason why qualitative analysis was difficult for students was that they learn facts and concepts in isolation, and thus, were unable to link or apply their knowledge under different circumstances. In her opinion, the concept map would be very useful in showing students the links and relationship among concepts in qualitative analysis.

Mrs. Chen teaches in the same school as Mrs. Boon, but her students were in the normal academic programme; still they were among the top ten percent of their cohort in Singapore. Like Mrs. Boon, Mrs. Chen also taught most of the material which Mrs. Ang pointed out not to be in the syllabus. She felt that her students needed to know what was happening to understand qualitative analysis better. Another consideration was that the material explained procedures that had appeared in previous O-level examinations. However, she said that she faced the dilemma of where to draw a line in teaching additional material, and often wondered whether the material would actually help students to understand qualitative analysis, or whether it would confuse them even more.

> I really don't know how much we ought to cover...are we confusing them or are we helping them? I really don't know. But how can you do chemistry without knowing all these things?

Mrs Deng teaches in an above-average independent church-affiliated school. She also taught her students most of the material which was not included in the syllabus because she believed that it would help them to understand the reactions that occur in qualitative analysis and why they were carrying out the given procedures, as well as, helping them remember what they had learnt. Her view is supported by Skemp (1976) who also believe that it is easier to remember knowledge if one understands it and inter-relate it as parts of a connected whole.

> As a teacher...I find it necessary to explain to them...otherwise it will be very difficult for them to connect what they learn and then it will be difficult for them to remember on a long-term basis.

She would tell her students that though the material was not in the syllabus and that they were not required to write the equations involved, they needed to have an idea what was happening for their own good. She also mentioned to them that the material would help them if they take chemistry at the A-level, so it was not a waste of time and effort knowing it.

> I will tell them...you just listen and know that such things exist. If you have time, it's good for you to read up. If not, just take it that such things do exist...but you need to know all about it at A-level.

Mrs. Deng, like Mrs. Chen, also has problems deciding on how much additional content to cover as the syllabus does not adequately define what to teach for qualitative analysis.

> We're in a quandary...how much to cover and how much not to cover...so when time permits I will cover. They (UCLES) should state the theoretical aspects of what the boys need to know, the practical aspects of what they need to do, and then what kind of deductions they ought to make based on the kind of observations that they get.

PROPOSITIONAL KNOWLEDGE STATEMENTS

Propositional knowledge statements were written for the content and concepts relevant to the topic of qualitative analysis. Apart from the statements on redox reactions which were taken from Garnett and Treagust (1992), the rest of the propositional knowledge statements were identified by this author from the O-level pure chemistry syllabus, his personal teaching experience, a chemistry textbook and two qualitative analysis manuals. The list of propositional knowledge statements consists mainly of statements on the reactions which occur in qualitative analysis and includes other reactions than those specified in the O-level pure chemistry syllabus. Thus, secondary chemistry teachers may not teach some of the propositional knowledge statements. The reasons for inclusion of such reactions are that they occur frequently in the experiments that the students do and many of these reactions are very similar to the ones that the students have learned. Furthermore, these reactions also are not beyond the understanding of the secondary students. The propositional knowledge statements were revised several times based on reviews by Drs. Aw, Chung and Lim, Mrs. Ang, Boon, Chen and Deng, and from the data obtained in Study One (Chapter 5).

The first version of the propositional knowledge statements is given in Appendix E, with four statements (32, 33, 34 and 35) taken from Garnett and Treagust (1992). After reviewing the list, Dr. Aw remarked that there were a number of facts which should not be in the list. He defined facts as entities which were found at the lowest levels in a concept map, for instance, specific examples of reactions or concepts. He gave examples such as "Acids turn blue litmus paper red" and "Soluble metal hydroxides and aqueous ammonia are alkalis". He also pointed out that a few statements were either not precise or non-inclusive. For example, "Acids ionise in water to form hydrogen ions" needed revision as only when substances ionise in water to liberate hydrogen ions would they be considered as acids. The points brought out by Dr. Aw were addressed when the list of propositional knowledge statement was revised.

This author also realised that there were propositional knowledge statements that did not have direct impact on qualitative analysis, and thus were subsequently deleted when the list was revised. Examples of such statements included those stating that the degree of ionisation of acids and alkalis determined the strength of the acids and alkalis. Students needed to know the properties and reactions of acids and alkalis, but the strength of acids and alkalis was not an issue in O-level qualitative analysis. The statement on flame tests also was deleted from the list when it was revised, following similar arguments presented in the discussion of the concept map on qualitative analysis.

The final version of the propositional knowledge statements for qualitative analysis is given in Figure 3.2. Changes which had been made included the rewording of a few statements to make them more precise and inclusive, the deletion of several inappropriate statements, the transfer of facts to a separate list, and the inclusion of a few statements as a result of Study One.

Arguments for inclusion of content not specified in the syllabus

The statement on the heating of hydroxides was removed as it was not stated in the syllabus and was not important to the students. However the statements (5, 13, 19 and 20) on the reaction of acids with sulphate(IV) salts, the formation of complex ammines, and the heating of nitrate(V) and sulphate(IV) salts were still retained though they were not stated in the syllabus because they were pertinent to qualitative analysis. For example, students were expected to test for sulphur dioxide but they were not required to know how this gas could be formed. Thus

1. When a substance ionises in water to produce hydrogen ions, an acid is formed.
2. Hydrogen ions are responsible for the reactions of acids.
3. When a more reactive element is added to a solution of an ionic compound of a less reactive element, a displacement (redox) reaction may occur, forming the less reactive element and the ionic compound of the more reactive element. (Normally reactive metals displace less reactive metals, and reactive non-metals displace less reactive non-metals. However a reactive metal may react with a dilute acid to displace hydrogen and produce the salt of the metal.)
4. An acid will react with a carbonate to produce a salt, carbon dioxide and water.
5. An acid will react with a sulphate(IV) to produce a salt, sulphur dioxide and water.
6. An acid will react with a base to produce a salt and water only.
7. When an acid reacts with a metal, an insoluble base, carbonate or sulphate(IV) to form an insoluble salt, the reaction may stop after a while due to the formation of the insoluble salt which coats the solid reactant particles, preventing further reaction with the acid.
8. If an acid is to be added before or after the addition of a barium, silver or lead(II) reagent to an unknown solution, the anion of the acid must be the same as that of the barium, silver or lead(II) reagent respectively. This is to prevent the introduction of an additional anion which may interfere with the reactions.
9. Alkalis are substances which produce hydroxide ions when dissolved in water.
10. Hydroxide ions are responsible for the reactions of alkalis.
11. An alkali will react with an ammonium salt to produce a salt, ammonia and water.
12. An amphoteric oxide/hydroxide is an oxide/hydroxide of a metal which will react with either an acid or an alkali to produce a salt and water.
13. Aqueous ammonia will react with zinc hydroxide, copper(II) hydroxide and silver chloride to produce the respective soluble complex ammines.
14. A precipitation/double decomposition reaction is a chemical reaction which involves the exchange of ions when two or more aqueous solutions of ionic compounds are added together, and results in the formation of a sparingly soluble ionic compound (which precipitates out of the solution).
15. The solubility of a salt in water determines whether it forms a precipitate during double decomposition reactions.
16. If a precipitate is formed due to the formation of an insoluble hydroxide, the colour of the precipitate and whether it reacts with excess aqueous sodium hydroxide or aqueous ammonia identifies the cation.
17. The ease of decomposition of ionic compounds by heat and the types of products formed depend on the reactivity of the metal present in the compound. The greater the reactivity of the metal, the more difficult it is to decompose the compound by heating.

Figure 3.2: List of propositional knowledge statements pertaining to O-level qualitative analysis

18. Most carbonates decompose on heating to form the oxide and carbon dioxide.

19. Most sulphate(IV) salts decompose on heating to form the oxide and sulphur dioxide.

20. Most nitrate(V) salts decompose on heating to form the oxide, nitrogen dioxide and oxygen.

21. The physical properties of a substance, for example, colour, odour and solubility, may help in the identification of the substance.

22. Oxidation can be defined as
    a. the gain of oxygen.
    b. the loss of hydrogen.
    c. the loss of electrons.
    d. an increase in the oxidation state.

23. Reduction can be defined as
    a. the loss of oxygen.
    b. the gain of hydrogen.
    c. the gain of electrons.
    d. a decrease in the oxidation state.

24. An oxidising agent (oxidant)
    a. causes the oxidation of another species.
    b. accepts electrons from the species being oxidised.
    c. is reduced.

25. A reducing agent (reductant)
    a. causes the reduction of another species.
    b. donates electrons to the species being reduced.
    c. is oxidised.

26. Oxidation-reduction (redox) reactions involve simultaneous oxidation and reduction processes.

27. Oxidising agents are identified through the use of specific reducing agents (e.g. aqueous potassium iodide). Colour changes produced in the reactions indicate the presence of oxidising agents.

28. Reducing agents are identified through the use of specific oxidising agents (e.g. acidified potassium dichromate(VI) or acidified potassium manganate(VII)). Colour changes produced in the reactions indicate the presence of reducing agents.

29. When a solid solute dissolves in a liquid solvent, a homogeneous mixture of the solute and the solvent is obtained; the solute can be recovered in its original form simply by removing (e.g. evaporating) the solvent.

30. A solute dissolves in a solvent because of the interaction among the solute and solvent particles. Generally, in a solution, the attraction between the solute-solvent particles is greater than the attraction between the solute-solute or solvent-solvent particles.

Figure 3.2 (continued): List of propositional knowledge statements pertaining to O-level qualitative analysis

how would they know when to test for the gas if they did not know when the gas would be evolved? This author considered that the lack of this knowledge would result in students randomly testing for this gas, and Mrs Boon and Chen concurred with this view. Mrs Chen also pointed out that the thermal decomposition of sulphate(IV) as well as its reaction with acids 'parallels' that of carbonates, so it was not much additional work for students. Mrs. Ang, who chose to follow the syllabus closely, said that although she did not teach her students the reactions liberating sulphur dioxide, she did teach them to test for the gas. This, she added, was all that was required and students could learn it easily. Similarly, students were required to test for oxygen but they were not required to know that when nitrate(V) salts were heated, oxygen, and in many cases, nitrogen dioxide would be liberated. Thus, students might not know that they have to prepare to test for oxygen when they heat a solid, especially if the brown fumes of nitrogen dioxide were evolved. Students also would not aware of why some precipitates reacted with excess aqueous ammonia while others did not; it is due to the formation of a complex salt (ammine). Mrs. Chen pointed out that the formation of ammines was similar to the formation of zincates and aluminates that was in the syllabus, so students should be able to understand it. Mrs. Deng said she would contrast the formation of ammines to that of zincates and aluminates to highlight that the formation of ammines was not due to the amphoteric nature of the ions involved though the two reactions were similar.

This author strongly believes that it is undesirable to instruct students to carry out procedures and get results without understanding what had occurred and why they had obtained such results. This approach would result in the procedures being meaningless to students, and produce gaps in their knowledge and understanding. Mrs. Ang agreed with the author, but she argued it was not worth the time giving students content which would not be tested; only when her students were curious enough to ask her, which was seldom, did she explain the reactions. As mentioned previously, stark realities such as her students' abilities and the requirements of the examinations were given attention rather than the ideals of teaching for understanding.

Displacement

The propositional statement on the reaction of acids with reactive metals in the first list (Appendix E) was substituted by a more inclusive statement on displacement. The students were taught that displacement was a redox reaction in which a more reactive element took the place of a less reactive element in a compound, resulting in the formation of the less reactive element and the compound of the more reactive element. The usual examples given to students were the reaction of zinc with aqueous copper(II) sulphate(VI) leading to the formation of copper and zinc sulphate(VI), and the reaction of chlorine with aqueous potassium bromide leading to the formation of potassium chloride and bromine. However, students were not explicitly taught that the reaction of acids with reactive metals, resulting in the formation of a salt and hydrogen gas, also was a displacement or redox reaction. They were usually taught this reaction earlier, in the chapter on 'Acids, Bases and Salts', and many regarded it as 'just another acid reaction'.

There was some confusion over the term 'displace' as it was sometimes used loosely, to mean 'replace'. The reaction between aqueous zinc chloride and aqueous sodium hydroxide resulted in the formation of a white precipitate, zinc hydroxide. The reaction was often described as 'sodium ions displacing the zinc ions, or hydroxide ions displacing the chloride ions to form the precipitate' in this author's interviews with students. The reaction between zinc chloride and sodium hydroxide was a double decomposition (metathesis) reaction and not a displacement reaction as no redox reaction was involved. It was interesting to note that Dr. Aw, an organic chemist, remarked that he would accept the loose description of 'hydroxide ions displacing chloride ions' but not 'sodium ions displacing the zinc ions', which could be considered as another way of describing the same reaction. This author believed that Dr. Aw's acceptance of an anion displacing another anion might have come from the description in organic chemistry, of a nucleophile 'displacing' another nucleophile in a nucleophilic substitution reaction.

Precautionary statements

This author referred to propositional statements 7 and 8 in Figure 3.2 as 'precautionary' statements. Although these statements were not explicitly taught to students, they were included because they explained certain procedures which students carry out, and they were within the students' ability to understand. Certain procedures required student to make solutions from insoluble substances, and instructions would be given on how to prepare the solutions, usually by adding specified acids to the insoluble substances. When asked in the interviews (described in Chapter 5) why the specified acids were used or whether any acid other than the specified ones could be used, very few students could give an explanation. Most times, students could not give any reason, saying that they just followed instructions. It was not surprising that qualitative analysis was meaningless to many students since they did things without understanding the underlying reasons. Students learned that certain salts were insoluble and most teachers required them to memorise a list of soluble and insoluble salts. Propositional knowledge statement 7 required the application of this knowledge to the making of solutions. In most cases, dilute nitric(V) acid would be used as the nitrate(V) salts formed were soluble; dilute sulphuric(VI) acid and dilute hydrochloric acid should be used with caution as some sulphate(VI) salts and chlorides were insoluble. Propositional knowledge statement 8 explained why certain acids must be used when students needed to acidify a mixture of an unknown sample after the addition of a barium, silver or lead(II) reagent.

Precipitation/Double decomposition (Part II)

As mentioned in the earlier section on the concept map, the propositional knowledge statement on double decomposition needed to be modified to accommodate the term 'precipitation'. This author used the definition of 'precipitate' as given in the Concise Dictionary of Chemistry (Oxford Science Publications, 1985) as "a suspension of small solid particles produced in a liquid by chemical reaction" (p. 233) to help him revise precipitation/double decomposition as follows:

> A precipitation (double decomposition) reaction is a chemical reaction which involves the exchange of ions when two or more aqueous solutions are added together, and results in the formation of a suspension of small solid particles in a liquid.

Dr. Chung suggested some changes to the above statement to highlight the formation of the precipitate due to double decomposition and the low solubility of the precipitate:

> A precipitation (double decomposition) reaction is a chemical reaction which involves the exchange of ions when two or more aqueous solutions *of ionic compounds* are added together, and results in the formation of a *sparingly soluble ionic compound (which precipitates out of solution).*

Using the suggestions from Dr. Chung and bearing in mind the arguments that this author had made in favour of accepting the equivalence of the terms 'precipitation' and 'double decomposition', the proposition knowledge statement on precipitation/double decomposition was finalised as in statement 14.

Redox

This author's thesis supervisor commented on a question, in Study One, concerning the choice of acid to acidify potassium dichromate(VI), that from the four propositional statements from Garnett and Treagust (1992) on redox reactions, students could still not work out which acid to choose. To address this, this author thought of including the following statement.

> Whether a substance can be oxidised or reduced depends on the oxidation state of the constituent elements in the substance. Generally, if the constituent elements are in the highest oxidation state, then the substance can only be reduced, and if the constituent elements are in the lowest oxidation state, the substance can only be oxidised. If any of the constituent elements is in an intermediate oxidation state, then the substance can be either oxidised or reduced.

Dr. Chung remarked that redox reactions are not as straightforward as the statement implied. He gave the example of the manganate(VII) ion where manganese was in its highest oxidation state but oxygen was in its lowest oxidation state, and said it was virtually instinctive for chemists to know that oxygen in the manganate(VII) ion would not be involved in the redox reaction. However, secondary chemistry students had no way of knowing that. He commented that the only practical thing to do was to state in the syllabus which oxidants and reductants the students needed to know, and ask the students to memorise their behaviours as factual knowledge. He suggested the following statement:

> A strong oxidising agent may oxidise both strong and weak reducing agents, but a weak oxidising agent may only oxidise strong reducing agents; similarly, a strong reducing agent may reduce both strong and weak oxidising agents, but a weak reducing agent may only reduce strong oxidising agents.

He also suggested that the above statement should be followed by a list of examples of strong and weak oxidising and reducing agents which were in the syllabus.

However, students were required by the syllabus to know only a few oxidants and reductants, and nothing on the strength of the various oxidants or reductants.

In addition, they were only required to know that a redox reaction had taken place if certain oxidants and reductants, which were specified in the syllabus, exhibited known colour changes when added to unknown samples. With these in mind, the author added another statement (26) from Garnett and Treagust (1992) which he had earlier overlooked, and wrote two more statements (27 and 28) which described how secondary students could determine whether a redox reaction had taken place, and identify whether the given unknown sample was an oxidising or reducing agent. Even with these statements on redox reactions, it was still beyond secondary school chemistry students to work out which acids to use to acidify potassium dichromate(VI); their teachers need to supply the reasons.

Dissolution

Originally, this author did not have any statement on dissolution until the last few versions of the list of propositional statements were drawn up. The need for statements 29 and 30 resulted from the interviews that the author conducted with students in Study One, as well as his reflections on several statements in the syllabus.

Studies have shown that students have difficulty in understanding dissolution (Abraham et al., 1994; Boo, 1994; Buell & Bradley, 1972; Butts & Smith, 1987; Ebenezer & Erickson, 1996; Fensham, 1994; Longden et al., 1991; Nusirjan & Fensham, 1987; Prieto et al., 1989). In this study, the point of contention on dissolution was whether, at the secondary level, it should encompass chemical reactions. As mentioned earlier, zinc hydroxide was produced when zinc chloride reacted with sodium hydroxide. When excess sodium hydroxide was added, the precipitate of zinc hydroxide would react further with it to form sodium zincate, a soluble complex salt. The formation and dissolution of this complex salt that gave rise to the disappearance of the white precipitate. The above reaction is described in the data sheet that students are given in the practical examinations, the 'Notes for Use in Qualitative Analysis' (reproduced in Appendix A), as "white ppt., soluble in excess giving a colourless solution". This author believed that the above description could give rise to the misconception that the precipitate dissolved because extra solvent (the excess aqueous sodium hydroxide) was added (Tan & Koh, 1999). In any case, if aqueous sodium hydroxide was considered to be a solvent, no precipitate should be formed at all when it was first added to zinc chloride. Mrs. Boon pointed out that that some of her more academically able students were confused by the statement that the precipitate 'dissolves', so she had to explain the reactions involved to clear their confusion. Mrs Chung also considered that the precipitate had reacted with the excess sodium hydroxide as a new substance, the zincate, was formed. On the other hand, when an article submitted to science education journal presented the above situation, a referee remarked that dissolving in water was itself a chemical reaction, which was very similar to the formation of the zincate ion. The only difference, the referee added, was the ligands involved.

Two tertiary chemistry educators, Drs. Lim and Tay, understood the term 'dissolve' to broadly mean 'the disappearance of a solid in a liquid'. To them, dissolving could involve chemical reactions. When asked to comment on the statement 'Metals dissolve in acid', Dr. Tay said that it was perfectly acceptable. However, when presented with the picture of metal atoms being dispersed in an acidic solution, which this author suggested that the statement could imply, Dr. Tay had second thoughts. He agreed with this author that experienced chemists were aware of whether a reaction had occurred or whether simple solvation had taken place when solids disappear in liquids, but this was beyond the ability of beginning chemistry students.

Fenham (1994) states that the categorisations of scientific concepts which exist as a continuum, for example, physical and chemical change, pose much difficulty for students, and teachers as well. How does one teach dissolution when the dissolution of ionic compounds such as sodium chloride is considered a chemical reaction (Palmer & Treagust, 1996), while the dissolution of a covalent compound such as sugar is not (Abraham et al., 1994; Ebenezer & Erickson, 1996; Prieto et al., 1989). It is also possible to give an example of the interaction between a covalent compound and water which is considered as a reaction, that is, the interaction between hydrogen chloride gas and water forming hydrochloric acid.

Consequently, this author concluded that how dissolution was to be defined and taught depended on the level of the students. He suggested that it might be better, at the secondary school level and for this study, to describe dissolution as given in propositional statement 29. This statement resulted from comments from Drs. Beng, Chung and Lim. This author contended that the statement was appropriate because students were taught that 'no new substances' were formed when the solute dissolved. If the original substance could be recovered from the mixture when the solvent was removed, then it should be considered that the substance dissolved in the solvent. Thus using this criterion, sodium chloride was considered to dissolve in water, while zinc hydroxide was considered to react with excess sodium hydroxide since sodium zincate, a new substance, could be isolated from the mixture. Mrs Boon, Chen and Deng agreed to the use of propositional statement 29 to determine dissolution. However, all three teachers stated that they still would instruct their students to write "the precipitate dissolved in excess reagent" during examinations because that was the required observation by the examination syndicate. Brosnan (1999) puts things into perspective when he states that definitions of, and distinctions between physical and chemical changes are trivial, confusing and should not be emphasised. Instead, he argues that what is more important is that students understand what happens at the unobservable micro-level. To apply his argument in the case of dissolution, it does not really matter how dissolution is defined as long as students understand what happens at the micro-level when a given solid disappears in a liquid. It is more important for students to be able to describe and differentiate what happens at the micro-level when metals, ionic compounds, sugar and hydrogen chloride gas 'dissolve' in acid than to be able to recite the definition of dissolution.

RELATING PROPOSITIONAL KNOWLEDGE TO THE CONCEPT MAP

To ensure the list of propositional statements and the concept map were internally consistent, a matching of the propositional knowledge statements to the concept map was carried out. This matching is shown in Figure 3.3.

FACTS ON QUALITATIVE ANALYSIS

As mentioned in Chapter One, in past years, students were allowed to bring into the examination laboratories any reference material they wanted. The examination paper also included a data sheet (Appendix A) describing tests and outcomes of tests for the various ions stated in the syllabus (Appendix B). From 1999 onwards, students are no longer allowed to bring in any reference material but are still given the data sheet. This author believed that the change was to prevent students from comparing any previous experiments which they had done with the examination experiments, and referring to the previous experiments for answers if they were similar to those in the examination.

In addition to the notes provided by the examination syndicate (Appendix A), this author identified an exhaustive list of facts (Appendix F) to show the extension of the demand of learning O-level qualitative analysis and doing it effectively. Similar to the concept map and list of propositional knowledge statements, this list of 98 factual statements contains some content knowledge which is not included in the O-level pure chemistry syllabus, and so may not be taught by teachers. However, the factual knowledge is relevant O-level qualitative analysis and can be explained in simple terms to which students can understand and relate. This author used Dr. Aw's definition of facts as "entities which are found at the lowest levels in a concept map, for instance, specific examples of reactions or concepts".

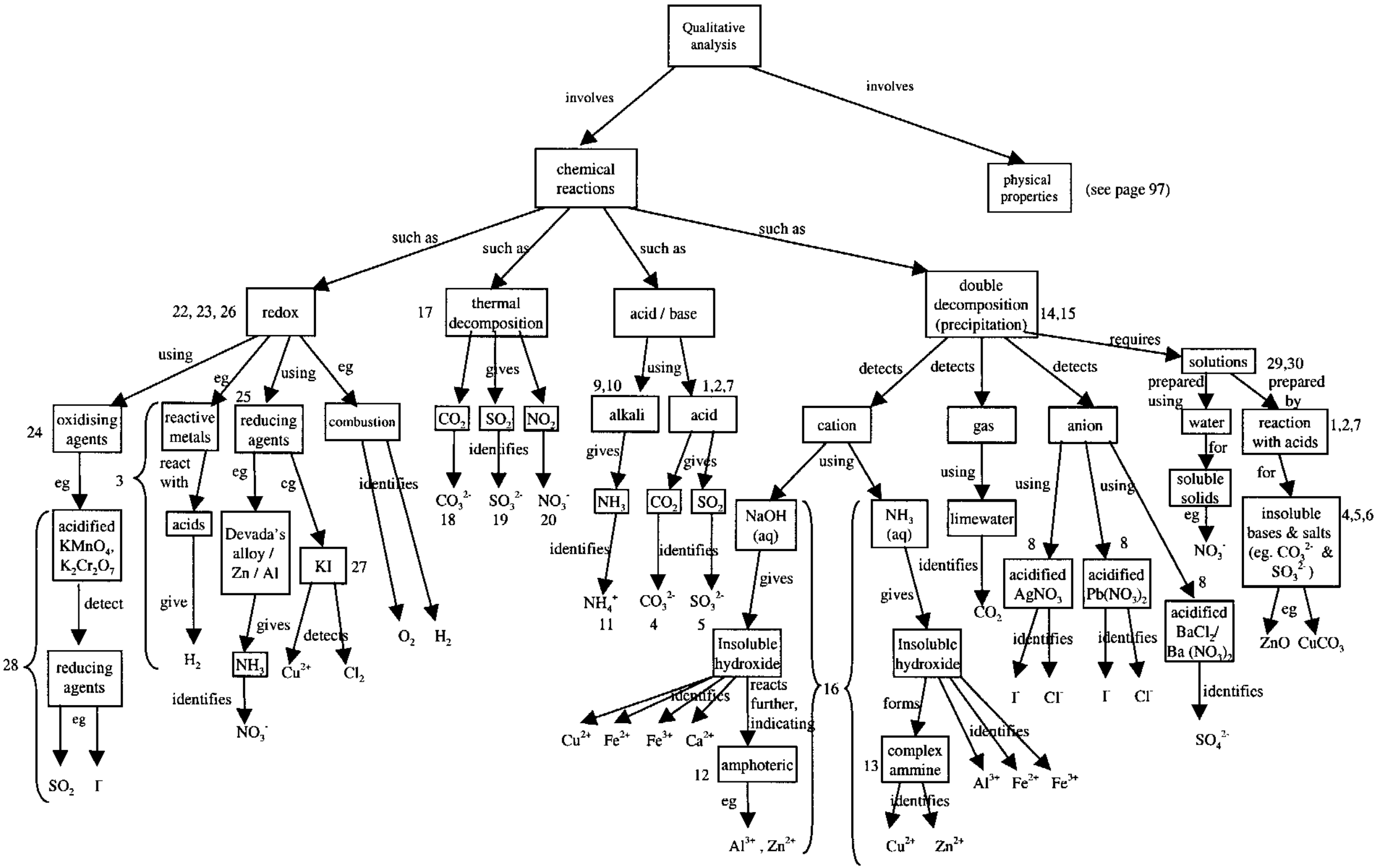

Figure 3.3: Relating propositional knowledge statements to the concept map

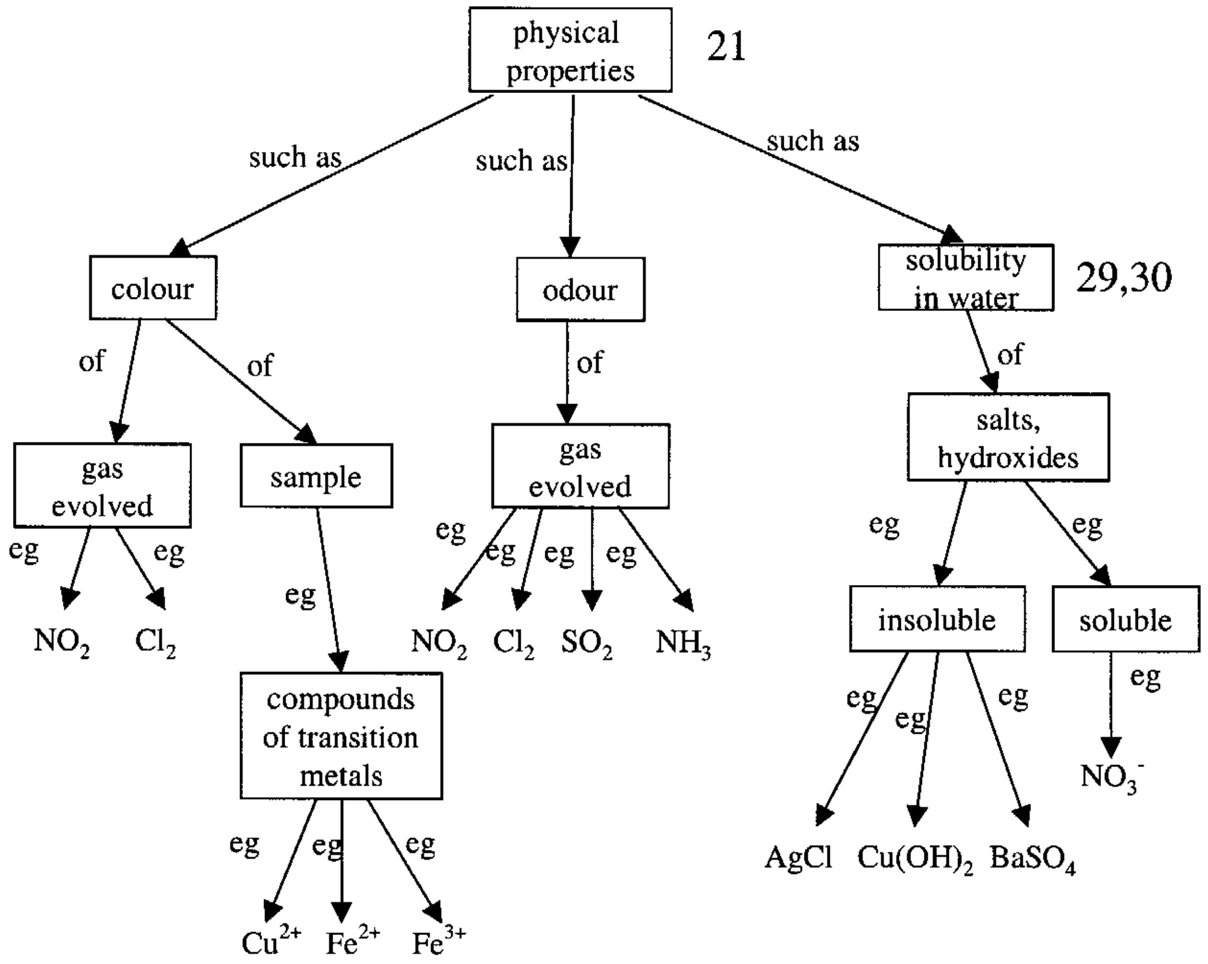

Figure 3.3 (continued): Relating propositional knowledge statements to the concept map

This list of facts is more comprehensive than the notes given by the examination syndicate and provides information on most of the reactions and results that a student would encounter in secondary school qualitative analysis. The notes given by the examination syndicate are adequate to help students identify the ions and gases stated in the syllabus but they require more than what is given to make deductions on the properties of the unknown substances or explain the results obtained. For example, if a student obtained a blue precipitate which disappeared to form a deep blue solution when he/she added aqueous ammonia to an unknown solution, he/she must be able to recall that copper(II) ions exhibited such behaviour or he/she could refer to the notes given by the examination syndicate. To understand or explain the above phenomenon, the student would require propositional statements 13, 14, 15 and 16; the notes are of no use here. The notes would also be of little use if the student was asked to comment, as in the October 1991 paper, on the oxidation states of a metal in two of its compounds. He/She needs to know that the ethanol used in the experiment was acting as a reducing agent (facts 40 and 41) in the reaction with a compound of the metal.

38. Iron(II) compounds are reducing agents.
39. When an acidified solution of an iron(II) salt is added to an oxidising agent, the iron in the +2 oxidation state, which gives a green colour to the solution, is oxidised to the +3 oxidation state, which gives a yellow colour to the solution.
40. Ethanol is a reducing agent.
41. When ethanol is added to an oxidising agent, ethanol is oxidised to form ethanoic acid.

Figure 3.4 Examples of statements in the list of facts on qualitative analysis

However, simply memorising facts is useless if a student does not know which relevant fact to recall in response to a given situation, or what to do with a piece of information. As mentioned in the above paragraph, a student might know the properties of ethanol but if he/she did not associate its reducing action to the question in the October 1991 paper, he/she would not be able to answer the question regarding the oxidation states of the metal. Thus, in addition to memorising, a student also needs to know how the facts are related to what he/she is doing in qualitative analysis so that he/she is able to recall and use them at the appropriate times. In the words of Mrs. Boon, the student needed to be able to "access and recall information at relevant points".

In this study, since this author was interested in the students' understanding and application of knowledge in qualitative analysis rather than the mere recall of facts, the students were given the notes on qualitative analysis (Appendix A) to refer to when answering questions. They were not given the list of facts (Appendix F) as it was unfamiliar to them and too detailed, thus too time-consuming to refer to. In addition, if they were asked to identify a gas or an ion, the names of the reactants would be given to them, and from their understanding of the reactions involved, they should be able to work out the products formed.

Content not specified in syllabus (Part II)

Mrs. Ang pointed out, in her review of the list of facts, that statements 21, 22, 29, 34, 79, 81, 82, 87 and 92, were unnecessary as they were not required in the syllabus. This author had already argued, in the earlier sections of this chapter, for the inclusions of the reactions of sulphate(IV) and nitrate(V) salts, and the formation of ammines. Fact 29 on the use of sulphuric(VI) acid to acidify potassium dichromate(VI) and potassium manganate(VII) resulted from this author's interviews with students. Many students could not explain why sulphuric(VI) acid was used to acidify the given reagents or why hydrochloric and nitric(V) acids were not used. Mrs. Ang also pointed out that the oxidising agents for use in the experiments would be prepared by the schools' laboratory technicians. Again, the author argued for its inclusion on the basis that it was an underlying reason for a given procedure, and students could understand it if it was explained in simple terms, namely that the oxidising agents react with the hydrochloric and nitric(V) acids. Using similar arguments, facts 34, 77 and 92 were included because these facts explained the results of procedures that students were required to perform in the 1988, 1992, 1993 and 1997 examinations, respectively.

Students would normally test for carbon dioxide when they were instructed to use dilute acids directly on the unknown samples. However, in interviews with students, this author found out that when asked to add a dilute acid after the addition of a silver or barium reagent (as in the 1991, 1992, 1993 and 1996 examinations), several students did not think of preparing to test for carbon dioxide. To these students, the addition of the silver or barium reagent followed by a dilute acid did not count as a 'legitimate' test for carbon dioxide. Thus this author included facts 81 and 87 to explain the above procedures. Teachers should make these facts explicit to their students, and as they involved simple reactions that the students have learned, for instance, the formation of an insoluble carbonate in a precipitation reaction followed by an acid-carbonate reaction, it was anticipated that the students should be able to understand them.

To summarise, this author argued for the inclusion of some content which is not required by the pure chemistry syllabus in the concept map, lists of propositional statements and facts because it explains common procedures and reactions in qualitative analysis. It is claimed that the content concerned is not beyond students' ability to understand if it is explained in simple terms, an argument supported by Mrs. Boon, Chen and Deng. If omitted, many procedures will be meaningless to students, and qualitative analysis will be akin to cooking – only the final results mattered.

SUMMARY

In this chapter, the concepts and propositional knowledge statements that upper secondary students need in order to develop an understanding of the topic, qualitative analysis, were described by an extract of the syllabus pertaining to it, a concept map, a list of propositional statements and a list of facts. Several issues, for instance, the definitions of certain chemical terms appropriate to the secondary chemistry students and content not stated in the syllabus, were discussed in the development of the concept map, list of propositional statements and list of facts. A matching of the propositional statements to the concept map also was carried out to ensure that they were internally consistent. Thus this chapter has defined the conceptual boundaries of O-level qualitative analysis in Singapore secondary schools, and this addressed Research Question 1. The development of the two-tier multiple choice diagnostic instrument takes place within the defined conceptual boundaries. Two chemistry textbooks and two workbooks on qualitative analysis that are used in Singapore secondary school are examined in the next chapter to determine if they contain the concepts and propositional knowledge statements necessary for the understanding of qualitative analysis.

CHAPTER FOUR

TEXTBOOK ANALYSIS

INTRODUCTION

The focus of this chapter is on Research Question 2 which seeks to determine whether the concepts and propositional knowledge present in the two approved chemistry textbooks and two practical workbooks used by Grade 9 and 10 chemistry students in Singapore are consistent with the concepts and propositional knowledge identified in Chapter 3 for understanding qualitative analysis in a meaningful manner.

The facts contained in the textbooks and workbooks were not compared with the facts identified in Chapter 3 because of the emphasis on understanding in this study. This author believes that the individual facts are not as important as the more super-ordinate concepts which govern when the individual facts apply. For example, if students are able to identify the type of reaction that is involved in a procedure and are able to recall the general equation of that type of reaction, they can work out the products formed. The author contends that the possession of facts such as equations of specific reactions is of little use if students do not know when to use them; the propositional knowledge statements provide the organisational framework for the specific reactions.

METHOD

Two commonly used approved chemistry textbooks in Singapore secondary schools, RH and JRGB, and two popular chemistry practical workbooks, CNP and LJR, were analysed for their treatment of qualitative analysis.

RH: *Chemistry: A new approach* (4^{th} ed.) (Heyworth, 1994)

JRGB: *Chemistry for 'O' level* (3^{rd} ed.) (Briggs, 1997)

CNP: *Chemistry: A course for 'O' level: Practical workbook. Volume 2* (Prescott, 1994)

LJR *Practical chemistry for 'O' level. Volume 2* (2^{nd} ed.) (Rasanayagam, 1986)

Text, illustrations (drawings and tables), and activities proposed were examined to determine if the propositional knowledge statements given in Chapter 3, which defined concepts and propositions involved in O-level qualitative analysis, were present in the texts. As in the study by de Posada (1999), a questionnaire was developed (Table 4.1) and used to analyse the textbooks and workbooks. The items in the questionnaire were concerned with the main reactions involved in the identification of cations, anions and gases in qualitative analysis, and the propositional knowledge statements involved in each item also were listed in Table 4.1.

RESULTS

In JGRB, qualitative analysis made up half of the chapter (10 out of 21 pages) on 'Chemical Analysis', the other half being devoted to volumetric analysis. In RH, qualitative analysis made up one section (3 out of 37 pages) on the chapter on 'Acids, bases and salts'. Forty-six pages out of 148 pages were solely devoted to qualitative analysis in CNP, beginning with an introduction, continuing with 10 tables, seven activities and ending with 15 worksheets. Almost the whole workbook (120 pages) by LJR was devoted to qualitative analysis and past years' examination questions.

Table 4.1: Questionnaire used to analyse the textbooks and workbooks

Items	Propositional statements
Identification of cations	
1. Is the formation of precipitates explained? Yes/No. If yes, how?	
a. Exchange of ions.	14
b. Formation of insoluble salt	15,16
2. Is the reaction between precipitates and excess alkali explained? If yes, which one?	
a. Reaction between aqueous sodium hydroxide and amphoteric hydroxide.	12,16
b. Reaction between aqueous ammonia and precipitate.	13,16
3. Is the reaction between ammonium salt and sodium hydroxide explained? Yes/No.	11
Identification of anions	
4. Is the formation of precipitates explained? Yes/No. If yes, how?	
a. Exchange of ions.	14
b. Formation of insoluble salt	15
5. Is the reaction between precipitates and acid explained? If yes, which one?	
a. Acid-carbonate.	4
b. Acid-sulphate(IV).	5
6. Is the reaction between silver chloride precipitate and aqueous ammonia explained? Yes/No.	13
Identification of gases	
7. Is the formation of gases explained? Yes/No. If yes, which ones?	
a. Ammonia	11
b. Carbon dioxide.	4,18
c. Chlorine.	22,23,24,25,26
d. Hydrogen.	3
e. Nitrogen dioxide	20
f. Oxygen.	20,22,23,24,25,26
g. Sulphur dioxide.	5,19
8. Is the test for gases explained? Yes/No. If yes, which ones?	
a. Ammonia	9,10,21
b. Carbon dioxide.	1,2,14,15
c. Chlorine.	1,2,21,22,23,24, 25,26,27
d. Hydrogen.	22,23,26
e. Nitrogen dioxide	1,2,21
f. Oxygen.	22,23,26
g. Sulphur dioxide.	1,2,22,23,24,25, 26,28

The textbooks

JGRB

There were many tables similar to the ones in 'Notes for use in qualitative analysis' (Appendix A) and flowcharts to help students identify ions and gases in JGRB, but hardly any explanations were given on the reactions behind the tests and the results of the tests. The only reaction described was the reaction between ammonium salts and aqueous sodium hydroxide. There was a statement in the chapter that the reactions of acids and alkalis were described in the preceding chapter on 'Acids, bases and salts'. In that chapter, the only explicit mention of the link between reactions of acids, bases and salts, and qualitative analysis was the statement that reactions between metal ions and alkalis were important in the identification of cations, and to see the relevant section in the following chapter. Exercises given in the chapter focussed on the identification of ions and gases based on experimental data given. Thus the focus of the content on qualitative analysis in JGRB was on procedures to identify the various ions and gases, and the identification of ions and gases. A summary of the analysis of JGRB and the other texts is given in Table 4.2. It could be seen that many reactions involved in the identification of cations, anions and gases were not explained, for example, the reactions involved in the formation of precipitates, complex salts, gases, and the reactions involved in the tests for the various gases. Thus, it was likely that students relying solely on JGRB for qualitative analysis would have little knowledge of the concepts and reactions involved in qualitative analysis.

RH

The amount of content on qualitative analysis in RH, though less in comparison with JGRB, had more explanations on the reactions behind the tests and results of the tests. The only table was for the identification of cations and there were no

Table 4.2: Summary of analysis of the two textbooks and two workbooks

Items	JGRB	RH	CNP	LJR
Identification of cations				
1. Is the formation of precipitates explained? Yes/No. If yes, how?	n	y	y	y
a. Exchange of ions.		y	y	y
b. Formation of insoluble salt		y	y	y^1
2. Is the reaction between precipitates and excess alkali explained? If yes, which one?	n	n	n	n
a. Reaction between aqueous sodium hydroxide and amphoteric hydroxide.				
b. Reaction between aqueous ammonia and precipitate.				
3. Is the reaction between ammonium salt and sodium hydroxide explained? Yes/No.	y	n	n	y^1
Identification of anions				
4. Is the formation of precipitates explained? Yes/No. If yes, how?	n	y	y^1	y^1
a. Exchange of ions.		y	y^1	y^1
b. Formation of insoluble salt.		y	y^1	y^1
5. Is the reaction between precipitates and acid explained? If yes, which one?	n	n	n	y^1
a. Acid-carbonate.				y^1
b. Acid-sulphate(IV).				y^1
6. Is the reaction between silver chloride precipitate and aqueous ammonia explained? Yes/No.	n	n	n	n
Identification of gases				
7. Is the formation of gases explained? Yes/No. If yes, which ones?	y	y	y^1	y^1
a. Ammonia	y			y^1
b. Carbon dioxide.		y	y^1	y^1
c. Chlorine.				
d. Hydrogen.				
e. Nitrogen dioxide			y^1	
f. Oxygen.			y^1	y^1
g. Sulphur dioxide.				y^1
8. Is the test for gases explained? Yes/No. If yes, which ones?	n	y	n	y^1
a. Ammonia				
b. Carbon dioxide.		y		y^1
c. Chlorine.				y^1
d. Hydrogen.				
e. Nitrogen dioxide				
f. Oxygen.				
g. Sulphur dioxide				

Note: 1 – not explained but students were asked to write the equations involved.

flowcharts for the identification of ions and gases. However, equations were given to explain the reactions for the tests to identify the carbonate, sulphate(VI), chloride and iodide ions, and carbon dioxide. Double decomposition reaction in the tests for cations using aqueous ammonia and sodium hydroxide also was explained, and an ionic equation describing the reaction between calcium ions and hydroxide ions was given as an example. However, reaction of precipitates with excess aqueous ammonia or sodium hydroxide was not mentioned, nor thermal decomposition of carbonate, sulphate(IV) and nitrate(V) salts. The reaction of ammonium salts with alkali was discussed in the section on 'Bases and alkalis', while the reactions of carbonate sulphate(IV) and nitrate(V) salts were discussed in the chapters on 'Carbon', 'Sulphur' and 'Nitrogen', but no explicit links were made with qualitative analysis. This researcher felt that RH provided a better 'understanding' of qualitative analysis compared to JRGB as it provided more explanations of the reactions and procedures involved than JRGB which focussed more on the 'doing' of qualitative analysis.

The practical workbooks

The two practical workbooks, CNP and LJR, as expected, gave a more detailed treatment of qualitative analysis than the two textbooks. The workbooks, which solely emphasised the practical aspects of the O-level syllabus, could afford to devote more material on qualitative analysis than the textbooks. Both workbooks were divided into four main sections and the first section gave some general information on qualitative analysis, with both workbooks having tables on tests for anions, cations and gases similar to those in Appendix A. Additional tables and information included the appearance and heating of substances, instructions in the question paper and possible inferences that could be made from the instructions, solubility of salts, and tests for oxidising and reducing agents. There were also many flowcharts on how to identify ions and gases in both workbooks. The second section consisted of introductory experiments to familiarise students with the procedures and tests involved in qualitative analysis; students are required to perform tests for specific substances. The third section of the workbooks required students to identify unknown substances, and finally, past years' examination papers were given in the fourth section. Thus the 'doing' part, how to identify substances, of qualitative analysis was well catered for.

CNP

The only information given on procedures in CNP was in the test for chloride, iodide and sulphate(VI). In the table on the tests for anions, it was stated that dilute acid had to be added in the test for chloride and iodide with aqueous silver nitrate(V) to 'remove any carbonate', and in the test for sulphate(VI) with aqueous barium nitrate(V) or chloride to 'remove any sulphite'. This researcher believed that the significance of removing carbonates or sulphite might not dawn upon the students; indeed, the results in later chapters of this thesis showed that students had little idea why acid had to be added. The worksheets to introduce qualitative analysis to students in CNP had the format of 'Aim', 'Apparatus', 'Materials', 'Procedure', 'Results' and 'Questions'; the theory involved in the activities were not discussed. The procedures given in the worksheets were clear but were not explained. The main emphasis of the worksheets was on the students carrying out the procedures, recording their observations, and making inferences from the observations.

However, in the worksheet on identifying anions, under the test for carbonates, the equation for the reaction between calcium carbonate and dilute hydrochloric acid was asked. This researcher took that to count as an explanation for the reaction involved in the test. Equations for the reaction between aqueous potassium iodide and lead(II) nitrate(V), and sodium sulphate(VI) and barium chloride also were asked for in the tests for iodide and sulphate(VI), respectively. Equations also were asked for in the tests for cations using sodium hydroxide. The ionic equation for the reaction between calcium ions and hydroxide ions was given as an example to explain the reaction involved. However, there was no explanation for the identification of ammonium ions using aqueous sodium hydroxide, the reactions between aqueous ammonia and cations, and the reaction of cations with excess alkali. In the worksheets to identify unknown compounds, students were asked to write equations on double decomposition reactions, decomposition of carbonate and nitrate(V), and an acid-carbonate reaction.

In a worksheet to identify substance S5, students were asked to give a balanced chemical equation for S5 dissolving in nitric acid. This researcher believed that the word 'dissolving' was incorrectly used in the worksheet, and could lead to alternative conceptions of dissolution, a topic that is further elaborated in the next chapter.

LJR

In the introductory section, some precautions and practical hints on qualitative analysis were discussed. Students were informed why the test tubes used need to be clean, how to heat substances, precautions to take when detecting gases, how to write observations and deductions. As with CNP, explicit references to reactions involved were generally made by asking students for equations in the various introductory experiments. The equation describing the reaction between carbon dioxide and limewater, and the explanation for the reaction between chlorine and litmus were asked for in the exercise part of the worksheet on identifying gases. Equations describing the decomposition of certain carbonates, nitrates (V) and sulphates (IV) were required in the worksheet on heating of substances. In the worksheet on tests for cations, students were told that aqueous ammonia and sodium hydroxide were used to precipitate insoluble hydroxides. Students also had to write a chemical equation for the reaction between an ammonium salt and aqueous sodium hydroxide, and an ionic equation for the reaction between a calcium salt and aqueous sodium hydroxide. Again, no explicit mention was made of the reaction between cations and aqueous ammonia, as well as the reaction of zinc and aluminium ions with excess alkali.

In the worksheet on tests for anions, equations for the reaction between dilute acid and carbonates and sulphate(IV) were required, as were the equations for the precipitation reactions of barium and silver salts with sulphate(IV) and sulphate(VI). Similar equations were asked in the worksheets on identification of unknowns, but the majority of the questions focussed on the identification of the unknown ions and gases. A worksheet on tests for redox reagents only concentrated on student observation and deduction.

DISCUSSION

From the results above, it could be seen that the two workbooks were better sources of information on qualitative analysis than the textbooks. Many of the reactions involved in qualitative analysis were discussed in the chapters on 'Acids, Bases and Salts' in JGRB and RH, but there were very few explicit links between what was written in the topic 'Acids, Bases and Salts' and qualitative analysis. Students might need such explicit links because they were novices in chemistry and did not have the expertise of textbook authors or teachers to appreciate or understand the reactions involved in the procedures that they carried out. Lacking this knowledge, qualitative analysis is likely to become a mechanical, recipe-driven activity with little meaningful learning.

The two workbooks provided more information on qualitative analysis but through indirect means; many of the reactions involved were highlighted by instructing students to write equations. However, students may be able to write the equations but they may not realise that similar reactions were involved in the same class of reactions or procedures; hence they may not see the overall picture in qualitative analysis. More explicit content should be given in the introductory sections of the workbooks or the introductory experiments on qualitative analysis to help students relate theory to practice. A more detailed discussion of how to relate theory to the experiments can be found in Chapter 9 where this researcher describes the development of a teaching package on qualitative analysis. Even though the workbooks covered more content on qualitative analysis than the textbooks, they still did not cover all the content required to understand O-level qualitative analysis meaningfully. The two areas lacking in the workbooks were the reactions between cations and excess alkali, and the reactions involved in the identification of gases.

SUMMARY

This chapter addressed Research Question 2 with the analyses of two textbooks and two practical workbooks commonly used in secondary schools in Singapore. Although the textbooks and workbooks were important sources of information for students on qualitative analysis, none explicitly highlighted all the reactions involved in the procedures in qualitative analysis. The omission was likely to give students the idea that qualitative analysis was merely a mechanical activity with few links to the content that they learn in class. Without the links, students could find it difficult to understand what they were doing in the qualitative analysis practical work.

The next chapter describes the students' feelings and attitude towards qualitative analysis practical work, and what they understand about the concepts and propositional knowledge related to qualitative analysis.

CHAPTER FIVE

STUDY ONE: STUDENTS' UNDERSTANDING OF QUALITATIVE ANALYSIS

INTRODUCTION

A review of the literature was conducted in Chapter 2 to determine known student knowledge, alternative conceptions and difficulties relevant to qualitative analysis. The concept map and propositional statements prepared in Chapter 3 provided the framework for the development of a written test instrument to diagnose Grade 9 and 10 students' understanding and alternative conceptions of qualitative analysis. This chapter addresses Research Question 3 which focuses on what students understand about the concepts and propositional knowledge related to qualitative analysis. In Study One, data were collected from the observations of six qualitative analysis laboratory sessions in April to May 1998 and one in March 1999, as well as, interviews with 51 Grade 10 students from July to September 1998. The findings of the laboratory observations and student interviews are described in this chapter.

OBSERVATIONS OF LABORATORY SESSIONS

This author went to four schools to observe a total of seven qualitative analysis laboratory sessions, each with 30 to 42 students. He observed Grade 10 (15 to 17 years old) students in six of the sessions, and Grade 9 (14 to 16 years old) students in the remaining one. All the schools had weekly laboratory sessions, and the experiments either followed the respective school's chemistry scheme of work or were decided by the teacher depending on his/her judgement of the needs of the students. In all the sessions observed, students were given unknown solutions to identify. This author observed the students carrying out the procedures required in the experiments and frequently asked students to explain the procedures that they were carrying out and the results obtained. Examples of the questions asked were:

> "Why are you adding sodium hydroxide?"
> "Why do you get a precipitate?"
> "How can you identify the precipitate?"
> "Do you need to prepare to test for gases?"
> "What gases will you test for? Why?"
> "Can you explain why you get such results?"

This author observed that the students, in general, were rushing to complete their experiments and reports. Only when they started to write their reports would they give a thought to their experiments and results. This author felt that answering questions posed by him were stressful to the students because they often did not know the answer, and it also used up precious time which they needed to complete their reports.

Difficulties and problems observed

The experimental procedures and tasks that students had difficulty in carrying out or carried out incorrectly are given in Figure 5.1. Goh et al. (1987) reported that the performance of students in qualitative analysis practical work in Singapore schools fell short of the various objectives of laboratory work and, in particular, the mastery of certain process skills. They, like Herron (1996), believe that to address this deficiency, there must be a systematic building up of skills as well as formative monitoring of students' mastery of these skills. Goh et al. (1987) also stressed the need to assist students in comprehending the meaning and purpose of the procedures in qualitative analysis practical work to enable students to link theory with practice. Questions that this author asked during his laboratory observations, which students had difficulty in answering, are given in Figure 5.2.

1. Heating
    a. Using a luminous flame for heating.
    b. Uncertain when to stop heating a sample.

2. Contaminating reagents
    a. Holding a filter paper soaked with reagent or litmus papers in contact with the wall of the test tube instead of holding them at the mouth of the test tube without any contact with the test tube.
    b. Placing wet litmus papers on the table-top before use.

3. Random testing of gases
    a. Testing for all gases when a gas is evolved, without taking into consideration the possible reactions.
    b. Forgetting to test for sulphur dioxide when heating the unknown solid or when adding an acid to the unknown sample.
    c. Testing for ammonia gas when adding ammonia solution to the unknown solution.

4. Using reagents
    a. Do not know how much reagent to add, and how to add the reagent to the unknown solutions.
    b. Adding reagents (e.g. aqueous sodium hydroxide) directly to a solid sample without first making a solution of the sample.

5. Do not know how to determine the colour of a precipitate in a coloured liquid, for example, the colour of the precipitate obtained in the reaction between aqueous barium chloride and aqueous copper(II) sulphate(VI).

Figure 5.1: The experimental procedures and tasks that students had difficulties in carrying out or carried out incorrectly

To answer the questions, students needed to be able to apply the knowledge from the various topics under which the questions were categorised. Samples of incorrect answers to two questions are given in Figure 5.3. The answers showed that the students concerned neither understood the purpose of the procedures they carried out nor the reactions involved.

INTERVIEWS WITH SECONDARY STUDENTS

Fifty-one Grade 10 students from three secondary schools, R, S and M, were interviewed in the period July to September 1998. Grade 10 students were chosen because they had more qualitative analysis practical work experience than Grade 9 students.

Double decomposition/Precipitation

1. Why is aqueous sodium hydroxide or ammonia used to test for cations?
2. What are the ions present in the precipitate (when aqueous ammonia, sodium hydroxide, silver nitrate(V) or barium chloride/nitrate is added to an unknown sample)?

Periodicity

Why are certain precipitates coloured?

Complex salt formation

Why does the precipitate disappear when excess aqueous sodium hydroxide or ammonia is added?

Reactions of acids

1. Why is there no precipitate initially when the alkali is added to the solution (formed by the addition of excess acid to a solid sample)?
2. Why does the precipitate (a carbonate) disappear when excess dilute acid is added?
3. Why does a precipitate reappear when dilute nitric(V) acid is added to the solution (containing complex salts of zinc, aluminium, copper(II) or silver)?

Reactivity - thermal decomposition

1. What gases can be evolved when the unknown sample is heated?
2. Why are these gases evolved when the unknown sample is heated?

Figure 5.2: Questions which students found difficult to answer

Question

Why does the precipitate disappear when excess reagent (e.g. aqueous sodium hydroxide or dilute acids) is added?

Answers

1. The acid decomposes the precipitate.
2. The sodium hydroxide acts as a solvent, so when more reagent is added, more of the precipitate dissolves.
3. Hydrogen ions displace the cations in the precipitate (when dilute nitric acid is added to barium carbonate).
4. Silver ions are displaced by ammonium ions to form ammonium chloride (when excess aqueous ammonia is added to silver chloride).

Question

Why does a precipitate reappear when dilute sulphuric(VI) acid is added to the solution (containing complex salts of copper(II))?

Answer

The acid displaces the copper which reacts to form the precipitate.

Figure 5.3: Sample of incorrect student answers

School R, an independent government girls' school, is one of the top five secondary schools in Singapore. School R runs two programmes, a normal academic programme and a gifted education programme. Only students from the normal academic programme were involved in the interviews. School S is an above-average independent church-affiliated boys' school and School M is an above-average government-aided church-affiliated boys' school. Both schools M and S have only the normal academic programme for secondary students. The schools R and S were chosen because this author had taught in the schools before, and the principals were supportive of this study. These two schools also had many students taking pure chemistry, so this author had an adequate supply of subjects for the various phases of this study. School M was chosen because this author had supervised trainee-teachers in the school and obtained permission from the principal to carry out the study in his school.

Students in Singapore are generally uncomfortable being interviewed by strangers, so this author decided to interview students in pairs or threes to put them at greater ease. He noted the warning given by Duit et al. (1996) that the social dynamics of such interviews might skew discussions so he made a conscious effort to give equal opportunity to all the interviewees to have their individual say. One of the main benefits of pair or group interviews is that students are able to talk to each other to develop, challenge and clarify ideas (Duit et al., 1996; Gilbert & Pope, 1986). This was especially important in this study because the students might not have previously given much thought to the procedures and reactions in qualitative analysis; consequently, they were forced to start formulating and organising their thoughts to answer the interview questions, and peer discussions helped in the process. This author realised that if the students had never thought reflectively about the procedures and reactions, then the answers that they give might not be valid or reliable (Johnson & Gott, 1996). The students might invent answers, for example, describing the first thing that came to their head, something which they might not really believe in (Johnson & Gott, 1996; McClelland, 1984). This issue is addressed in a later section.

This author interviewed 30 students in pairs, 21 students in groups of three, and one student individually who was known to this author and felt comfortable being interviewed alone. One student took part in two consecutive sets of interviews as he was very interested in testing his knowledge of qualitative analysis. Students whom this author interviewed were either chosen by their teachers (students from Schools R and S) or had volunteered to be interviewed (School M). Each interview lasted between 45 minutes to an hour. The transcript of the interview with Students 40 and 41 is given in Appendix G to illustrate how the interviews were conducted. Table 5.1 describes the composition of the various groups interviewed and the schools from which they came.

Table 5.1: Schools and composition of groups of interviewees (n=51)

School	Students	Total number of groups
R	(1,2), (3,4), (5,6), (7,8), (25,26), (27,28), (38,39), (40,41)	8
S	(9,10,11), (12,13), (14,15), (16,17), (18,19), (18,20,21), (22), (23,24)	8
M	(29,30,31), (32,33,34), (35,36,37), (42,43,44), (45,46,47), (48,49), (50,51)	7

Note: The numbers in a bracket denote the students in each interview group, for example, (1,2) denotes that Students 1 and 2, from School R, were interviewed together.

Interview protocol - general questions

The interviews with students were meant to solicit information on their perceptions of qualitative analysis, the difficulties that they encountered learning and doing qualitative analysis, whether they perceived any links between theory and practical work, and their understanding of the procedures and reactions involved in the practical work. This author would ask students a few general questions (Figure 5.4) at the start of every interview to collect information on students' attitude towards qualitative analysis, the problems and difficulties that they faced, and whether they saw any links between the theory lessons and what they did in the laboratory. The findings from the general questions are discussed in the following headings, namely 'Tedious and irritating', 'Results – right or wrong', 'Memory work', 'Knowing what to do or what we are doing', 'Lack of time' and 'Links between theory and practical work'.

Students' feelings and attitude towards qualitative analysis

1. How do you find qualitative analysis?
2. What are your feelings on qualitative analysis?

Problems and difficulties faced

1. Do you find any aspects of qualitative analysis difficult?
2. Why do you find the aspects that you mentioned difficult?

Links between theory and practical work

1. Do you see any link between what you are doing in qualitative analysis and the chemistry topics that you have previously learned?
2. If so, which topics?
3. Can you give examples of the links between what you have previously learned and what you are doing in qualitative analysis?

Figure 5.4: General questions asked in the interviews

Tedious and irritating

Many students did not like qualitative analysis practical work as is illustrated by the following excerpt of the verbatim transcript of Student 1's response:

I : How do you find QA (qualitative analysis)?

S1 : We do it almost every practical...quite, shall we say irritating because you always have to do the same thing again and sometimes you get frustrated because your results don't tally and you can't find an answer. So it gets frustrating sometimes.

Teachers normally begin teaching qualitative analysis by reviewing the reactions involved and demonstrating some procedures that the students need to carry out. Students then do a series of tests for the various cations, anions, gases, oxidising and reducing agents. After they are familiar with the tests, students are given a few unknown samples to identify. Finally, they attempt past years' examination questions. Thus students would be doing about 10 to 15 weeks of qualitative analysis practical work continuously. This might be why Student 1 found qualitative analysis irritating as she had to carry out week after week similar "boring, tedious, step-by-step procedures which often give students training only in mindless manipulation" (Markow & Lonning, 1998, p. 1016). Hodson (1990) commented on the irony that young children were often involved in fairly unstructured personal investigations while older children were compelled to do "practical exercises, according to a set of explicit directions – at the very time in their lives when they are struggling to establish their individuality" (p. 35).

Other students also found qualitative analysis practical work tedious. Student 14 explained that there was a lot of procedures involved when doing experiments, especially when testing for gases, and Student 12 stressed the need to be meticulous for if a mistake was made at the beginning of the experiment, it could affect all the subsequent results. Student 23 summed up the situation in the following excerpt:

S23: Actually it [QA] can be quite difficult, especially if you make a mistake because ...you have to go through it [the experiment] all over again...and you might not have the time to do it.

I : What do you mean by mistake?

S23: Such as...maybe you...you add the wrong chemicals or...you make a wrong observation, you record the wrong observation...you maybe...you may test wrongly for one gas.

Only six students had positive feelings about qualitative analysis, stating that it was fun and interesting to mix chemicals and see the different effects, the different colour changes. Student 18 found the investigative nature of qualitative analysis interesting and a challenge to determine the identity of the unknown sample given. Student 19 commented that it was very enlightening to see the reactions which were taught in the theory lessons. Hidi (1990) believes that interest is important to "cognitive functioning and the facilitation of learning" (p. 565). Thus it is likely that those who find qualitative analysis tedious and irritating would be less motivated to be cognitively involved in qualitative analysis, resulting in it being even less interesting and more mechanical. Marzano and Pickering (1991) stressed the need to establish an appropriate "attitudinal environment" (p. 94) and that teachers need to structure the learning tasks for success, make the tasks valuable and relevant to the students, and communicate to students a sense of confidence in their ability.

Results – right or wrong

Four related fears of students doing qualitative analysis were not getting the anticipated results, getting results which were different from those of their classmates, not knowing whether the results obtained were correct, and getting results for different parts of the experiment which did not tally with each other. The following excerpt describes the dilemma that many students faced:

S2 : OK, let's say you are given this question like you add hydrochloric acid to this thing. So you are expecting it to be a carbonate or something...but somehow if let's say the results ...they come out to be different...then you...you would feel like ...should I write down what I think it is or should I write down my actual results.

When she obtained an unexpected result, Student 2 did not know whether it was due to experimental errors or whether it was correct. Thus she was undecided whether to ignore the results and write down what she thought it should be, or whether to describe it as it was. She also complained that she did a certain procedure four times in one experiment and obtained a precipitate each time while her classmates obtained a colourless solution when they carried out the same procedure. She did not know whose results were correct. She tended to believe that in such situations her results were wrong as she explained below:

S2 : I am quite clumsy when it comes to lab stuff so half the time my results end up to be very funny...and if I don't get the correct results I won't be able to write the report, right?

Student 2 was unable to evaluate her anomalous results because she was unable or did not know that she had to apply the knowledge she was taught in the classroom to her practical work. Teachers, too, seldom encourage students to evaluate their results, and often merely informed students that their results were incorrect. This could instil "a concern with what 'ought' to happen' and a preoccupation with the 'right answer'" (Hodson, 1990, p. 37). Other excerpts of interviews further illustrate the four fears of qualitative analysis.

S27: In practicals, sometimes you don't get the results that you expect...so when we refer to the QA handbook, we can't really find anything [cannot match the results obtained with data in the handbook to identify an ion or gas]. So you get confused and don't know what the answers [identities] are.

S48: Sometimes like you do a test...you know that there is supposed to be a certain.... product, but you don't see it...you test for a gas but...you don't get it.

S37: Sometimes it's difficult to get the results...the expected results...like limewater turning chalky...then very...sometimes the carbon dioxide gas is very hard to test.

S11: ...when you have your results...it might differ from the...person next to you, you see...so maybe you panic...so you try to redo (the procedure)...that means you are not confident... something like that.

S33: Then...sometimes people get different results from us...then we wonder why our results are so...different.
I : What do you mean by different results? Can you give an example?
S33: Like some...their white precipitate is soluble in excess...but mine is not...it's stressful.

It could be seen from the above excerpts that the students did not have confidence in the results obtained especially if the results were not what they anticipated or if the results differed from those obtained by their classmates. They tend to avoid risk-taking (Costa, 1991), and are reluctant to "venture forth with ideas or statements that might be considered bizarre or far-out" (p. 104). These students often believed that their results obtained were incorrect and rejected them on the grounds that their samples or the reagents used were contaminated, or that they did not follow instructions properly. The following excerpt illustrates this:

S24: ...sometimes when you add two chemicals together...you...you may not get the results you want.

I : What do you mean?

S24: For example, in the lab...you might add two chemicals, you are supposed to see a precipitate...you don't see it...maybe because of some contamination or something like that.

Students' lack of confidence in their experimental results and students attributing unexpected results to experimental errors also have been reported in the literature. In their study on the response of science students to anomalous data, Chinn and Brewer (1993) suggest that one of the reasons that individuals give to reject anomalous data is that "the procedure by which the data were collected is flawed" (p. 6). In another study, Pickering and Monts (1982) observed how undergraduates behaved when they obtained two inconsistent sets of results from a redox experiment. The experiment involved two different modes of preparation of a non-stoichiometric oxide of tungsten and the determination of its formula. However, unknown to the undergraduates, the formula of the oxide depended on the mode of preparation. Pickering and Monts expected that undergraduates would simply develop two different formulas for the oxide and state that there were at least two different oxides obtained in the experiment. However, they found that only 25% of the 240 undergraduates concluded that the formula depended on the mode of preparation. Almost half of undergraduates believed that their results were incorrect due to experimental errors, and about 12% wrote the experiment off as it did not produce the expected results. Gunstone (1991) also found that science graduates in a pre-service teaching programme rejected observations which did not meet their expectations "via a denial of the legitimacy of the observations" (p. 72). Schauble, Klopfer, and Raghavan (1991) showed that another way students dealt with anomalous data was to misinterpret or distort them to support a favoured belief, and Bekalo and Welford (1999) reported that student-teachers in their study often altered their experimental data to match their expected answers. These studies agreed with Duit and Treagust (1995) who reported that "empirical studies in the field of psychology indicate that humans in general tend to observe only what fits their conceptions and to ignore counterexamples" (p. 50).

The secondary students' responses to 'anomalous' results also were commented upon by the examiners for the O-level chemistry examinations. The examiners believed that students had first decided on or guessed the identity of the unknown ions before carrying out the procedures. If the actual results proved otherwise, the students would reject those results and wrote what they believed should happen.

> Most correctly reported a white precipitate although disappointingly a significant proportion failed to spot that it dissolved when nitric acid was added. Whether this was due to bad practical technique or to candidates deciding that R was a chloride and therefore the precipitate should not dissolve is hard to say. Candidates should be encouraged to carry out the test first and then attempt the inferences rather than trying to work out practical observations having guessed, often wrongly, the identity of the unknown substance. (UCLES, 1994, p. 32)
>
> The addition of aqueous ammonia produces a green or blue green precipitate which is not soluble in excess. Blue precipitate was not acceptable although if the precipitate did not dissolve in excess this second statement was scored. Several candidates clearly decided that copper was present and therefore claimed that the precipitate did dissolve thus losing marks. Candidates should be encouraged to carry out the experiments carefully and record their actual results even if they seem unexpected. (UCLES, 1995, p. 34)
>
> Several tests required the observation 'no reaction' or 'no change'. This lack of reaction worried several candidates who promptly

> invented observations.... With S, the addition of aqueous barium nitrate does not produce a precipitate, but the addition of acid leads to the slow formation of a white precipitate which then becomes yellower. Many reported a precipitate on the addition of the aqueous barium nitrate, presumably because they had decided that the solution contained a sulphate or sulphite. (UCLES, 1997, p. 30)

Thus, the examiners' comments on inventing observations agreed with Schauble et al. (1991), Lazarowitz and Tamir (1994), and Bekalo and Welford (1999).

Lazarowitz and Tamir (1994) contend that sometimes "students hold beliefs so strongly that they adjust the observation to fit them, rather than change their views on the basic of observations" (p. 100). This author believed that this might be the result of the students' futile attempts to reconcile the actual results obtained with those that they expected to get, or the results with which they were familiar. As indicated by the examiners, students seemed to be uncomfortable with the lack of visible reaction on addition of the given reagents, and decided to invent some reactions. This could be due to the students' beliefs that the main aim of the experiments was to produce effects (Schauble et al., 1991) rather than the facilitation of the understanding of the processes involved which resulted in the effects. Students need to be taught to think more critically (Costa, 1991; Marzano & Pickering, 1991), to be open-minded, to strive for accuracy and precision, and to control their impulsivity such as avoiding invented answers without forethought.

Memory work

Sixteen students expressed the opinion that qualitative analysis involved a lot of memory work, as illustrated by the following four excerpts of interviews:

S30: I...don't really like QA.
I : Why don't you like QA?

S30: Because (it is) not that I don't like it...I don't like memorising this kind of things.
I : What do you mean by memorising?
S30: You see...for example...you know you have to memorise you add this [reagent] it [the unknown] will change to what colour that sort of thing.

S5 : ...there is a lot of things to memorise...it's (QA) just basically memorising.

I : How to you find QA?
S32: Needs a lot of memory.
S33: Yes.
I : Why do you say that?
S32: Because you have to memorise a lot of things, the colour, the formulas...know what is being produced and so on.
S33: Must find conclusion also...kind of difficult sometimes.
I : Why is it difficult?
S33: Because...like he says, you need a lot of memory...have to memorise what colours all these [colours of precipitate will indicate the identity of the unknown ions present]...sometimes we forget about the colours, then cannot come to a conclusion...what does this contain?

S42: Sometimes I don't know how to identify...like when you add something (to the unknown) then it changes colour...sometimes you don't know what the colour means.
I : So you cannot conclude from the results?
S43: Takes a lot of memorising work
I : Why memorising?
S43: Because you have to remember those results...tests for cations...to see what gas will be produced...what substances will be produced so that you can relate to the results to find the answer.

Many students believed that qualitative analysis mainly involved memory work, that is, they just needed to memorise what happened when different reagents were added to different ions (Tan et al., 1999). This author felt that either rote learning was the preferred mode of learning of many students or they treated the memorisation of data as a 'security blanket'. Once they had memorised the knowledge, they felt confident that they could deduce the identity of the unknown ions from their results to get the correct answer. They seemed to believe, as Carr et al. (1994) pointed out, that those who were able to memorise enormous quantity of facts would do well in science, or in qualitative analysis in this instance, and those who did not have such ability will not perform as well as those who had. Reif and Larkin (1991) also stated that students primarily strive to memorise information because they believed that science was merely a collection of knowledge. However, one of the shortcomings of merely being able to recall facts was that students were not able to evaluate 'anomalous' results to determine if the results are possible or if they had made experimental errors. They needed to understand the procedures and reactions, and to think critically in order to evaluate their results.

Knowing what to do or what we are doing

In their study of practical work in school, Tasker and Freyberg (1985) wrote:

> Our observations have shown that pupils did not have any idea of what were the critical scientific factors in the experiment, even though teachers assumed that they did. Pupils had little appreciation for features in the design of an investigation and consequently no real basis for anticipating the nature of its outcome. (p. 71)

Twenty-six students admitted that they frequently did not have any idea about what they were doing in the qualitative analysis practical sessions. Thirteen students mentioned that when they had to test for a gas, they did not know which gases to test for in a given situation, and hence they randomly tested for all the required gases in the syllabus. This resulted in them wasting time testing for the 'wrong' gases, and using up all the gas evolved before they could complete all the tests. Pintrich et al. (1993) stated that the student's belief that he/she could accomplish a task motivates him/her to be cognitively involved in the task. Unfortunately, many of the students who were interviewed seemed to feel helpless and directionless in qualitative analysis, and this might affect their learning of it. Three excerpts of interviews depicting the students' situation are given:

I : OK...now do you find any aspects of QA difficult?
S5 : Doing the tests.
S6 : Yes...when there's a gas.
I : Why do you say that?
S6 : Because...you have so many gases and then there's...different tests for each gas...so if you do the wrong test for that gas...then you have to repeat it [keep doing different tests] and...you just keep doing it until you find out [reach the correct test for the gas]

I : Why is testing of gases difficult?
S15: There are many different tests...so you don't know which type to use...or maybe this type may not confirm what gas it is.

I : So can I say that you're not too sure of the reaction that has occurred?
S10: Yes...sort of.
S11: I mean it's like you're learning blindly...you don't know whether to do the hydrogen gas test or the carbon dioxide test. If you do the carbon dioxide test, you can't do the hydrogen test you see, but then it may not be hydrogen or it may not be carbon dioxide. So you may be directing hydrogen gas to limewater instead but that doesn't do anything. But by then you can't put in the glowing splint...er... lighted splint and let it extinguish. You really don't know what is...coming out.

Nineteen students said that they often had no idea why they were instructed to use a certain reagent or what they were testing for. They did not know the reactions which occurred or why they obtained a particular result. Excerpts of the students' laments are given below.

S7 : No, I think the main thing is that we don't know what we are testing for...that's the main thing.
S8 : Yes...throughout the experiment.
S7 : So when you don't know what you are testing for, you cannot come to sort of a conclusion.
S8 : Usually it's like...we get the results then we try to guess from the results. So if it happens that you did not do the test properly and the results are not what...what you are supposed to obtain, you wouldn't know it. Whereas if you knew what you are testing

for, then you will expect a certain result...so if you get something that is different from the (expected) results, you know that you did it wrongly. But usually we don't know that.

S25: It's like if they give you a question asking you to add in a reagent like sodium hydroxide...I won't be sure like... what cation or anion they are trying to test.
I : What do you mean you wouldn't be sure?
S26: I think she means like we won't know what we are testing for... we always do this thing [the experiments] blindly [without much thought] and then at the end when we have to make some...deductions...then we'll guess ...or just flip through our QA book.

S39: Mainly we do not know the reactions.
I : What do you mean you do not know the reactions?
S38: Like we just note the colour change and we memorise try and recall what it means.
S39: We jump to conclusions readily.
I : What do you mean jump to conclusions?
S39: Like we see a black solid and as only copper oxide is in our syllabus, we just write copper oxide is present.

S40: OK...it's like when they just give you some X substance and ask you identify the anion and cation present. You are half the time... I just don't know where to start. I'm very insecure as to...what I do is...when I do a test...I'm never thinking on what it might be, I just write down all that I see...so in the end when I have to make a conclusion, I find it very difficult.

This author believed that the lack of relational understanding (Skemp, 1976) of the procedures and reactions, the critical factors of the experiment, was the main cause of student difficulties in qualitative analysis. Lacking the theoretical understanding, students will not know what to look out for, when to look, how to look, and what sense to make of their observations (Hodson, 1992). If students knew why they were carrying out a given procedure and what reactions were likely to occur when they use a given reagent, they would know what products they were likely to get. They would then know what results to expect or what gases to test for. Unfortunately, as discussed in Chapter 3, they concentrated more on getting the right answer (Tasker & Freyberg, 1985) than understanding what they were doing. If students understood what they were doing, they would be able to evaluate any 'anomalous' results to determine whether the possible reactions would give such a result. This might prevent them from inventing an answer to replace the 'anomalous' results too readily. Student 9 summed up the situation in the following excerpt:

S9 : ...so when you understand it [the theory behind the procedures], if something goes wrong, you will know it...if you don't know what you are doing and if you made a mistake in first step, everything will be wrong. It is better if you understand what you're studying. When you apply it...if you make a mistake you can understand why. You can question your result, you can see why the result is like that and then maybe you can go back a few steps.

Based on his personal teaching experience, laboratory observations, interviews with students, and conversations with secondary chemistry teachers, this author believed that many students were unable to relate the content knowledge that they learned with the qualitative analysis practical work. Many students did not seem to make an effort to think and understand what went on in the experiments. Little meaningful learning of qualitative analysis will take place during practical work unless students realise that they have to apply and know how to apply the content knowledge that they learn in the classroom to the experiments that they do. They also need to be aware of their own thinking (Costa, 1991) to be able to describe, monitor, evaluate and reflect on what they do in the practical sessions.

Lack of time

Domin (1999a) believes that students are not given enough time to "actually think about the science principles being applied in the laboratory" (p. 109). The rush to complete the experiment might be a factor as to why Singapore students thought very little during practical work and did not understand what they were doing. Three excerpts from interviews illustrate this point.

I : OK...so now...before you carry out any experiment, do you read the procedure and roughly guess what's going on or what you think the unknown could be?

S3 : If we actually take the time to read and try to figure it out, but there's no time.

S28: You have to read the text, then you have to determine what test it is. You carry out the test and all that. But we only have very little time for each experiment as we still have to do the titration experiment. We don't have enough time and when you don't have enough time you cannot be so accurate, so detailed. Just don't have the time to think about what the test is for until you finish all the experiment. Then you need to identify the ions so you have to think what the tests are for.

I : OK...any other difficulty that you face?

S40: Well, actually most of the time when we do QA in school, we do it together with titration and everything...and you have limited time to complete both. So we are...I tend to take more time for the titration so when it comes to QA, I'll be panicking. So you tell yourself go slowly and look carefully. But then you're thinking about...oh no will I finish it. So I think for me it's the time factor. I'm sure if I do it like slowly and steadily, you give me two hours to do it, I probably will get the right things. But for me it's the time...I get very panicky.

In the practical examinations, students usually have to do two questions, one on volumetric analysis and the other on qualitative analysis, in 90 minutes. The titration that Students 28 and 40 mentioned is part of volumetric analysis. Students were expected to spend equal time (45 minutes) on each question. Thus, in order to prepare students for the examinations, teachers would normally give students both types of experiments to do in a session when the examinations drew nearer. However the laboratory sessions usually lasted between 70 to 80 minutes compared to 90 minutes for the examinations, so students had 10 to 20 minutes less to complete the experiments. In most cases, students were expected to complete the experiments and record their results, but were allowed to complete their reports at home and submit them the following day. In ordinary qualitative analysis practical sessions, teachers would frequently give students one and a-half to two qualitative analysis experiments to complete. This was because one experiment would usually take only 45 minutes to complete and teachers loathed wasting the remaining time. Denny (1986) found that students wanted more time in practical work but the students did not give any reasons why. For the secondary students in Singapore, squeezing two activities into 70 minutes resulted in too much work to be completed in too limited a time. This could cause the overloading of the students' mental faculties (Johnstone & Wham, 1982), and was probably one of the reasons why they adopted a cookbook approach to qualitative analysis. Pintrich et al. (1993) also warned that teachers who increased time pressure on their students would create a need for closure and decrease the cognitive activity of the students in their classes. Trying to maximise time in this case seemed a waste of time as students were discouraged from thinking, hence, failed to understand what they are doing.

Links between theory and practical work

Forty-seven students pointed out the link between qualitative analysis and the topic 'Acids, Bases and Salts'. However, the students did not seemed to be able to apply what they learned in that topic to qualitative analysis. This author believed that the students pointed out this link because the chemistry textbooks that they used could have discussed the identification of ions and gases in the chapter on 'Acids, Bases and Salts' (e.g. Heyworth, 1994). Other topics that students said to be related to qualitative analysis were 'Reactivity of Metals' (9 students), 'Redox' (7), and 'Periodicity' (5). Two students said that qualitative analysis was linked to the topic 'Rate of Reactions' because of the effects of concentration, catalysts and particle size on the rate of reaction. This author believed that 'Rate of Reactions' was not important to qualitative analysis as students were not required to apply knowledge that they learned from that topic to qualitative analysis, and the reagents that the students used were prepared for them by the laboratory technicians. Four students saw no links between qualitative analysis and their theory lessons.

Summary

In general, students found qualitative analysis practical work tedious and uninteresting. They were generally preoccupied with getting the 'right' answer, had little idea about what they were doing in the practical sessions and could not link theory with practical work. They seemed to lack confidence in carrying out the procedures and were often unsure of the results they obtained. This resulted in the frequent checking of their results with classmates and teachers. They also often ignored actual results obtained and wrote down results that they thought they should have obtained. The students felt that memorisation of facts was important in qualitative analysis, and believed that they were not given sufficient time to do the experiments satisfactorily.

The literature review in Chapter Two highlighted the possible causes of student difficulties in qualitative analysis. These included the lack of understanding of the purpose and critical features of the experiments (Tasker & Freyberg, 1985), lack of appropriate frameworks (Duit & Treagust, 1995), lack of cognitive strategies (Gunstone, 1994; Wittrock, 1994), the content of qualitative analysis (White, 1994), motivational beliefs and learning contextual factors (Pintrich et al., 1993), passive view of learning (Treagust et al., 1996), overloading (Johnstone & Wham, 1982; Nakhleh & Krajcik, 1994) and lack of mastery of process skills (Goh et al, 1987, 1989; Herron, 1996). Freedman (1997) believes that laboratory work has a positive influence on students' attitude toward science and their achievement because it makes science interesting and encourages students. This was most likely not the case for qualitative analysis practical work in Singapore schools. To paraphrase the words of Hodson (1990), qualitative analysis practical work seem to contribute little to the learning of chemistry or learning about chemistry, nor does it engage students in doing chemistry in any meaningful sense.

Interview protocol - reactions and procedures

As mentioned earlier in this chapter, all interviews started with the general questions (Figure 5.4). To collect information on students' knowledge of the procedures and reactions in qualitative analysis, this author used four sets of interview questions (Appendix H1 to H4). Each set of interview questions covered only a subset of the reactions and procedures in qualitative analysis. This author felt that it was not possible to cover all the different procedures and reactions in one sitting; there would be too many questions to ask, and it would be too long and taxing for the interviewees, as well as, the interviewer.

Each interview protocol had two experiments (Parts A and B) which formed the basis of the interview questions. These experiments were familiar to students as they were the usual ones carried out during practical work. To start this part of the interview, students were given a sheet of paper with just the description of the procedures. They were then asked questions, such as, what they thought the reagents were for, what reactions could possibly occur, what results they would expect, and whether they would carry out any test for gases. Next, they were given another sheet of paper, this time with both the procedures and the results described, and asked to explain the results. The observations were written the way students were taught to write. For example, in Set 1, Part A (Appendix H1), when the precipitate reacted with excess aqueous sodium hydroxide to form a solution, it was described as "white ppt (precipitate) is soluble in excess reagent to give a colourless solution", even though this author disagreed with the use of the term 'soluble'.

In addition, this author also followed his thesis supervisor's suggestion to actually carry out the procedures during the interviews. Many studies using interviews also involved the manipulation of concrete objects to determine student alternative conceptions (Lazarowitz & Tamir, 1994). Thus reagents were added to the unknown samples in front of the students, or students were asked to do it themselves and were allowed to examine the results. Any experiment which involved heating, for example, Parts A and B of Set 2 (Appendix H2) and Part A of Set 3 (Appendix H3), were not carried out as the interviews were carried out in classrooms. This was because, most of the time, the schools' laboratories were not available as they were used for lessons.

The interviews were semi-structured in that although there was a list of questions to ask, this author could deviate from the list to pursue any interesting comments or alternative conceptions given by the students. This flexibility enabled the author to gain a greater understanding of students' understanding or alternative conceptions of qualitative analysis. As a result, due to constraints of time, not all the questions in each set were discussed, but what was lost in breadth was compensated by what was gained in depth. Table 5.2 describes the reactions and propositional statements involved in each set of interview questions. The experiments used in the interview protocols also appeared in past years' October/November examination papers, and the years the experiments appeared were also noted in Table 5.2. Since teachers would usually give their students past years' examination questions, or very similar questions to practise on, students would be familiar with the experiments. Thus they should be able to draw on their practical work experiences to answer the interview questions. Table 5.3 describes the distribution of the interview protocols.

This author believed that many of the students' conceptions did not pre-exist before the interviews, but were created on the spot during the interviews. This was because, as mentioned in Chapters 1 and 2, and in previous sections in this chapter, many students adopted a cookbook approach to the practical work, so it was rather unlikely that any student gave serious thoughts to the procedures and reactions in the practical sessions. Thus many students could have come to the interviews with a 'clean slate' on qualitative analysis, and for the first time, had to really think about and make sense of what they knew about qualitative analysis to answer the questions. They had to struggle to organise their thoughts, and the answers given were often different from the expected ones.

Table 5.2: Specifications of the interview questions

Experiment	Possible reactions involved	Propositional statements involved	G.C.E. 'O' Level practical examination experiments
Set 1			
Part A	double decomposition,	9, 10, 14, 15, 16, 29, 30	90, 91, 93, 95 & 97
	complex salt formation,	9, 10, 12	
	base-ammonium,	9, 10, 11	
	neutralisation & reversal of complex salt formation	1, 2, 6, 9, 10, 12	
Part B	double decomposition,	14, 15, 29, 30	91, 92 & 96
	acid-salt,	1, 2, 4, 5, 8	
	redox (test for SO_2),	22, 23, 24, 25, 26, 28	
Set 2			
Part A	thermal decomposition,	17, 18, 19, 20, 21	95
	redox (decomposition of nitrate(V) & test for SO_2)	22, 23, 24, 25, 26, 28	
Part B	double decomposition,	9, 10, 14, 15, 16, 29, 30	94
	complex salt formation,	9, 10, 12	
	base-ammonium,	9, 10, 11	
	redox	22, 23, 24, 25, 26	
Set 3			
Part A	double decomposition,	9, 10, 14, 15, 16, 29, 30	93
	complex salt formation,	9, 10, 12	
	base-ammonium	9, 10, 11	
Part B	double decomposition,	14, 15, 29, 30	93 & 97
	complex salt formation,	13	
	neutralisation & reversal of complex salt formation	1, 2, 6, 9, 10, 13	
	acid-salt,	1, 2, 4, 5, 8	
	redox (test for SO_2)	22, 23, 24, 25, 26, 28	
Set 4			
Part A	double decomposition,	14, 15, 29, 30	94
	acid-carbonate	1, 2, 4	
Part B	double decomposition,	9, 10, 14, 15, 16, 29, 30	94 & 97
	neutralisation,	1, 2, 6, 9, 10	
	acid-salt,	1, 2, 4, 5	
	redox (test for SO_2)	22, 23, 24, 25, 26, 28	

Table 5.3: Distribution of the interview protocols

Question Set	Groups	Total number of groups
Set 1		
Parts A and B	(1,2), (3,4), (22), (9,10,11), (29,30,31), (35,36,37), (40,41)	7
Part A only	(25,26)	1
Part B only	(14,15), (27,28)	2
Set 2		
Parts A and B	(5,6), (7,8), (12,13), (14,15), (18,20,21), (42,43,44), (48,49)	7
Part B only	(38,39)	1
Set 3		
Parts A and B	(16,17), (18,19), (38,39), (40,41), (45,46,47), (48,49), (50,51)	7
Part B only	(23,24)	1
Set 4	(22), (23,24), (25,26), (27,28), (32,33,34), (42,43,44)	6

This author believed that any created conceptions in the interviews should be considered as valid alternative conceptions as the students had carried out the procedures many times during practical work and had been taught the theory behind the reactions involved in the procedures. Thus any created conceptions would be based on what they knew and had done before, not on what they had never seen or heard about (Duit et al., 1996). As stated in an earlier section of this chapter, if the students had never thought reflectively about the procedures and reactions, then the answers that they give might not be valid or reliable (Johnson & Gott, 1996). The students also might give answers that they did not really believe in (McClelland, 1984; Johnson & Gott, 1996) just to satisfy the interviewer. Thus, this author tried to triangulate data as described by Johnson and Gott (1996), for example, "to explore component aspects of an event" (p. 567) and to ask questions on different experiments, but involving similar reactions. Data collected from free response items (Chapter 6) would be used to corroborate and complement the data obtained from the interviews.

The interview data were transcribed verbatim by this author and analysed. The various alternative conceptions determined were then categorised and discussed under the various reactions concerned. Reactions and procedures which students had little knowledge of and could not explain were classified as non-conceptions. The alternative conceptions and non-conceptions were summarised in the form of a table at the end of each discussion of the reactions concerned.

Formation of precipitates in double decomposition reactions

Many cations and anions are identified through the formation of precipitates in double decomposition reactions. For example, cations are identified by the colour of the insoluble hydroxide formed when aqueous ammonia or sodium hydroxide is added to an unknown solution and whether the precipitate reacts further with excess alkali. Anions such as chloride and iodide are identified through the use of aqueous silver nitrate(V) or lead(II) nitrate(V), while sulphate(VI) is identified by reaction with aqueous barium salts. Many students had difficulty explaining the reactions which occurred in the formation of precipitates and a number of alternative conceptions were recorded.

A more reactive ion displaces a less reactive ion. Fourteen students said that the formation of precipitates, for example, when aqueous sodium hydroxide was added to an unknown solution, was due to a more reactive cation displacing a less reactive one. Similar findings were reported by Boo (1994, 1998) in her study of older A-level students (16 to 19 years old). As mentioned in Chapter Three, secondary chemistry students are taught that displacement is a redox reaction in which a more reactive element reduces a less reactive element in its compound resulting in the formation of the less reactive element and the compound of the more reactive element. However, many students used the term 'displace' when they described double decomposition/precipitation reactions. For example, in Set 1 Part A (Appendix H1), when students were asked why the white precipitate was formed, 11 of them said that the sodium ions 'displaced' the unknown cation resulting in the formation of the precipitate. This concept interference (McDermott, 1988) is illustrated in the following excerpt.

S9 : Does it have anything to do with its...being a reactive metal?
I : Why do you say that?
S9 : Because the metal at the top displaces the bottom [less reactive] metal. So maybe because sodium is a reactive metal, it will be able to displace those below it. Rather than you get something like iron or lead that's not as reactive as sodium and may not be able to displace the other metal.
I : So in this case what will happen?
S9 : Either you get a precipitate or perhaps there will be no change.
I : OK. Can you explain how the results in the experiment tie in with what you said about displacement?
S9 : I think the metal is less reactive than sodium. That's why sodium hydroxide is able to displace it and form a new insoluble salt.

A possible reason for the above confusion is that Student 9 could not differentiate between an ion and an atom (Nakhleh & Krajcik, 1994; Taber, 1996), or the characteristics of an element in its elemental state or in a compound. Thus, Student 9 could have thought that the sodium atom and the sodium ion behave in the same way, so the sodium ion could also displace the unknown cation. Another explanation could be that Student 9 did not understand the term 'displacement' and thought that ions could also displace other ions. Reif and Larkin (1991) believe that scientific terms are commonly taught to students, but the use of these terms are rarely explicitly elaborated by teachers or practised by students. Thus, students do not fully understand the meaning of the terms, are unable to explain the use of the terms explicitly and cannot use them correctly. In addition to being taught that a more reactive metal displaces a less reactive metal from its compounds in the topic 'Reactivity of Metals', students were also required to memorise the reactivity series which is a list of several metals arranged in order of decreasing reactivity. Thus, what they learned in 'Reactivity of Metals' could have become more prominent compared to what they learned about double decomposition. This resulting set effect (Hashweh, 1986) could cause students to inappropriately apply knowledge from previous learning (Ebenezer & Erickson, 1996), that is, reactivity and displacement, to explain double decomposition. As this author's thesis supervisor pointed out, the students' attempts to reconcile their observations (macroscopic system) with their existing knowledge of how particles react (microscopic system) created the 'more reactive ion displaces the less reactive ion' alternative conception. It was quite obvious that students had little understanding of displacement and double decomposition reactions or were unaware of the differences between the two reactions. The following excerpts are further illustrations of this problem.

I : OK...so what actually happens that gives rise to this insoluble substance?
S7 : What actually happens?
S8 : Is displacement possible?
I : Why do you say that?
S8 : Because...because sodium is a metal higher in the reactivity series. So er...any cation that is below it may be displaced.

I : ...if a precipitate is formed, can you tell me why...or what leads to its formation?
S33: Displacement.
I : Why displacement?
S33: Why displacement...the more reactive one displace the less reactive.
S34: Sodium...displaces the...
S33: Sodium is very reactive...so it displaces things under it in the reactivity series.

One student viewed the reaction slightly differently; she believed that it was the unknown cation that displaced the sodium ions.

I : Can you tell me, why is sodium hydroxide added?
S41: Is it something to do with the reactivity series...metals...will displace sodium, something like that.
I : Can you elaborate further what do you mean by displace?
S41: If it is more reactive than sodium, then it should displace sodium from sodium hydroxide.

Ammonia is included in the reactivity series. In Interview Questions Set 4 (Appendix H4), the aqueous ammonia was used instead of aqueous sodium hydroxide to determine the identity of the unknown cation. Student 22 believed that the unknown cation displaced the ammonium ion because the unknown cation was more reactive.

I : What sort of reaction happens that produces the precipitate?
S22: Precipitation...discharge...displacement, er displacement reaction.
I : Can you elaborate further what do you mean by displacement?
S22: Displacement that er...cation is more reactive than the ammonium ion...cation.
I : OK.
S22: And thus it will displace the ammonium cation to form...a... hydroxide.

The interviewer's initial question in the above excerpt might appear to lead Student 22, but the interviewer used the term 'precipitate' because Student 22 himself used the term to answer a previous question on what he saw when aqueous ammonia was added to the unknown solution. The same reason applied for the interviewer's use of the term 'precipitate' in the two excerpts below.

Even though ammonia is not a metal and is not included in the reactivity series, Student 22 still applied the concepts of reactivity and displacement to the use of aqueous ammonia, giving another example of the 'more reactive ion displacing less reactive ion' alternative conception. Interestingly enough, when students were asked questions on why aqueous barium chloride (Appendix H1) or silver nitrate(V) (Appendix H2) could be used to identify anions, none of them mentioned anything about reactivity and displacement even though double decomposition reactions also were involved. The following excerpts of interviews illustrate student conceptions of the processes involved in the identification of anions through double decomposition reactions.

I : What sort of reaction occurs to give you a white precipitate?
S22: A...precipitation.
I : OK. Can you describe what happened?

S22: Because...it's like...both are aqueous solutions...so the sulphate ion will react with the barium ion to form barium sulphate. Then that barium sulphate will become a precipitate which is insoluble...and therefore precipitates out.

I : OK...why is the precipitate formed...how is the precipitate formed?

S 41 : When silver reacts with the chloride ion...forms silver chloride, an insoluble salt.

Thus it seemed that the students interviewed only associated reactivity and displacement with cations and not anions. For example, Students 22 and 41 applied the 'reactive ion displaces less reactive ion' alternative conception to explain the formation of precipitates using alkalis but they could give acceptable answers as to why precipitates were formed when aqueous barium nitrate(V) and silver nitrate(V) were used. This finding seemed to support the hypothesis that the set effect from the learning of the topic 'Reactivity of Metals' interfered with the understanding of double decomposition reactions involved in the identification of cations, and showed that the students lacked an adequate conceptual framework of relevant chemical reactions; they might have a collection of scientific concepts and alternative conceptions, and choose to use different ones in different situations (Palmer, 1999).

Equating displacement with replacement. Another alternative conception was the equating of 'displacement' with 'replacement' or 'substitution'. This is illustrated in the following excerpt of an interview:

I : OK, now why is the precipitate formed?

S35: The hydroxide reacts with the chemical...and displaces the other chemical.

I : You used the word displaces...can you explain the word?

S35: That means like using hydroxide replacing another nitrate and another compound is formed.

This author had earlier thought, before the interviews, that the main problem would be due to students equating 'displace' with 'replace' as discussed in the section on displacement in Chapter 3. However only Student 35 brought it up, and interestingly enough, to explain the replacement of an anion with another anion; this was similar to what Dr. Aw referred to in Chapter 3. This author believed that Student 35 lacked understanding of the term 'displacement' rather than had an alternative conception.

Reactivity of the metal in a compound affects the solubility of the compound. Another student conception concerning the reactivity of metals and the formation of a precipitate was detected. Students 23 and 27 believed that the reactivity of the ions affected the solubility of their compounds, thus the formation of the precipitate.

I : Why is ammonia solution used?
S23: Because it contains ammonium ions...which is more reactive than most of the other ions.
I : And what happens?
S23: There will be a precipitate formed.
I : Why?
S23: Besides the ammonium ions, there are also hydroxide ions present.
I : Yes?
S23: And the cation below the ammonium will form a precipitate...it's insoluble in water. The hydroxide of the cation below ammonium is insoluble...so it will give a precipitate.

S27: Something that cannot dissolve...I don't know...it depends on the reactivity series.
I : Again, why depends on the reactivity series?
S27: Is it because...if metal ion is higher...cannot dissolve?
I : What do you mean by that?
S27: High in the reactivity series then the hydroxide is not strong enough to dissolve the metal cation.
I : If it's low?
S27: It should dissolve.

Student 23 was able to state that the precipitate was the hydroxide of the unknown cation. However, he believed that the hydroxide was insoluble because the unknown cation was 'less reactive' than the ammonium ion. As stated in an earlier section, ammonia is not a metal and is not included in the reactivity series. Yet another student thought that it was in the reactivity series. It was unfortunate that this author did not probe the ammonia-reactivity series issue further. This author believed that Student 23 might have included ammonia in the reactivity series because he knew that the ammonium ion was also a cation, just like ions of metals. Since ammonium salts are soluble, as are the salts of reactive metals such as sodium and potassium, and some salts of less reactive metals such as chlorides of lead(II) and silver are insoluble, Student 23 might have concluded that precipitates were formed when aqueous ammonia was used because cations less reactive than the ammonium ion were present. Student 27 also stated that the precipitate was a hydroxide of the unknown cation, as well as, attributed the insolubility of the precipitate to the reactivity of the metal present in the precipitate. The difference was that she thought the hydroxide ions were not 'strong enough' to dissolve reactive cations. Again, it was unfortunate that this author did not probe deeper into what she meant by 'strong enough' and 'dissolve'.

Identity of the precipitate. Five students had difficulty in identifying the precipitate formed in a double decomposition reaction in which aqueous sodium hydroxide was used.

I : Now can you tell me what the sodium hydroxide is used for?
S15: To form...to react with something to form precipitate.
I : OK...can you give me an example?
S15: Sodium chloride with calcium, then calcium something cannot dissolve.
I : What's that something?
S15: A salt of calcium...calcium chloride or...can't remember is it... (paused to think)
I : What do you think?
S14: I'm not sure.
I : Let me see if I got it correct. You have a calcium compound...you react it with sodium hydroxide...it will give you a precipitate and that precipitate is a calcium compound...but you're not sure what...what calcium compound that is.
S14: Right.
S15: Right.

Students 14 and 15 were not able to state that the precipitate was a hydroxide of the unknown cation. This would imply that they had no conception that a double decomposition reaction had occurred. Hence they were unable to work out that hydroxide was present in the precipitate. Students 9, 20 and 21 admitted that they did not understand what occurred in double decomposition, and Students 30 and 31 also had problems naming the precipitate.

S 9 : We're just given this [notes on QA] you see...and given the table and you follow it...you add sodium hydroxide, you get this result and the table tells you it's something, you add ammonia you get this, you see...so that's all we learn...we don't know why this is added and how it affects...we don't learn that.

I : Oh you mean that once there's a displacement reaction, a metal salt will come out?
S 20 : Now I'm getting kind of mixed up.
S 21 : Never thought of it...serious!
S 20 : I also do not understand. Actually, we have never thought of that before...why is there a precipitate.

I : I'm going to add sodium hydroxide until a change is seen [interviewer adding aqueous sodium hydroxide to a test tube containing the unknown solution]. OK...can you make any deductions so far?
S30: Well it's either aluminium, calcium or zinc [referring to the white precipitate formed].
I : OK if it's aluminium, calcium or zinc...what salt of aluminium, calcium or zinc is formed?
S31: I don't know [translated from Mandarin]
I : How do you know it is aluminium, calcium or zinc?
S31: Refer to the QA table.
I : OK...so what do you look for?
S31: White precipitate.
I : OK so white precipitate ...you're assuming that calcium is part of it right, calcium, aluminium or zinc. OK...but if it's a compound, it must have an anion too, right?
S 31 : Yes.
I : So now...can you identify what the anion is?
S 31 : Chloride or sulphate.
I : Eh?
S 31 : Chloride or sulphate.

Instead of saying calcium, aluminium or zinc hydroxide, Student 31 replied that he thought the precipitate was a chloride or sulphate. This author believed that Student 31 had no idea how the precipitate was formed, and that he used his knowledge of insoluble salts to give the answer. Students were usually instructed to memorise a table of soluble and insoluble salts in topic 'Acids, Bases and Salts', and Student 31 might have recalled that a number of chloride and sulphate(VI) salts were insoluble, so he gave them as the answer. Student 9 spoke for many students when he indicated that he had little understanding of what he did in the practical sessions, and relied much on the notes or handbooks on qualitative analysis to decipher the results obtained.

More students were able to identify the precipitate formed when aqueous barium or silver salts were used in the tests for anions. For example, Student 15, who did not to identify the hydroxide earlier, was able to identify barium sulphate as a white precipitate.

I : OK...now can you tell me why barium chloride is added?
S 15 : Use to test the presence of sulphate.
I : Use to test the presence of sulphate. OK...if it is a sulphate, what will happen?
S 15 : It will form barium sulphate...an insoluble salt.

However, as this author did not probe further, he was uncertain whether Student 15 actually understood the reaction which occurred or whether he merely recalled that if a precipitate was formed when aqueous barium compounds were used, then the precipitate was barium sulphate. In another interview, Student 29 could state that barium chloride was used to test for a sulphate but could not explain the reaction involved:

I : OK...now why do I add barium chloride?
S29: Test for sulphate.
I : Why is it used to test for sulphate?
S29: Don't know...no idea.

Thus, it seemed that knowledge of the identity of the precipitate involved in the reaction or that a particular reagent was used to test for a given ion did not necessarily imply understanding of the reaction involved.

Adding aqueous reagents to solids. In one practical session, this author observed a few students adding aqueous ammonia directly to an unknown solid sample to test for the cation present. The students should first make a solution of the unknown sample before adding the aqueous ammonia. If not, they would not be able to decide, if there was a solid present after adding and mixing the reagents, whether the solid was a precipitate formed or whether it was the undissolved unknown sample. Thus this author decided to ask students whether it was possible to test for cations by adding alkali to a solid unknown sample. Many students explained that alkali should not be added to a solid sample because there must be mobile ions for a reaction to occur, so aqueous solutions were required. They seemed to see the alkali as consisting of cations and hydroxide ions, ignoring the water present in aqueous alkali which could dissolve the solid. Prieto et al. (1989) and Ribeiro et al. (1990) also found that students tend to ignore the solvent or regard it as a passive component. None of the students pointed out that one could not be certain whether the solid in the test tube was a precipitate or the undissolved original solid.

I : Why can't you add sodium hydroxide directly to a solid?
S35: Because it must be aqueous.
I : Why?
S35: Because if it's aqueous, then it will have effect when you add the sodium hydroxide, then you'll produce a precipitate.
I : Why do you think there is no effect when you add to a solid?
S35: As I said, it must be aqueous and then it can react to form precipitate. So without adding water, then it is not aqueous...then I don't think it will show any results.

I : OK, have you ever done this test using sodium hydroxide solution on a solid sample?
S40: No.
I : Can it be used for a solid sample?
S40: No.

I : Why not?

S40: Because the ions have to dissociate in aqueous...condition.

I : Why must it dissociate?

S40: So that they react with the...I mean...

S41: Free ions so that they can...

S40: React...

S41: React with the sodium hydroxide ion.

One other related matter arose. When the author asked the students how they thought the aqueous sodium hydroxide that they used in the laboratory was prepared, this author was surprised that none mentioned dissolving solid sodium hydroxide in water. Students 3, 4, 7 and 8 believed that it was formed by mixing reagents together, for example, a compound containing sodium and a compound containing hydroxide so that the ions will inter-exchange, and Student 36 said that it was made by adding sodium to water. This showed that the students had little knowledge of basic preparation of reagents and had taken all the reagents that they used for granted because all that they needed were prepared by the schools' laboratory technicians. Thus, they did not know what went on behind the scenes in the laboratory. Wang (2000) also commented that students were rarely required to prepare their own solutions so when they had to actually do it, many could not even though they knew how to prepare solutions in theory and do calculations involving concentration.

Alternative conceptions and non-conceptions that students have on formation of precipitates in double decomposition reactions are summarised in Table 5.4.

Formation and reactions of complex salts

As mentioned in Chapter 3, students were required to know that oxides and hydroxides of aluminium, lead and zinc would react with excess aqueous sodium hydroxide to form aluminates, plumbates and zincates, respectively. However, they were not required by the syllabus to know that zinc hydroxide, copper(II)

Table 5.4: Alternative conceptions and non-conceptions on the formation of precipitates in double decomposition reactions

Alternative conceptions	Non-conceptions
1. A more reactive ion displaces a less reactive ion.	1. Double decomposition a. What a double decomposition reaction is/ What happens in a double decomposition reaction. b. The identity of the precipitate formed in double decomposition reactions. c. Why reagents should not be added directly to solid samples.
2. Ammonia is included in the reactivity series.	2. Equating displacement with replacement.
3. The reactivity of the metal in a compound affects the solubility of the compound. a. Compounds of less reactive metals are likely to be insoluble. b. Reagents added may not be 'strong enough' to dissolve compounds of reactive metals.	3. How bench reagents are prepared.

hydroxide and silver chloride would react with excess aqueous ammonia to form the respective ammines. These reactions were similar to the reactions of the amphoteric oxides/hydroxides with sodium hydroxide, and students also encountered them frequently in the qualitative analysis practical work. In many experiments, students were instructed to add dilute acid to reverse the formation of complex salts, but again, they were not required to know the reactions involved. This author felt that this created an awkward situation in that students might just follow these common instructions without understanding what they were doing. This was proven to be true during the interviews when students had to answer questions on the formation and reaction of complex salts; 11 students admitted that had no idea what reaction had taken place or what a complex salt was. Generally, the students struggled to answer the questions posed, and several ideas such as the precipitate merely dissolved in the excess reagent added and displacement reactions were proposed.

Precipitate dissolves in excess reagent. Based on the definition of the term 'dissolve' in Chapter 3, this author found that many students had problems differentiating dissolution and reaction. This supported White's (1994) claims that specialised use of common words might lead to greater incidence of alternative conceptions, and that the specialised use of these terms are rarely explicitly elaborated by teachers or practised by students (Reif & Larkin, 1991). Student conceptions on dissolution were illustrated by the following excerpts of interviews in which students were asked why the precipitate disappeared when excess sodium hydroxide was added:

I : My point is that if the precipitate is insoluble in the first place, why should it be soluble later?
S11: Maybe you add extra solvent...there's more liquid for the substance formed to dissolve.
I : OK, so you're saying that more solvent that's why...
S11: More and more...
S10: Hold on...if you add more you might make it more concentrated.
I : Sorry?
S10: If you add more you might make it more concentrated because if R...with the unknown inside already...it (R?) could become very diluted.
I : OK when you add more what happens?
S10: Maybe you could make it (solution?) more concentrated and then cause it to dissolve.
S11: I think the reason why we get a precipitate first...is maybe...there is a limited amount of solvent...that's why some of them dissolve in the solvent, whereas the rest did not dissolve...that's why when you add more...then it will dissolve...I think it is like that...I think that's how it works.

Student 11 believed that the precipitate 'dissolved' when the additional 'solvent' was added. This author was uncertain exactly what Student 10 meant by making things more concentrated or diluted. He proposed that Student 10 was saying that if more sodium hydroxide was added, the solution would be more 'concentrated' with sodium hydroxide, thus 'diluting' the amount of precipitate present, causing it to 'dissolve'. Solomonidou and Stavridou (2000) believe that people usually "ignore the possibility that a substance must sometimes interact chemically with one or more other substance(s) and/or energy to produce new substances(s) completely different from the initial one(s)" (p. 383). They also contend that "the learning of language by children may suggest that substances are inert objects" (p. 384) and do not interact with other substances or energy.

The mere disappearance of the precipitate without any visible sign of reaction such as colour change, evolution of gas or release of energy could deceive students into thinking that the precipitate merely dissolved. They would be comfortable with that idea because they focus on the initial state of the precipitate without taking into account the final state just as Solomonidou and Stavridou (2000) proposed, and also how the precipitate was obtained in the first place.

In Chapter 2, the assertion by Brosnan (1999) on the triviality of the definitions of and distinctions between physical and chemical changes and how it applies to dissolution were discussed. The definition of dissolution is trivial if the students understand what happens at the microscopic level. However, it seemed clear in this case that a number of students did not understand what actually happened when excess alkali was added and that their understanding of the term 'dissolve could led them to the incorrect conclusion that more alkali meant more 'solvent' for the precipitate to 'dissolve'. The following excerpt further illustrates this alternative conception.

I : OK...is a precipitate insoluble?

S12: Yes.

S13: Yes.

I : Then why should it dissolve in excess?

S13: Because before adding excess, that solution perhaps could be concentrated, so...it gives out a precipitate. By adding excess sodium hydroxide, you're giving more volume for the... you're creating more space for precipitate to actually dissolve in it.

I : So in other words, it's just like adding water to excess sugar. I put in more water and more sugar will dissolve.

S13: Yes...it's for a nitrate.

S12: I think I read somewhere that when you add an excess of hydroxide to certain compounds, you produce another chemical which disappears from the solution as well.

I : So you're telling me that adding hydroxide results in a chemical reaction rather than what you [indicating to Student 13] say, diluting something.

S12: I think it's something like that...I'm not too sure...it's very vague in (my) mind. I think I recall reading somewhere that this happens to certain compounds.

Student 13 also believed that the precipitate dissolved in the additional aqueous sodium hydroxide added. In addition, he had some difficulty with the concept of dissolution, which was shown when he said that more solvent added meant more space or volume for the precipitate to dissolve. This author was uncertain what Student 13 meant when he said that "it's for a nitrate" in agreeing with this author's analogy of more water dissolving sugar; perhaps Student 13 was comparing sugar with nitrate(V) salts, both of which were soluble. Student 12, however, remembered some of what he was taught about amphoteric compounds and thus, was able to give a better picture of the reaction concerned. This author also discovered an interesting alternative conception on dissolution. Student 11 believed that the size of the particle and space between water molecules played a major role in dissolution as the following excerpt illustrates.

S 11 : I think whether something will dissolve depends on, I think from our textbook, the space…the molecular space between the water. So if let's say sand, the atom, the size of the atom is bigger than the molecule of the water, that's why it cannot sink between them, so it cannot dissolve …something like that.

Ebenezer and Erickson (1996) also found that some students believed that "substances do not dissolve because they do not find sufficient space in the dissolving medium" (p.192) and that size of the solute affects its solubility.

Students 7 and 8 discussed the disappearance of the precipitate and also had some interesting ideas as to what happened to the precipitate.

I : Not like water dissolving sugar [the precipitate disappearing].
S7 : No.
S8 : No because when you first add sodium hydroxide to R, R is the pure compound form, so a precipitate appears. But now the precipitate is another compound already, so when you add sodium hydroxide to it, it is acting on another compound. It is not acting on the original R.
I : So it is a reaction.
S7 : Yes.
I : In that case, is dissolving a correct term to use?
S8 : I don't think so.

I : Why do you say that?

S8 : Dissolving is like...adding water to something...and [interrupted by Student 7]

S7 : The thing may be soluble in the reagent but the reagent may not be water because it might be another reaction taking place.

S8 : Yes it may not be dissolving...yes...it may just [interrupted by Student 7]

S7 : Soluble in that...in that reagent but insoluble in water.

I : What about this case, sodium hydroxide?

S8 : When you add sodium hydroxide to the precipitate, some chemical reaction happens...the compounds formed may not be in solid form. It may be in a liquid state so you can't say it is dissolving...it's just that it's in a liquid state.

I : Liquid state only.

S8 : Yes...so if there are two compounds formed and both are liquids, they will mix together...so you can't say that is soluble...you can't say it is dissolved.

Students 7 and 8 knew that there was a reaction between the precipitate and the excess aqueous sodium hydroxide. However, they were uncertain about the product formed. Student 8 attributed the disappearance of the precipitate to the formation of a liquid product which was merely mixed with the excess reagent. Student 7 believed that the compound formed was soluble in aqueous sodium hydroxide but not water. As mentioned earlier, students very often ignored or forgot that water constituted the major part of a solution (Prieto et al., 1989); students seemed to see a solution as an entity consisting solely of the solute rather than a mixture of the solute and solvent. Student 7 also seemed not to realise that water played a major part in the dissolution of a substance. This author felt that Students 7 and 8 did not fully understand the concept of dissolution and their ideas were categorised as non-conceptions.

Displacement revisited. Student 31 believed that excess aqueous sodium hydroxide was able to displace the cation from the precipitate to give a solution.

I : Why should it be soluble when you add more aqueous sodium hydroxide?

S 31 : Because...if the concentration of sodium hydroxide is more, so it will be able to...is it displace?

I : Why...what do you mean by displace?

S 31 : I think that maybe with more of the sodium hydroxide, you will be able to displace the ions from the compound used to...the compound you want to test.

Student 31 continued to share his thoughts below.

S 31 : When you take something, you use a more reactive substance to replace the thing and you place this more reactive substance in its place.
I : OK, what is displaced?
S 31 : Displace...what...the compound.
I : Which compound?
S 31 : For example if this calcium carbonate...
I : OK.
S 31 : You add this sodium hydroxide in, you will be able to displace the calcium from it and then something like sodium carbonate will be produced.
I : And why does the precipitate...disappear?
S 31 : Because more of the sodium hydroxide...the calcium will more and more be displaced and will be removed completely so that you will not see it.

As this author did not probe any further, no further elaboration of Student 31's interpretation of the reaction was obtained.

When aqueous silver nitrate(V) is added to a solution containing chloride ions, a white precipitate of silver chloride is formed. If aqueous ammonia is added to the mixture, the ammonia and silver chloride react to form a soluble ammine, giving a colourless solution. However, Student 51 believed that a displacement reaction between silver chloride and aqueous ammonia had occurred.

I : OK, what do you think happened?
S51: Maybe the silver chloride is further displaced...
I : Meaning?
S51: Some sort of reaction, then turns to another compound which is colourless.
S52: A new silver salt...maybe...
S50: Which is colourless.
S 51 : Yes.

Students 50 and 51 believed that a colourless silver salt formed, so the precipitate disappeared. This author was uncertain whether they meant that a colourless solid silver salt was formed or a colourless solution of the silver salt was formed.

Formation of ammonium chloride. Still on the reaction of silver chloride with aqueous ammonia, Students 16 and 17 had this to say:

I : OK, what do you think happens?
S16: The ammonia reacts with the insoluble salt to break it up.
I : To break it up...what do you mean to break it up?
S16: Break the ions up.
I : And what does it form?
S16: Forms a soluble solution.
I : OK...can you sort of guess the identity of the solution?
S16: Ammonium chloride.
I : Ammonium chloride...why do you say that?
S16: Because when you add silver nitrate right...there is a precipitate so it could be silver chloride.
I : OK.
S16: So when you add ammonia...might be ammonium chloride... because it reacts with the silver chloride.
I : So it's something like the ammonium ion...exchanging places.
S16: Yes...with the silver.
I : Do you have any opinions?
S17: Maybe it's zinc chloride.
I : Why do you say it's zinc chloride?
S17: Because zinc chloride is soluble in excess...I'm not sure.
I : Zinc chloride is soluble in excess...so you mean the white precipitate disappears when ammonia is added...that's why you say it is zinc chloride.
S17: Yes.

Student 16 knew that there was a reaction between the aqueous ammonia and the silver chloride precipitate as the precipitate was 'broken up', but he did not know what the reaction was. Since students were taught that all ammonium salts were soluble and a colourless solution was obtained when the procedure was carried out, this author believed that Student 16 guessed that ammonium chloride was formed. Logically, then ammonium must have either exchanged places with silver or 'displaced' it. Student 17, on the other hand, believed that zinc chloride was formed. This author proposed that Student 17 knew that zinc hydroxide would react with excess aqueous ammonia to form a colourless solution. The reactions involved were similar but Student 17 seemed to ignore the fact that a precipitate was formed when aqueous silver nitrate(V) was added and not aqueous ammonia. Thus Student 17 selectively attended to certain details and ignored others to explain, using what he knew, the phenomenon observed (Hesse & Anderson, 1992).

Students 38, 39, 40 and 41 also believed that ammonium chloride was formed, most likely because it is soluble.

I : Why is it soluble?
S39: Why...ammonium chloride...
I : Why do you say ammonium chloride?
S39: Because when you add silver nitrate to chloride, it will form silver chloride ions...the silver chloride salt...so if you add aqueous ammonia, there will be...silver chloride...ammonium chloride.
S38: Ammonium chloride.

I : OK, now I'm adding ammonia [adding aqueous ammonia to silver chloride precipitate]...can you see it...what happens?
S41: Precipitate dissolves.
S40: Dissolves.
I : OK...why do you think it dissolves?
S40: No but ammonium...silver...ammonium chloride...
S41: Ammonium chloride, is it soluble..yes.
I : What did you say?
S 40 : The precipitate from the first reaction is silver chloride, and when it reacts with aqueous ammonia...ammonium chloride is formed...which is soluble.

The alternative conceptions and non-conceptions on the formation and reactions of complex salts are summarised in Table 5.5.

Table 5.5: Alternative conceptions and non-conceptions on the formation and reactions of complex salts

Alternative conceptions	Non-conceptions
1. Formation of complex salt. a. The precipitate dissolves in additional solvent (excess reagent) added. b. The cation in a precipitate will be displaced when the excess alkali is added. c. Ammonium chloride is formed when aqueous ammonia is added to silver chloride.	1. How a complex salt is formed or what a complex salt is. 2. Ignorant of the fact that miscible liquids dissolve in each other. 3. Ignorant of the fact that water is the major constituent of an aqueous solution.
2. Solubility a. When more solvent is added, more solute will dissolve because there is more space/volume for the solute to dissolve in. b. Size of particle of a substance and space between water molecules determine if a substance is soluble. If the particle is bigger than a water molecule, then the substance is insoluble.	

Addition of acid/base

Several students had difficulties with procedures involving the addition of acids and bases as they were unaware of the reactions taking place. They had learned the reactions in the chapter on 'Acids, Bases and Salts' but could not make the link between what they had learned and the procedures they carried out. Students' conceptions on the use of litmus paper and the reactions involved when acids or bases were used are discussed in the following sections.

Moist litmus paper. Students 50 and 51 did not know why litmus paper had to be damp to test for ammonia.

I : OK now, how do you test for ammonia gas?
S51: Red litmus turns blue.
I : OK...dry litmus paper or moist?

S50: Moist.

S51: Moist.

I : Why must it be moist?

S50: This one...we're also not very sure.

I : If you use dry (litmus)...will you get the same test (result)?

S51: Sometimes.

I : Have you ever tried?

S50: No...I have not tried it.

I : So you're not sure why you use moist red litmus paper?

S50: I'm not sure.

Students frequently used litmus paper to test the acidity or alkalinity of a gas evolved in qualitative analysis experiments but Students 50 and 51 did not know the reason why the litmus paper had to be damp. They did not know the gas had to dissolve and dissociate in the water present so that any hydroxide or hydrogen ions formed would react with the dyes in the litmus paper present, causing it to change colour. Thus this was another instance of instrumental understanding (Skemp, 1976), of "rules without reasons" (p. 20).

Redox reactions involved. Several students were uncertain when acids behaved as acids and when they acted as oxidising or reducing agents. Others commented that neutralisation involved redox. Many students could not give the correct answer when asked why a precipitate reappeared and then disappeared when acid was added to a mixture containing excess alkali and a complex salt. These reactions were common in the procedures that the students carry out; unfortunately they did not understand what they were doing. The following excerpts of interviews highlight the students' difficulties:

I : OK now can you tell me then what will happen if I add acid?

S25: It might turn colourless...I'm not sure.

I : Why do you think that?

S25: Don't know...maybe there's some neutralisation or...I'm really not sure.

I : OK.

S26: Maybe...because the oxide may be reduced...or something like that.

I : Reduced by?

S26: If you add in the acid…is it reduced or oxidised? I'm not too sure whether it is reduced or oxidised.

I : OK…by nitric acid…or acids in general?

S26: I think…acids in general.

Students 25 and 26 and this author were discussing the addition of nitric(V) acid to a mixture containing excess aqueous ammonia and a precipitate of iron(II) hydroxide. Student 25 had an inkling of what had happened as she stated there could be "some neutralisation". Student 26, however, believed that a redox reaction had taken place. Students were taught that nitric(V) acid was an oxidising agent, so that might be why Student 26 thought that a redox reaction had occurred. Another reason might be that Student 26 knew that hydrogen ions were involved in reactions of acid and that a definition of reduction was the addition of hydrogen to a substance. So she might have thought that when an acid was used, hydrogen ions were 'added' to the other reactant, reducing it. This assumption was supported by one student who told this author, when he observed the practical sessions, that concentrated and dilute hydrochloric acids were reducing agents because they contained hydrogen ions. When given the same situation, Students 32, 33 and 34, agreed that iron(II) nitrate(V) and water were formed. However, Student 33 stated that a redox reaction could be involved.

I : So what sort of reaction happened?

S33: What sort of reaction happened? The iron hydroxide is being oxidised.

I : Iron hydroxide is oxidised by?

S33: By the nitric acid.

I : To form?

S33: To form iron nitrate and water.

I : Why do you use the word oxidised?

S33: Because it has an increase in oxygen but a loss in hydrogen.

Iron(II) hydroxide ($Fe(OH)_2$) reacted with nitric(V) acid to form iron(II) nitrate(V) ($Fe(NO_3)_2$) and water. From the formulas of the compounds involved, one could be easily misled to think that hydrogen was 'lost' from the first compound and that there was an 'increase' in the number of oxygen particles in the second compound. Looking at it this way, and knowing that an oxidation reaction involved the loss of hydrogen from a compound or the addition of oxygen to a compound, one could understand why Student 33 had believed that iron(II) hydroxide was oxidised by nitric(V) acid. If Student 33 had used the oxidation number model of redox, he would have realised that no redox reaction had occurred (Davies, 1991; Garnett et al., 1990; Herron, 1975; Ringnes, 1995; Sisler & VanderWerf, 1980). Thus, Student 33 could have arrived at this alternative conception of neutralisation by not understanding what actually happens in a neutralisation reaction, and using inappropriate models of redox for the situation.

Displace, decompose and some others. This author was told, during a practical session, that when aqueous barium nitrate(V) was added to an unknown solution, followed by the addition of nitric(V) acid, the hydrogen ions displace the cations in the precipitate to form a solution. The student obviously did not realise that the acid was added to determine whether the precipitate was barium carbonate, sulphate(IV) or sulphate(VI) even though this was a common procedure in qualitative analysis experiments. Unfortunately, this author did not pursue what the student meant by displacement, so no further conclusions could be made. Student 16 also used the term 'displace' to describe a reaction involving a silver ammine complex, excess aqueous ammonia and dilute nitric(V) acid. In this reaction, the acid neutralised the excess alkali and reversed the formation of the ammine, resulting in the reappearance of the white precipitate, silver chloride.

I : Can you describe what happened?

S16: When the acid reacts with the ammonia [sic] chloride ...then displacing it...breaking it up. The silver ion from the solution reacts with the chloride again to form silver chloride.

I : Now let me see whether I understand you. You say that the ammonium chloride formed...the acid comes in...it sort of breaks the compound apart...

S16: Sort of...

I : And then the silver ions which were present join to form the silver chloride again.

S16: Yes.

I : OK...do you think any gas was liberated?

S16: Maybe ammonia gas was liberated.

I : Why do you say that?

S16: Because it is broken up, sort of broken up from the chloride, so it might escape to form a gas.

As discussed in an earlier section, Student 16 believed that ammonium chloride was formed when excess aqueous ammonia was added to a precipitate of silver chloride. When nitric(V) acid was added, he believed that the acid broke the ammonium chloride into ammonium ions and chloride ions, so the silver ions present in the mixture could again react with the chloride ions to form the precipitate. The idea that the acid decomposed the precipitate could stem from the knowledge that acids are corrosive. However, when ammonium chloride dissolves to form a solution, it dissociates to form ammonium and chloride ions in solution; there is no need for an acid to break the compound up as Student 16 believed. If 'free' silver ions are present in solution, it will spontaneously react with the chloride ions even before the acid is added. This author assumed that Student 16 could detect the pungent odour of ammonia so he believed that ammonia was 'liberated' by the action of the acid. Students 8 and 17 also believed that acid reacted with ammonium compounds to produce ammonia gas. However, whenever aqueous ammonia was used, ammonia gas would escape and hence could be detected, and it seemed that Students 8, 16 and 17 were unaware of this. Students 18 and 19 also showed ignorance of this fact when they said that aqueous ammonia could be used to test for the presence of ammonium ions in an unknown sample. A few teachers complained that this unnecessary testing of ammonia gas by the students when aqueous ammonia was used occurred very frequently in practical work. Even the O-level examiners commented on it:

> Many candidates wasted time in this part of the exercise by testing for ammonia which not surprisingly they were able to find. (UCLES, 1995)

> The addition of aqueous ammonia gives a white precipitate which does not dissolve in excess. A few found that the precipitate dissolved in ammonia and this led to the incorrect conclusion that zinc ions were present. A significant number of candidates wasted time testing for the evolution of ammonia here and in Test 3. (UCLES, 1998)

A drastic means of correcting this mistake is to ask student to open a bottle of aqueous ammonia and inhale the vapour! After the unpleasant olfactory experience, students will most likely remember that ammonia gas is always present when aqueous ammonia is used.

Students 40 and 41 had similar ideas as Student 16 on the disappearance and appearance of the precipitate.

I : This is the nitric acid. Let's see what happens if I add in the acid. Can you see it? What do you think happens?
S41: Silver chloride is formed...again.
I : Silver chloride...how do you think it's formed?
S40: Just replace the ammonium from the...
S41: Maybe when the acid is added, the ammonium chloride...you get ammonia...ammonium nitrate is formed so the chloride ions react with silver again.

Students 18, 19 and 23 had a different explanation for the same reaction.

S18: Silver hydroxide
S19: Silver hydroxide.
S18: You say [telling Student 19 to respond to the question].
S19: Ionic precipitation between silver ions and hydroxide ions from ammonium hydroxide probably give rise to the insoluble silver hydroxide which we see as a white precipitate.

S23: Maybe the nitric acid...the nitrate in the nitric acid is stripping the ammonium ions. So there's an excess of hydroxide from the aqueous ammonia which then reacts with the cation.
I : You say that the nitrate ions would react with the ammonium ions.
S23: Yes.
I : OK, leaving the hydroxide ions behind which will then...

S23: React with the cation
I : Reacts with the cation present...to form a precipitate.
S23: Yes.

Unless a double decomposition or redox reaction was involved, students should know that the anion of an acid would not take part in reactions. This author assumed that the students believed that the silver ions would react with hydroxide ions present in the aqueous ammonia to give a precipitate, similar to the testing of cations using aqueous ammonia. They seemed to ignore the reaction of the acid with the aqueous ammonia, and the presence of the chloride ions.

Student 35 when asked to explain what happened when dilute nitric(V) acid was added to a mixture containing excess aqueous sodium hydroxide and zincate ions, said that an insoluble salt was formed when the acid reacted with the alkali.

I : OK, I add nitric acid slowly...do you see anything?
S35: White precipitate.
I : Can you explain what happened?
S37: Neutralisation has occurred. The hydroxide reacts with the acid to form another salt.
S35: And that salt is insoluble.

Student 35 ignored the zincate which was present and overlooked the fact that the salt formed, sodium nitrate(V), was soluble in water and hence would not form a precipitate. Student 9 had slightly different ideas about the salt formed in the neutralisation reaction.

S9 : Neutralisation because we are adding excess sodium hydroxide... that means the concentration of the hydroxide is more than previously. So, an alkali here and an acid here, you get salt and water. So, salt is the white precipitate which reappears and then it dissolves...giving a colourless solution because nitric acid means its something nitrate, and all nitrates are soluble, you see.

Student 9 believed that the salt formed in the reaction between sodium hydroxide and nitric(V) acid appeared to give a precipitate and then disappeared because it was soluble. He did not understand that if the salt formed is soluble, it will not appear as a solid and then dissolve. Student 11, who was interviewed together with Student 9, had his own explanation of the appearance of the precipitate.

S11: Or maybe, I think I know why. OK there's now...because it dissolves, there is an excess of sodium hydroxide. But when you use acid, this acid reacts with the sodium hydroxide so the salt that is formed has no more space to dissolve in the sodium hydroxide...that's why it reappears again.

Student 11, as discussed in an earlier section, believed that zinc hydroxide 'dissolved' in excess sodium hydroxide because more volume or space was provided for it to 'dissolve'. He used the same idea of 'space' to explain that since sodium hydroxide was removed by the acid, the 'space' provided by the sodium hydroxide decreased and thus the precipitate that was 'dissolved' had to come out of the 'lost space' and appear as a solid.

Student 31 believed that, in general, when an aqueous reagent was added to a mixture containing a precipitate, the precipitate would disappear.

S31: Maybe because one is soluble, one is insoluble, so there won't be any precipitate.
I : I don't understand what you mean.
S31: Because the new...just now you poured more nitric acid.
I : Yes.
S31: The part, more nitric acid inside right [there is more nitric acid in the test tube]. The compound is like this already [there is already a precipitate in the test tube]...then if you add nitric acid right...because one is insoluble, one is soluble...they react to form a clear solution, transparent solution without any precipitate.
I : So can you tell me what sort of reaction occurred?
S31: What sort of reaction...is there a name for it?
S30: Is there a name for it actually?
I : Maybe you can describe what reacts with what.
S30: Soluble substance plus insoluble substance...like if you add soluble and...soluble substance and soluble substance together, it will form a precipitate right?

Student 31 also believed that mixing two solutions together would result in the formation of the precipitate, and expressed his astonishment when he was told otherwise.

S31: You mean sometimes when two soluble substances are added together there will still...there will not be a precipitate?

Order of addition of acid is important. Aqueous barium chloride/nitrate(V), aqueous lead(II) nitrate(V) and aqueous silver nitrate(V) are used to identify unknown anions. To differentiate the anions which form precipitates with barium, silver or lead(II), students are instructed to either add dilute acid before or after adding the barium, silver or lead(II) solutions. This is because carbonates and sulphate(IV) ions react with the acids liberating carbon dioxide and sulphur dioxide, which can be detected and identified. If the precipitate remains unreacted, then it can be either barium sulphate(VI) or halides of silver or lead(II). However, Students 1 and 2 believed that the order of addition of acid was important; if acid was added after the addition of the barium solutions, then carbonate ions could not be detected.

I : OK now...looking at that, can a carbonate be present and detected using that test?

S1 : No because you are already reacting it with barium nitrate.

I : And?

S1 : Then if you were to add in the nitric acid later, it will not be able to show whether...

S2 : Maybe it's because if you were to react carbonate with barium nitrate, you will get barium carbonate which is insoluble right? I mean acidified barium nitrate but I think it's how you're going to differentiate between barium sulphate or barium nitrate [carbonate?] because barium sulphate is also an insoluble salt. So in this case you wouldn't be able to know what to write down. I mean you won't be able to conclude whether it is a sulphate that you're getting or a carbonate that you are getting because both are white precipitates.

Students 1 and 2 seemed to believe that if acid was added prior to the addition of the barium solution, only then would any carbonate present react with the acid; to them the barium solution 'interferes' with the reaction between acid and carbonate. They seemed to be unaware that the acid could still react with the barium carbonate precipitate.

Other conceptions. A few students showed rather limited understanding of chemistry. For example, Student 22 thought that hydrogen gas was liberated when an acid was added to a barium precipitate. Students 2 and 30 said that any acid could be added to an unknown sample to test for carbonates; they ignored the possibility of the reaction stopping due to the formation of insoluble sulphates (VI) and chlorides if sulphuric(VI) acid and hydrochloric acid were used. Students 37 and 41 said that acid was added to remove impurities but could not elaborate what the impurities were. Student 15 mentioned that acids react with nitrate(V) salts liberating nitrogen dioxide. Student 2 also believed that though copper will not react with dilute acids to produce hydrogen, copper(II) oxide would. This author believed that she knew copper, being low in the reactivity series, would not react with acids to produce hydrogen, and that one way to prepare copper(II) salts was to react copper(II) oxide with acids. She could have 'mis-linked' the facts together to get the idea that copper(II) oxide would react with acids to produce hydrogen. This author believed the above examples were mainly due to faulty knowledge; students either had no knowledge of the reactions and made them up, or they remembered the facts incorrectly.

I : Now instruction says to add hydrochloric acid...can I add any other acid?
S36: Don't think so.
I : Why not?
S36: Because there's a chloride, so must add hydrochloric acid.
I : Why?
S36: I mean what if we add nitric acid, then we form barium nitrate.
I : What happens then?
S36: The white precipitate disappears. Is barium nitrate soluble?
S35: Barium nitrate is soluble.
S36: Soluble...then dissolve...I mean forms colourless solution...white precipitate disappears.

Student 36 did not realise that the effects of hydrochloric acid and nitric(V) acids were similar if barium solutions were used; both provided hydrogen ions to react with any carbonates or sulphates (IV) present. However, if barium chloride was used, hydrochloric acid was usually added so that no foreign anions were introduced, similarly with barium nitrate(V) and nitric(V) acid. This was pointed out in the list of propositional knowledge statements (Number 8) in Chapter 3. Student 36 seemed to believe that the use of nitric(V) acid would result in the disappearance of any precipitate because barium nitrate(V) was soluble; he could have problems resolving why a precipitate of barium sulphate(VI) would not disappear when nitric(V) acid was added! Alternative conceptions and non-conceptions that students have on the general reactions of acids or bases are summarised in Table 5.6.

Redox reactions

Students mainly encounter redox reactions when they test for the presence of sulphur dioxide, nitrate(V) ions and, to a lesser extent, copper(II) ions. They frequently use acidified potassium dichromate(VI) or acidified potassium manganate(VII) to determine whether sulphur dioxide is evolved. Students 5, 6, 7, 8, 27 and 28 were not certain why the two oxidising agents needed to be acidified or which acid to use to acidify them. This is illustrated in the following excerpt of interview with Students 7 and 8:

I : Do you normally acidify the potassium dichromate?
S7 : I don't think so.
S8 : But in the experiment that we had yesterday, we had to acidify the potassium dichromate and potassium manganate. But usually we don't know...oh...we used sulphuric acid.
I : Why do you use sulphuric acid?
S8 : We have no idea why we use it.
S7 : To acidify, Mrs. C [their teacher] said sulphuric acid...so we just use it.
I : But do you know why?
S8 : No.
S7 : No idea...I don't know what acid to use.

Table 5.6: Alternative conceptions and non-conceptions on the reactions of acids/bases

Alternative conceptions	Non-conceptions
1. Concentrated and dilute hydrochloric acids are reducing agents because of the hydrogen ions present.	1. Why litmus paper needs to be moistened before using it on a gas.
2. Neutralisation involves redox reactions.	2. When an acid behaves like an acid and when it behaves like a reducing or oxidising agent.
3. Hydrogen ion from an acid displaces the cation in a precipitate.	3. Ignorant of the fact that ammonia gas would be detected/evolved whenever aqueous ammonia was used
4. Acids decompose ammonium compounds. a. Ammonium chloride is decomposed to give ammonia gas b. Nitrate ions from nitric(V) acid, when added to a mixture containing aqueous ammonia and a silver ammine complex, remove the ammonium ions resulting in the formation of a silver hydroxide precipitate.	4. What happens when ionic compounds dissolve or exist in solution.
5. Acids react with the excess alkali in a mixture to form a precipitate.	5. Why an acid is added before or after the addition of aqueous barium or silver salt to an unknown solution.
6. Acid must be added directly to carbonates for reaction to take place; no reaction will occur if acid is introduced after the addition of aqueous barium salt to the carbonates.	6. Why the anion of an acid must be the same as the anion of the barium or silver salt which is added to an unknown solution.
7. Neutralisation reaction between sodium hydroxide and nitric(V) acid produces an insoluble salt.	
8. A soluble salt formed in reactions involving aqueous solutions appears as a solid before disappearing.	
9. Hydrogen gas is liberated when an acid is added to a barium precipitate.	
10. Any acid can be added to an unknown sample to test for carbonates.	
11. Copper(II) oxide reacts with acids to produce hydrogen.	
12. Acid is added to remove impurities in a mixture.	
13. Acids react with nitrate(V) salts to liberate nitrogen dioxide.	
14. When nitric(V) acid is added to any insoluble barium salt, the precipitate will disappear.	

As mentioned in Chapter 3, only sulphuric(VI) acid is used to acidify potassium dichromate(VI) and potassium manganate(VII) to provide the acidic medium which is required for the reduction of chromium (VI) to chromium (III), and manganese (VII) to manganese (II). Hydrochloric acid is oxidised by the two reagents while nitric(V) acid is itself an oxidising agent, so side reactions may result from its use. Students will not know the above facts, so teachers need to inform them. Otherwise, students will not know why the two commonly used oxidising agents have to be acidified or why sulphuric(VI) acid is used.

Students are required to test for nitrate(V) ions using aluminium powder, zinc powder or Devada's alloy and aqueous sodium hydroxide, and to know that if ammonia gas is liberated, then nitrate(V) is present. They are, however, not required to know the reaction that occur, that is, the nitrate(V) ions are reduced by aluminium or zinc in alkaline solution. Thus, Students 13, 20 and 44 believed that aluminium was a catalyst in the reaction. Student 20 also did not know that he had to first confirm that ammonium ions were absent before he could conclude that the ammonia detected in the reaction was due to the presence of nitrate(V) ions. This is because any ammonium ions present will react with the aqueous sodium hydroxide added to give ammonia gas. This author believed that there were only non-conceptions on redox reactions, and these are given in Table 5.7.

Table 5.7: Non-conceptions on redox reactions

Non-conceptions
1. Why sulphuric(VI) acid is used to acidify potassium dichromate(VI) and potassium manganate(VII).
2. Why aluminium, zinc or Devada's alloy are used to test for the presence of nitrate(V) ions
3. Why ammonium ions must be ruled out before testing for nitrate(V) ions using zinc, aluminium or Devada's alloy and aqueous sodium hydroxide.

Thermal decomposition

Students are usually taught to take note of colour changes in the unknown sample when it is heated and to test for any gas evolved. However, many students do not know what reactions can occur when substances are heated and what gases to test for as the following excerpt illustrates.

I : Do you think you can ever get carbon dioxide (from heating a sample)?
S7 : I don't think so.
S8 : No.
I : What about sulphur dioxide?
S8 : If it's only plain heating I don't think so...I think you have to add a reagent.

Students 7 and 8 did not know that many carbonates and sulphates (IV) decompose on heating to give carbon dioxide and sulphur dioxide respectively. They could have thought that only combustion was initiated by heating, so if the sample did not go up in flames, then no reaction had occurred. Similarly, Student 6 stated that if a black sample was heated, carbon dioxide might be evolved as the sample could be carbon, but if the sample was white, then carbon dioxide could not be formed. Again, this shows the lack of awareness of thermal decomposition reactions and the tendency of students to equate them with combustion. Two reasons for this could be that students encounter burning or combustion more in everyday life than thermal decomposition reactions, and that combustion is more perceptible than decomposition. Thus students are more familiar with combustion and tend to use it in their explanations.

Other comments which students made about heating were that ammonia was liberated in the heating of nitrates (V) (Student 43), no sulphur dioxide could be formed because sulphur could not be decomposed (Student 13). During this authors' observations of practical sessions, students also gave comments such as there being a need to test for hydrogen as it could evolve when unknown samples were heated. The unknown samples were usually simple ionic salts so it was impossible to get hydrogen when they were heated. These comments showed poor knowledge of chemistry in general, rather than specifically poor knowledge of qualitative analysis. Alternative conceptions and non-conceptions on thermal decomposition are summarised in Table 5.8.

Table 5.8: Alternative conceptions and non-conceptions on thermal decomposition

Alternative conceptions	Non-conceptions
1. Ammonia is liberated when nitrates (V) are heated.	1. Ignorant that heating causes decomposition.
2. Carbon dioxide and sulphur dioxide cannot be liberated when substances are heated.	
3. Hydrogen can be liberated when substances are heated.	

The findings from the interviews are summarised in Tables 5.9 and 5.10 where all the alternative conceptions and non-conceptions were collated respectively.

SUMMARY

This chapter addressed Research Question 3 with a study, based on laboratory observations and interviews with students, on Grade 10 students' understanding of the concepts and propositional knowledge related to qualitative analysis. Students' feelings towards qualitative analysis, the difficulties they had learning and doing qualitative analysis, as well as their alternative conceptions and non-conceptions were illustrated in the various sections of the chapter. The next chapter describes the use of the data obtained in this study to develop a two-tier multiple choice diagnostic test on qualitative analysis.

Table 5.9: Alternative conceptions determined in the interviews

Alternative conceptions

Displacement

1. A 'more reactive' ion will displace a 'less reactive' ion to form a precipitate.

2. Formation and reaction of complex salts
a. The cation in a precipitate will be displaced when excess alkali is added.
b. The cation in a precipitate will be displaced by hydrogen ion from the acid added.

Solubility/Dissolution

1. The reactivity of the metal in a compound affects the solubility of the compound.
   a. Compounds of less reactive metals are likely to be insoluble.
   b. Reagents added may not be 'strong enough' to dissolve compounds of reactive metals.

2. In the formation of complex salts (e.g. ammines, zincates and aluminates), the precipitate dissolves because extra solvent (excess alkali) is added.

3. More solute will dissolve when more solvent is added as there will be additional space/volume to dissolve in.

4. Size of particle and space between water molecules determine if a substance is soluble. If the particle is bigger than a water molecule, then the substance is insoluble.

5. A soluble salt formed during a reaction involving aqueous solutions appears as a solid before dissolving.

Redox

1. Concentrated and dilute hydrochloric acids are reducing agents because of the hydrogen ions present.

2. Neutralisation involves redox reactions.

Table 5.9 (continued): Alternative conceptions determined in the interviews

Alternative conceptions

Reactions involving acids

1. Acids decompose ammonium compounds.
    a. Ammonium chloride is decomposed to give ammonia gas.
    b. Nitrate ions from nitric(V) acid remove ammonium ions when added to a mixture containing aqueous ammonia and a silver ammine complex resulting in the formation of a silver hydroxide precipitate.
2. Neutralisation reactions between alkalis and acids produce insoluble salts.
3. Acid must be added directly to carbonates for reaction to take place; no reaction will occur if acid is introduced after the addition of aqueous barium/silver salt to the carbonates.
4. Hydrogen gas is liberated when an acid is added to a precipitate.
5. Any acid can be added to an unknown sample to test for carbonates or sulphates (IV).
6. Copper(II) oxide reacts with acids to produce hydrogen.
7. Acid is added to remove impurities in a mixture.
8. Acids react with nitrate(V) salts liberating nitrogen dioxide.
9. When nitric(V) acid is added to any insoluble barium salt, the precipitate will disappear.

Others

1. Ammonia is included in the reactivity series.
2. Ammonium chloride is formed when aqueous ammonia is added to silver chloride.
3. Ammonia is liberated when nitrates (V) are heated.
4. Carbon dioxide and sulphur dioxide cannot be liberated when substances are heated.
5. Hydrogen can be liberated when substances are heated.

Table 5.10: Non-conceptions determined in the interviews

Non-conceptions

Acids, bases and salts

1. Double decomposition
   a. What double decomposition reaction is/ What happens in a double decomposition reaction.
   b. The identity of the precipitate formed in double decomposition reactions.
   c. Why reagents should not be added directly to solid samples.

2. Complex salt formation and reaction
   a. How a complex salt is formed or what a complex salt is.
   b. What happens when acid is added to a mixture containing excess alkali and a complex salt.

3. Why litmus paper need to be moistened before using it on a gas.

4. Use of acid
   a. When an acid behaves like an acid and when it behaves like a reducing or oxidising agent.
   b. Why an acid is introduced before or after the addition of aqueous barium or silver salt to an unknown solution.
   c. Why the anion of an acid must be the same as the anion of the barium or silver salt for both to be added to an unknown solution.

Dissolution

6. Ignorant of the fact that miscible liquids dissolve in each other.

7. Ignorant of the fact that water is the major constituent of an aqueous solution.

8. What happens when ionic compounds dissolve or exist in solution.

Experimental procedures

1. How bench reagents are prepared.

2. Common procedures
   a. Ignorant of the fact that ammonia gas would be detected/evolved whenever aqueous ammonia was used.
   b. Which acid to use, and why, to acidify potassium dichromate(VI) and potassium manganate(VII).
   c. Why zinc, aluminium or Devada's alloy are used to test nitrate(V) ions.
   d. Why ammonium ions must be ruled out before testing for nitrate(V) ions using zinc, aluminium or Devada's alloy and aqueous sodium hydroxide.
   e. Ignorant that heating causes decomposition.

CHAPTER SIX

STUDY TWO: DEVELOPMENT OF THE TWO-TIER MULTIPLE CHOICE DIAGNOSTIC INSTRUMENT ON QUALITATIVE ANALYSIS

INTRODUCTION

The main emphasis of this chapter is on Research Question 4 which is on the difficulties in producing a written test consistent with the identified concepts, propositional knowledge and known student alternative conceptions on qualitative analysis. Through the administration of the various versions of the free response and two-tier multiple choice tests, Research Question 3 on students' understanding of the concepts and propositional knowledge related to qualitative analysis was also addressed. In the first phase of the development of the qualitative analysis diagnostic instrument, the data collected in the Study One, described in the Chapter 5, were used to develop a free response test to be administered to Grade 10 students. The results obtained from the administration of the free response test and Study One were then used to develop the first version of the two-tier multiple choice test. Further trials and refinement led to the development of the second version of the diagnostic test, and subsequently, the final version of the diagnostic instrument.

PILOT STUDY: FIRST VERSION OF THE FREE RESPONSE TEST

In the new school year beginning in January 1999, further study on secondary students could not be carried out until after May because the 1998 cohort of Grade 10 students involved in Study One had taken the O-level examinations and had left secondary school. Thus, the study had to continue with a new cohort of Grade 10 students in 1999. However, these students first had to be taught qualitative analysis, and then, carry out a sufficient number of experiments to be familiar with what was involved in qualitative analysis. Thus from January to April 1999, this author carried out a pilot study (described in Appendix I) with graduate trainee-teachers and final-year undergraduates to develop and evaluate the first version of the free response test on qualitative analysis. The results of this pilot study contributed to the development of the second version of the free response test to be administered to Grade 10 students in the Phase 1 study.

PHASE ONE: SECOND VERSION OF THE FREE RESPONSE TEST

The 13-item second version of the free response test (Appendix J) in this Phase 1 study was developed from Parts 1 and 2 of the first version of the free response test (Appendices I1 and I2) administered in the pilot study (Appendix I) to the 19 undergraduates and 34 graduate trainee-teachers (July 1998 intake). It was then administered to 203 Grade 10 students (15 to 17 years old) from three secondary schools and 11 graduate trainee-teachers (January 1999 intake) in the last week of May 1999. The data collected were analysed and used to design the first version of the two-tier multiple choice diagnostic instrument.

The development of the second version of the free response test

As mentioned in the previous section, the second version of the free response test was developed from Parts 1 and 2 of the first version of the free response test administered in the pilot study. The questions were reviewed, and modifications were made or questions were deleted based on the data collected from the administration of the first version of the test. Though the subjects were tertiary chemistry undergraduates and graduates, many had very similar alternative conceptions and difficulties as the secondary chemistry students (Tables 5.9, 5.10 and I.3). Figure 7.1 describes how the second version of the free response test was derived from Parts 1 and 2 of the first test (Appendix I1 and I2). To avoid confusion, questions in the second version of the free response test would be referred to as 'Question 1', 'Question 2' and so forth, while questions in the first version would be referred to as 'Part 1 Q1', 'Part 1 Q2' and so forth.

Experiment A
Under the observations, 'precipitate' was substituted by 'solid' because in Question 1, 'double decomposition' was replaced by 'precipitation'; this author did not want to lead students to the answer. As discussed in Chapter Three and Five, secondary students and even tertiary undergraduates and graduates were less familiar with the more accurate term 'double decomposition' than the term 'precipitation', so the less accurate term was used to avoid penalising those who had not come across the more accurate term in their lessons.

Question 1(Part 1 Q1)
The term 'precipitate' in the stem was replaced by 'solid', and 'Double decomposition' in the options was replaced by 'Precipitation' as previously discussed. 'Neutralisation' added to options as this was discovered through the administration of first version.

Question 2 (Part 1 Q3)
Q2 in the first version was deleted because the reasons given would be the same as in Question 1. Thus Q3 became Question 2, with 'precipitate' replaced by 'white solid'.

Question 3 (Part 1 Q4) and Question 4 (Part 1Q5)
Again 'precipitate' was replaced by 'solid' in both questions.

Experiment B
Under the observations, 'precipitate' was replaced by 'solid'.

Question 5
Question 5 was a new question to test whether students knew what precipitate was formed and what type of reaction occurred.

Question 6 (Part 2 Q1)
'Experiment B' in stem was deleted.

Question 7 (Part 2 Q2)
In the discussion of the results obtained for Part 2 of the first version, it was noted silver sulphate(VI) was slightly soluble so sulphuric(VI) acid could theoretically be used if the silver sulphate(VI) formed did not exceed the saturation point. Thus to avoid complications, dilute sulphuric(VI) acid was deleted from the stem and options.

Question 8 (Part 2 Q3) and Question 9 (Part 2 Q4)
There were no changes made to Question 8 while 'precipitate' was replaced by 'white solid' in Question 9.

Question 10 (Part 1 Q9)
Sulphur dioxide was deleted based on the argument reason previously discussed in the section on Part 1 Q8 in Appendix I.

Figure 6.1: Development of the second version of the free response test

Question 11
Question 11 was a modification of Part 2 Q9, 10 and 11 to test whether students understood the purpose of adding barium nitrate(V) followed by nitric(V) acid and the reactions involved.

Question 12
This was a new addition to determine if students knew the reason for the selection of the acid to add after the introduction of barium nitrate(V). Unlike Q16 in version 1, all students should know that barium sulphate(VI) was insoluble because they were taught that barium nitrate(V) was used to test for the presence of sulphate(VI).

Question 13
This was a new addition to test students understanding of the reactions involved in heating, similar to Question 10.

Part 1 Q6 and 7
Q6 was deleted because the reagent, silver nitrate(V), was already used in Experiment B and Questions 5 to 9, so 'silver nitrate(V)' was substituted by 'barium nitrate(V)', leading to the Question 11 in version 2. Q7 was deleted because students need to recall that silver carbonate was insoluble and it was also a follow-up question to Q6.

Part 1 Q8, Part 2 Q5
Part 1 Q8 was deleted mainly because if students could not recall that calcium chloride was soluble and calcium sulphate(VI) was insoluble, then they could not answer the question. In addition, secondary students seldom encounter reactions of sulphate(IV) in practical work and reactions of sulphate(IV) were excluded from the syllabus (reason for the deletion of Part 2 Q5) although testing and identification of sulphur dioxide was required. This discrepancy was discussed in Chapter Three.

Part 1 Q10
This question was deleted because secondary students had no way of working out which acids to use to acidify the oxidising agents. Even university undergraduates and graduates had problems with this question.

Part 1 Q11
Question 11 was deleted as many would know that aqueous samples were required though they might not know the exact reason. In addition, this question was more on experimental techniques and did not directly address students' understanding of double decomposition reactions.

Experiment C, Part 2 Q6 to 8
These were deleted because they were similar to Experiment A and Questions 1 and 2 in that they deal with reactions of cations with alkali, and because this author wanted to reduce the number of questions so that all the questions in the second version of test could be answered in an hour.

Figure 6.1 (continued): Development of the second version of the free response test

The specifications for each question in the second version of the free response test are given in Table 6.1. Four secondary chemistry teachers, Mrs. Ang, Mrs. Chen, Mr. Er and Mr. Fong reviewed the free response test before it was administered to their students. Three of them said that their students should be able to answer all the questions as the content covered was taught to them. The fourth teacher, Mrs. Ang, however, believed that a few questions would pose difficulties as her students were not taught content such as complex ammine formation, nor exposed to the 'thinking' required to answer the questions.

The results from the administration of the free response test

The second version of the free response test was administered in the last week of May 1999 to 214 subjects, comprising 203 Grade 10 students (15 to 17 years old) from three secondary schools and 11 graduate trainee-teachers in Postgraduate Diploma in Education (PGDE) programme (January 1999 intake) from one university. Table 6.2 shows the distribution of the subjects.

Grade 10 students were chosen because qualitative analysis was taught in Grade 10 in the schools involved. The students who sat for the test in schools N, R and S were chosen by the liaison teachers in the respective schools. Schools R and S are the same schools which were involved in the interviews. School N is a neighbourhood government school where Mrs. Ang teaches chemistry. The trainee-teachers involved volunteered to take the test as they wanted to assess their knowledge of qualitative analysis; many found out that they needed to read up on qualitative analysis as they could not answer all the questions or give reasons for their choices. The 'Notes for Use in Qualitative Analysis' (Appendix A) was given to all subjects as a reference during the test. The results of the test are discussed in the following sections.

Table 6.1: Table of specifications for the second version of the free response test

No	Concepts tested	Propositional knowledge statements	Possible alternative conceptions
1	double decomposition / precipitation	9,10,14,15	a. ion displace ion b. redox reactions involved
2	complex salt formation base-amphoteric hydroxide reaction	9,10,12	a. displacement of cation in precipitate b. dissolving i. more solvent ii. NaOH 'strong'/ reactive enough to dissolve precipitate
3	reaction of complex & NaOH with acid to give the insoluble hydroxide	1,2,6,9,10,12	a. displacement of cation in solute by hydrogen ion b. reduction of solute by acid
4	acid-alkali and acid-amphoteric hydroxide reactions	1,2,12	a. displacement of cation in precipitate by hydrogen ions b. reduction of precipitate by hydrogen ions c. dissolving i. more acid ii. acid strong enough to dissolve precipitate
5	double decomposition / precipitation	14,15	displacement of a. cation b. anion
6	reaction of sulphate(IV) & carbonates with acids	1,2,4,5	a. dissolving b. silver nitrate(V) is only to test halides
7	introduction of foreign ions and formation of insoluble salts	7,8	Any acid can be added
8	complex salt formation – ammonia-silver chloride reaction	13	a. displacement of cation in precipitate b. dissolving i. more solvent ii. aqueous ammonia strong/ reactive enough to dissolve precipitate
9	reaction of complex & aqueous ammonia with acid to give the insoluble chloride	1,2,6,9,10,13	a. displacement of cation in solute by hydrogen ion b. reduction of solute by acid c. acid strips away ammonium ions d. acid reacts with alkali to give insoluble salt
10	thermal decomposition of carbonates	18	a. all gases need to be tested b. hydrogen can be liberated when a substance is heated
11	a. double decomposition / precipitation b. acid-carbonate reaction	1,2,4,14,15	a. barium nitrate(V) is to only test for sulphate(VI) b. the acid must be added directly to the carbonate
12	introduction of foreign ions and formation of insoluble salts	7,8	any acid can be added
13	thermal decomposition of oxides or nitrate(V) salts	20	all gases need to be tested

Table 6.2: Distribution of the subjects who took the second version of the free response test

School	Class	No. of students
N	4A	42
R	4/3	39
	4/7	39
	4/13	24
S	4A1	31
	4A4	28
NIE	PGDE Jan 1999	11
	Total	214

For Questions 1 to 4, refer to Experiment A:

	Experiment A	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white solid is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	*White solid disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid (HNO_3) to the mixture from (b) until no further change is seen.	*White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.*

1. What type of reaction occurs when aqueous sodium hydroxide reacts with aqueous zinc chloride to form a white solid?

A Displacement
B Neutralisation
C Precipitation
D Redox
E ____________________

Option	Secondary	PGDE	Total	Percentage
A	45	6	51	23.8
B	5	0	5	2.3
C*	133	3	136	63.6
D	17	1	18	8.4
E	2	1	3	1.4
O	1	0	1	0.5
Total	203	11	214	100.0

Fifty-one (45 + 6) subjects chose 'Displacement' as the reaction between aqueous zinc chloride and sodium hydroxide. Twenty-one secondary students and one trainee-teacher supplied the reason that sodium was more reactive than zinc, so sodium displaced zinc or more specifically, the sodium ion displaced the zinc ion. One secondary student wrote that 'chloride is displaced to form zinc hydroxide'. Sixteen secondary students and two trainee-teachers mentioned that zinc hydroxide was formed without any reference to reactivity. Only five subjects chose option B so this option was deleted in the first version of the two-tier multiple choice test.

Out of the 136 (133 + 3) subjects who chose option C, 109 wrote that zinc hydroxide was insoluble hence it precipitated out. More precise reasons were given by 17 secondary students and two trainee-teachers who either wrote that zinc ions reacted with hydroxide ions to form insoluble zinc hydroxide or gave the equation for the reaction. Out of the 18 (17 + 1) subjects who chose option D, four secondary students believed that a redox reaction had taken place because sodium hydroxide 'lost' oxygen or 'gained' chloride in forming sodium chloride while zinc chloride 'gained' oxygen in forming zinc hydroxide. The incorrect use of redox concepts first surfaced in Study One where a student described the neutralisation reaction between iron(II) hydroxide and nitric(V) acid as a redox reaction because 'there is an increase in oxygen but a loss in hydrogen'. Interestingly, none of the four students referred to the 'lost' or 'gain' of hydrogen which also was present in the hydroxide ion.

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

A dissolves in
B reacts with
C. ______________________________

Option	Secondary	PGDE	Total	Percentage
A	166	6	172	80.4
B*	33	2	35	16.4
C	4	3	7	3.3
Total	203	11	214	100.0

Out of the 172 (166 + 6) subjects who chose option A, five wrote that it was stated in the notes (Appendix A) that the precipitate was soluble in excess sodium hydroxide. One trainee-teacher and 108 secondary students and gave reasons such as 'no further reaction was seen except the disappearance of the solid', 'a colourless solution was obtained', 'no new products were formed', or 'excess solvent allows more salt to dissolve'. Perhaps they believed that only more obvious changes in colour or effervescence indicated a reaction. Fourteen other secondary students believed that the white solid was sodium chloride.

3. A student concludes that the white solid obtained in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

Option	Secondary	PGDE	Total	Percentage
A*	81	7	88	41.1
B	121	4	125	58.4
O	1	0	1	0.5
Total	203	11	214	100.0

Out of the 88 (81 + 7) subjects who chose option A, only 12 secondary students and four trainee-teachers supplied the correct reason that the acid reversed the formation of the complex salt. Twenty-five other secondary students and two trainee-teachers believed that the acid neutralised the sodium hydroxide and removed the solvent for the precipitate resulting in the reappearance of the precipitate. Out of the 125 (121 + 4) subjects who chose option B, 28 secondary students and one trainee-teacher reasoned that the white solid should not be the same as previously because a different reagent was used. Fifty-three other secondary students believed that the white solid was either zinc nitrate(V) or sodium nitrate(V). Many students would know that all nitrate(V) salts were soluble so it was unusual for the students to write that the white solid was either zinc nitrate(V) or sodium nitrate(V); they could have thought that the nitrate(V) salts appeared as solids upon formation and later dissolve in solution. Student 9 previously brought up the idea in Study One that a nitrate(V) salt formed in a reaction first appeared and then disappeared.

4. The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Option	Secondary	PGDE	Total	Percentage
A	131	3	134	62.6
B*	69	5	74	34.6
O	3	3	6	2.8
Total	203	11	214	100.0

Out of the 134 (131 + 4) subjects who chose option A, 41 secondary students and one trainee-teacher supplied reasons such as 'the white solid only disappeared when more acid was added', 'no new reagent was added', 'no further reaction was seen', and 'neutralisation was completed so the acid could now start to dissolve the solid'. Some of these ideas were highlighted in the discussion of Question 2. Fifteen other secondary students thought that the white solid was either sodium chloride, zinc nitrate(V) or sodium nitrate(V) since all these salts were soluble. Thus, a few more students seemed to believe that soluble salts appeared as solids upon formation and subsequently dissolve in solution. Two out of the 74 (69 + 5) subjects who chose option B wrote that a displacement reaction occurred between the acid and the white solid.

For Questions 5 to 9, refer to Experiment B:

	Experiment B	Observations
a	To a portion of S, add an equal volume of aqueous silver nitrate(V) ($AgNO_3$). Divide the mixture into 2 portions.	*A white solid is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction.*
c(i)	To the second portion, add aqueous ammonia.	*White solid disappears and a slightly cloudy liquid is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White solid appears.*

5. Write down the formula of the white solid formed in step (a).

Six trainee-teachers and 145 secondary students stated that the precipitate was silver nitrate(V) with 20 secondary students writing the formula as '$AgCl_2$', four as '$AgCl_3$' and one as '$AgCl_5$'. Only three out the 203 secondary students supplied reasons for their answers but the reasons they gave were incorrect - 'chloride was more reactive than nitrate(V) so it displaced the nitrate(V)' and 'the more reactive cation in S displaced silver from its salt'. The 'anion displacing another anion' conception did not surface during the interviews. A few secondary students thought that S was an element, and thus, stated that 'SNO_3' was the precipitate. Five secondary students made a similar error and stated that 'Ag' was the precipitate since all nitrates, including 'SNO_3', are soluble. This author must elaborate that S was a compound in the first version of the two-tier multiple choice test to prevent any misunderstanding. Eight secondary students wrote that the white solid was either the nitrate(V), chloride or sulphate(VI) of zinc, possibly because the white solid disappeared in excess aqueous ammonia.

6. In step (b), what is the purpose of adding the dilute nitric(V) acid?

A To remove impurities.
B To oxidise the white solid.
C ______________________________

Option	Secondary	PGDE	Total	Percentage
A	55	0	55	25.7
B	29	1	30	14.0
C	114	8	122	57.0
O	5	2	7	3.3
Total	203	11	214	100.0

Out of the 55 secondary students who chose option A, 26 stated that nitric(V) acid could either dissolve, react with or oxidise impurities to form soluble nitrates (V). Eight other secondary students believed that it was important to remove impurities so as to achieve an accurate and fair test. The 30 (29 + 1) subjects chose option B most likely because they knew that nitric(V) acid was an oxidising agent.

Out of the 122 (114 + 8) subjects who supplied answers for option C, only 27 secondary students correctly stated that the acid was added to determine if the unknown contained carbonate; there was no mention of sulphate(IV) at all, most likely a consequence of it being left out of the syllabus and not being taught. Thirty-seven secondary students and four trainee-teachers wrote that the acid was 'to acidify the mixture' or 'to provide an acidic medium' giving reasons such as 'acids are added to acidify solutions', 'so that chloride can react properly with silver nitrate(V)' and 'to prevent other reactions from taking place'. Other answers for option C included 'it was the usual procedure to add nitric(V) acid to confirm the presence of chloride', 'the acid was used to test if the solid would react with it', 'the acid catalysed the reaction', 'the acid reacted with silver chloride to form silver nitrate(V)', 'the acid neutralised any alkali present', and 'the acid was to test whether the solid was soluble in nitric(V) acid'.

7. In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A Yes B No

Option	Secondary	PGDE	Total	Percentage
A	65	2	67	31.3
B*	136	8	144	67.3
O	2	1	3	1.4
Total	203	11	214	100.0

Out of the 67 (65 + 2) subjects who chose option A, 42 secondary students and one trainee-teacher reasoned that hydrochloric acid also could supply hydrogen ions to acidify the mixture or remove impurities. Five secondary students stated that since chloride ions were already present in the mixture, the chloride from dilute hydrochloric acid would not matter; they did not understand the importance of not introducing a foreign anion, chloride, which would give a precipitate with any free silver ions. It should be noted that if all the silver ions were used up in reaction with the unknown anion in S, addition of hydrochloric acid would result in no visible reaction if the unknown anion was chloride. If the unknown anion was a carbonate or sulphate(IV), there would be effervescence if it was present in excess; otherwise, there would only be a small amount of reaction as the formation of silver chloride would effectively stop any further reaction between silver carbonate or silver sulphate(IV) and the dilute hydrochloric acid.

Out of the 144 (136 + 8) subjects who chose option B, 34 secondary students and six trainee-teachers supplied the reason that the chloride ion from hydrochloric acid would interfere with the system. Twenty other secondary students stated that not all chlorides were soluble, so precipitates could be formed if hydrochloric acid was used. Fourteen secondary students noted, without further elaboration, that the acid added must contain the same anion as silver nitrate(V) or simply that nitric(V) acid must be used when silver nitrate(V) was added. Alternative reasons such as 'hydrochloric acid will never react with a chloride' was given by 13 secondary students, 'the acid will react with the white solid' was given by 10 students, and 'oxidation will not take place as hydrochloric acid is not an oxidising agent' was given by nine students. Less common reasons included that 'hydrochloric acid was too weak or too strong compared to nitric(V) acid', 'the acids were chemically different', and 'hydrochloric acid might react with the nitrate(V) present instead of carbonate'.

8. In step (c (i)), it can be concluded that a reaction, resulting in the formation of ammonium chloride, has occurred.

A True B False

Option	Secondary	PGDE	Total	Percentage
A	130	2	132	61.7
B*	69	6	75	35.0
C	1	0	1	0.5
O	3	3	6	2.8
Total	203	11	214	100.0

Forty-five out of the 130 secondary students who chose option A gave reasons such as 'silver chloride reacts with aqueous ammonia to produce ammonium chloride' or 'ammonium ions displaced silver from silver chloride'. Sixteen subjects wrote that the cloudiness in the solution was due to insoluble silver chloride or silver hydroxide, or undissolved ammonium chloride. In the final instruments, this author will rewrite the results to read 'a colourless solution was obtained' to avoid misunderstandings. Fourteen secondary students had a different view; they believed that the chloride ions still present in solution reacted with the ammonium ions. Eight subjects believed that ammonium chloride was formed simply because it was soluble.

Fifteen out of the 75 (69 + 6) subjects who chose option B argued that no chloride ion was involved because they thought that the precipitate was 'SNO_3'. Eight subjects wrote that since ammonium chloride was soluble, no precipitate should have been formed in the first instance. Only two secondary students and three trainee-teachers knew that a complex salt was formed.

9. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid.

A True B False

Option	Secondary	PGDE	Total	Percentage
A	88	3	91	42.5
B*	105	6	111	51.9
O	10	2	12	5.6
Total	203	11	214	100.0

Reasons given by the 91 (88 + 3) subjects who chose option A included that 'hydrogen or hydrogen ions was a reducing agent' or 'reduction occurred when hydrogen ions were added to a substance', 'silver ions were reduced to silver metal', 'hydrogen ions were able to displace or reduce the silver ions as silver was not a reactive metal'. Twenty-three secondary students and one trainee-teacher out of the 111 (105 + 6) subjects who disagreed argued that hydrogen ions could not reduce silver ions because both were positive, or that there were no electrons left in the hydrogen ion to donate to the silver ion. It was uncertain whether all of them knew that positive ions of elements with variable oxidation states, for example iron(II) ions, could still act as reducing agents. Twelve students pointed out that since silver metal was silver in appearance and not white, the formation of a white solid in step c(ii) ruled out presence of silver metal. Only three secondary students and two trainee-teachers supplied the correct reason that the acid reacted with the aqueous ammonia to reverse the formation of the complex salt. Other alternative ideas included 'hydrogen ions react with the ammonium ions to produce the insoluble salt' and 'nitric acid decomposed the ammonium chloride liberating chloride ions which react with the silver ions'.

10. Which of the following gas(es) can be obtained when an ionic compound is heated?
I Carbon dioxide.
II Hydrogen.

A I only B II only
C I and II D None of the above

Option	Secondary	PGDE	Total	Percentage
A*	65	5	70	32.7
B	23	0	23	10.7
C	35	0	35	16.4
D	74	5	79	36.9
O	6	1	7	3.3
Total	203	11	214	100.0

Twenty-nine students and four trainee-teachers out of the 70 (65 + 5) subjects who chose option A supplied the reason that carbonates decomposed on heating to give off carbon dioxide, or that hydrogen was only obtained when acids reacted with metals or during electrolysis of certain aqueous salts. Twelve students believed that oxygen reacted with the ionic compound to produce either carbon dioxide or water. Three out of the 23 secondary students who chose option B wrote that hydrogen ions could be present in certain ionic compounds so hydrogen was liberated when these compounds were heated. Ten students out of the 35 secondary students who chose option C explained that if the compound contained hydroxide or carbonate ions, then hydrogen or carbon dioxide could be evolved. Twenty out of the 79 (74 + 5) subjects who chose option D stated that no reaction would occur because ionic compounds had strong bonds and hence were stable to heat. Four students stated that the gases could only be given off by covalent compounds. Another four wrote that ionic compounds did not contain hydrogen and/or carbon; perhaps they believed ionic compounds were binary compounds, so zinc carbonate was not considered as a ionic compound; however there is hydrogen in metal hydrides and carbon in metal carbides. Similar conceptions were brought to light in Study One.

11. A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first and followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A Yes B No

Option	Secondary	PGDE	Total	Percentage
A*	101	3	104	48.6
B	100	5	105	49.1
O	2	3	5	2.3
Total	203	11	214	100.0

Out of the 104 (101 + 3) subjects who chose option A, 79 secondary students and three trainee-teachers stated that all carbonates would react with nitric(V) acid to give carbon dioxide. One student wrote that the nitric(V) acid was added to get rid of impurities and the barium nitrate(V) would test for carbonates. Two other students wrote that any carbonate present would not react with barium nitrate(V) but with the acid. Thirty-seven secondary students and one trainee-teacher out of the 105 (100 + 5) subjects who chose option B stated that the nitric(V) acid must be added directly to the unknown to test for the presence of a carbonate. Twenty-two students wrote that the procedure outlined could only test for the presence of sulphate(VI). Fifteen students stated that both carbonates and sulphate(VI) would give white precipitate with barium nitrate(V) so one could not determine which was responsible; they did not realise that the acid added later would react with carbonates but not sulphate(VI). Four students and two trainee-teachers argued that the insoluble barium carbonate would precipitate out, leaving no 'free' carbonate ions in solution to react with the acid. Again, the conceptions discussed here also surfaced in Study One.

12. Instead of adding dilute nitric(V) acid in Question 11, can the student add sulphuric(VI) acid (H_2SO_4)?

A Yes B No

Option	Secondary	PGDE	Total	Percentage
A	99	1	100	46.7
B*	101	8	109	50.9
O	3	2	5	2.3
Total	203	11	214	100.0

Out of the 100 (99 + 1) subjects who chose option A, 79 secondary students reasoned that both acids served the same purpose, that is, to acidify the mixture or react with carbonates. This was double the number of those who agreed that hydrochloric acid could replace nitric(V) acid in Question 7 which tested similar concepts. Thirty-nine students and three trainee-teachers out of the 109 (101 + 8) disagreed that sulphuric(VI) acid could be used, mainly because the acid would react with the barium nitrate(V) to give insoluble barium sulphate(VI) which would complicate the test; a similar result was obtained for Question 7. Other reasons given for choosing option B were 'sulphuric(VI) acid would react with the nitrate(V) ions', 'nitric(V) acid must be used with barium nitrate(V)' and 'sulphuric(VI) acid is too concentrated or strong to be used'. The last statement could be due to this author not specifying in the stem that the sulphuric(VI) acid added was dilute acid. Three students argued that the question was meaningless as they believed that adding a different acid made no difference because the addition of barium nitrate(V) in Question 11 had 'spoilt' the test for carbonates.

13. When do you test for oxygen gas? When you
    I. heat an unknown sample.
    II. add acid to an unknown sample.

A	I only	B	II only
C	I and II	D	None of the above

Option	Secondary	PGDE	Total	Percentage
A*	118	6	124	57.9
B	3	0	3	1.4
C	21	1	22	10.3
D	59	1	60	28.0
O	2	3	5	2.3
Total	203	11	214	100.0

Seventy-four students and three trainee-teachers out of the 124 (118 + 6) subjects who chose option A stated that the heating of nitrates, oxides and hydrogen peroxide would give oxygen or that reactions involving acids would not produce oxygen. Four out of the 22 (21 + 1) subjects who chose option C thought that if the sample contained oxygen in it, for example, an oxide, then heating it or adding acid to it would liberate oxygen gas. Another three stated that one should test for all known gases for all reactions. Sixteen out of the 60 (59 + 1) subjects who chose option D stated that when a sample was heated, oxygen would be used up rather than be produced, and four stated that only carbon monoxide, carbon dioxide or sulphur dioxide would be produced.

The alternative conceptions determined from the results of the second version of the free response test are given in Table 6.3. Many of them were also highlighted in Study One, lending credibility to the findings thus far.

Table 6.3: Alternative conceptions determined from the administration of the second version of the free response test

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Displacement

1. An ion will displace another ion to form a precipitate.
    a. A more reactive ion will displace a less reactive ion.
    b. Equating 'displace' with 'replace'.

2. Formation and reaction of complex salts
    c. The cation in a precipitate will be displaced when excess alkali is added.
    d. The cation in a precipitate will be displaced by hydrogen ion from the acid added.

Solubility/Dissolution

1. A precipitate is formed in a double decomposition reaction because the solution is saturated with a soluble salt.

2. In the formation of complex salts (e.g. ammines and zincates), in an acid-carbonate reaction or in a neutralisation reaction, the precipitate dissolves because
    a. extra solvent (excess alkali or acid) is added,
    b. no visible reaction is seen other than the disappearance of the precipitate,
    c. no new reagents are added.

3. When acid is added to a mixture containing excess alkali and a complex salt, the acid neutralises the alkali, thus removing the solvent for the precipitate, resulting in the reappearance of the precipitate.

4. When a soluble salt is formed during reaction, it will appear as a solid upon formation and subsequently dissolve in solution.

Redox

1. Redox reactions occur in double decomposition reactions.

2. Acids are reducing agents because they contain hydrogen ions.

3. Neutralisation and acid-carbonate reactions involve redox reactions.

Heating

1. Ionic compounds have strong bonds in them, hence they do not decompose on heating.

2. Ionic compounds when heated will react with oxygen to produce water or carbon dioxide, so oxygen will not be produced.

3. Hydrogen gas can be liberated when ionic compounds which contain hydrogen or hydroxide in them are heated.

4. Gases are evolved only when covalent compounds are heated.

Table 6.3 (continued): Alternative conceptions determined from the administration of the second version of the free response test

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Reactions involving acids.

1. Nitric(V) acid decomposes ammonium chloride to liberate chloride ions.
2. Hydrogen ions react with ammonium ions to produce an insoluble salt.
3. Neutralisation reactions between alkalis and acids produce insoluble salts.
4. Addition of acids after an aqueous barium or silver salt has been added to an unknown sample is to ensure the unknown sample reacts properly with the aqueous barium or silver salts, or to catalyse the reaction between the unknown sample and the aqueous barium or silver salt.
5. Any acid can be added after the addition of an aqueous barium or silver salt to an unknown sample.
6. Acid must be added directly to carbonates for reaction to take place; no reaction will occur if acid is introduced after the addition of aqueous barium/silver salt to the carbonates.
7. Any acid can be added to an unknown sample to test for carbonates.
6\. Acids will only react with carbonate ions in solution and not precipitates containing the carbonate ion.
7\. Acid is added to remove impurities in a mixture to ensure an accurate and fair test.
8\. Nitric(V) acid reacts with silver chloride to form silver nitrate(V).
9\. Acids will react with the nitrate(V) ion.
10\. Sulphuric(VI) acid is too strong to be used to acidify samples.
11\. Acids will react with oxides to liberate oxygen.

Others

1. Ammonium chloride is formed when aqueous ammonia is added to silver chloride.
2. Barium nitrate(V) will not react with carbonate ions.

PHASE TWO: FIRST AND SECOND VERSIONS OF THE TWO-TIER MULTIPLE CHOICE TEST

The aim of Phase 2 of Study Two was to develop the two-tier multiple choice diagnostic instrument on qualitative analysis. The data obtained in Study One and Phase 1 of Study Two were used to design the first version of the diagnostic instrument (Appendix K). This diagnostic test was administered to 118 students from two secondary schools in July 1999. Data obtained from the administration of this test were used to refine and produce the second version of the diagnostic instrument (Appendix L) which was administered in August 1999 to 111 students from three secondary schools. Refinement of the second version led to the development of the final version, the Qualitative Analysis Diagnostic Instrument.

The development of the first version of the two-tier multiple choice diagnostic instrument

The items in the first version of the two-tier multiple choice diagnostic instrument (Appendix K) were taken from the second version of the free response test (Appendix J). Several revisions resulted from the data gathered from the administration of the free response test in Phase 1. In addition, a second tier of options based on the alternative conceptions determined in the preceding studies was included in each item.

No changes were made to Experiment A. 'Neutralisation' was deleted from the first-tier options of Item 1 because it attracted very few students. Another reason for its deletion was that the first-tier must not have too many options; if there were, then the second-tier must have more reasons to account for every option in the first-tier. Too many options would make the items difficult to read and answer, thus this author set a maximum of five options in the second-tier. The second-tier options for Item 1, as well as, every other item are described in Table 6.4.

Table 6.4: Table of specifications for the first version of the two-tier multiple choice diagnostic instrument

No	Items, reasons and their sources	Areas of alternative conception
1	What type of reaction occurs when aqueous sodium hydroxide reacts with aqueous zinc chloride to form a white solid? A Displacement B Precipitation C Redox (1) Hydroxide ion is more reactive than chloride ion. (D) (2) Sodium chloride precipitates out because the solution is too concentrated. (D,2) (3) Sodium hydroxide loses oxygen but gains chlorine in forming sodium chloride and zinc chloride loses chlorine but gains oxygen in forming zinc hydroxide. (2) (4) Sodium ion is more reactive than zinc ion. (I,D,2) **(5) Zinc ions combine with the hydroxide ions.**	displacement, reactivity series, double decomposition, redox
2	In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide. A dissolves in B reacts with (1) More solvent is added so there is more space for the white solid to dissolve. (I,2) (2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added. (2) (3) Sodium ion displaces the cation from the white solid.(I) (4) Sodium is a very reactive metal, hence sodium hydroxide is a strong solvent. (I) **(5) The white solid forms a soluble compound with the excess sodium hydroxide.**	dissolution, displacement, complex salt formation, reactivity series, what constitutes a reaction
3	A student concludes that the white solid obtained in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion? A Yes B No (1) Different reagents were used. (2) (2) The acid reacts with the excess sodium hydroxide to form sodium nitrate(V) which appears as the white solid. (2) (3) The acid reacts with the zinc compound to form zinc nitrate(V) which appears as the white solid. (D,2) **(4) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).** (5) The acid removes the solvent for the precipitate so the precipitate reappears. (2)	dissolution, properties and reactions of acid

Note:

Symbol	Source of alternative conception
I	interviews
D	first version of the free response test
2	second version of the free response test
	The correct reason is in bold

Table 6.4 (continued): Table of specifications for the first version of the two-tier multiple choice diagnostic instrument

No	Items, reasons and their sources	Areas of alternative conception
4	The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion? A Yes B No (1) Adding more acid dilutes the solution. (I,D,2) (2) Hydrogen is more reactive than the cation in the white solid, so it displaces the cation from the solid. (I) (3) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added. (2) (4) The acid contains hydrogen ions which reduce the white solid. (I) **(5) The acid reacts with the white solid to form a soluble compound.**	dissolution, displacement, reactivity series, redox, what constitutes a reaction
5	What is the white solid obtained in step (a)? A Ag B AgCl C $ZnCl_2$ D $Zn(NO_3)_2$ (1) The silver ions are displaced by the more reactive cations from Q. (2) **(2) The silver ions combine with the chloride ions.** (3) The white solid disappears when aqueous ammonia is added in step c(i). (2) (4) The nitrate(V) ions are displaced by the more reactive chloride ions. (2)	displacement, reactivity series, selective attention to details
6	In step (b), what is the purpose of adding the dilute nitric(V) acid? A To acidify the mixture. B To determine if the sample contains carbonate ions. C To dissolve the white solid. D To oxidise the white solid. E To remove impurities to ensure a fair test. (1) All nitrate(V) salts are soluble. (2) **(2) Carbonate ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.** (3) Nitric(V) acid is a strong oxidising agent. (D,2) (4) Nitric(V) acid is a good solvent. (D,2) (5) So that Q can react properly with silver nitrate(V). (2)	properties and reactions of acids, redox, dissolution,
7	In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid? A Yes B No (1) Both nitrate(V) and chloride ions are present in the mixture. (2) **(2) Chloride ions from hydrochloric acid will interfere with the test.** (3) Hydrochloric acid can be used as it has similar properties and reactions. (D,2) (4) Hydrochloric acid will not react with the white solid. (2) (5) Hydrochloric acid will react with the white solid. (2)	properties and reactions of acids

Table 6.4 (continued): Table of specifications for the first version of the two-tier multiple choice diagnostic instrument

No	Items, reasons and their sources	Areas of alternative conception
8	In step (c (i)), it can be concluded that a reaction, resulting in the formation of ammonium chloride, has occurred. A True B False (1) Ammonium chloride is a soluble salt. (I,2) (2) Chloride ions still present in solution react with the aqueous ammonia. (2) (3) The ammonium ion is more reactive than the silver ion, so it displaces the silver ion. (I,D,2) **(4) The aqueous ammonia reacts with the white solid to produce a soluble compound which is not ammonium chloride.**	complex salt formation, displacement, reactivity series
9	In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid. A True B False (1) The acid decomposes the ammonium chloride to liberate chloride ions which reacts with the silver ions present in solution. (I,2) (2) The acid reacts with the aqueous ammonia to produce a new insoluble salt. (2) **(3) The acid reacts with the aqueous ammonia and the soluble compound in step (c (i)) to produce the same white solid as in step (a).** (4) The acid removes the ammonium ions so that silver ions can react with hydroxide ions. (I) (5) The white solid is the element silver. (D,2)	properties and reactions of acids redox
10	A student believes that she has to test for hydrogen and carbon dioxide every time she heats an ionic compound. Do you agree? A Yes B No (1) Ionic compounds have strong bonds and do not decompose on heating. (D,2) (2) Ionic compounds which contain carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen on heating. (2) **(3) Some carbonates decompose on heating to give carbon dioxide but hydrogen is never liberated when ionic compounds are heated.** (4) The ionic compounds would react with oxygen on heating to give water and/or carbon dioxide. (D,2) (5) Gases are only evolved when covalent compounds are heated. (2)	thermal decomposition oxidation ionic bonding

Table 6.4 (continued): Table of specifications for the first version of the two-tier multiple choice diagnostic instrument

No	Items, reasons and their sources	Areas of alternative conception
11	A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure? A Yes B No (1) An insoluble carbonate would be formed leaving no free carbonate ions in solution to react with the acid. (2) **(2) Nitric(V) acid will react with both a soluble and an insoluble carbonate.** (3) The above procedure is strictly to test for the presence of sulphate(VI) only. (I,D,2) (4) The acid must be added directly to the solution to test for the presence of a carbonate. (I,D,2) (5) The unknown compound will only react with the nitric(V) acid and not with the barium nitrate(V). (2)	double decomposition, properties and reactions of acids
12	Instead of adding dilute nitric(V) acid in Question 11, can the student add dilute sulphuric(VI) acid (H_2SO_4)? A Yes B No C There is no difference (1) Any acid can be used as they have similar properties and reactions. (2) (2) Sulphuric(VI) acid is much stronger than nitric(V) acid. (2) **(3) Sulphate(VI) ions from sulphuric(VI) acid will interfere with the test.** (4) Sulphuric(VI) acid will react with the nitrate(V) ions. (2) (5) The addition of barium nitrate(VI) invalidates the test. (2)	properties and reactions of acids
13	Will you test for oxygen gas when you heat an unknown solid? A Yes B No (1) All gases must be tested when a substance is heated. (2) (2) Oxygen gas is produced only when acids react with compounds containing oxygen. (2) (3) Oxygen gas will not be liberated during heating, instead it would be used up. (2) **(4) Some compounds decompose on heating to give oxygen gas.**	thermal decomposition, oxidation

No changes were made to the stems and first-tier options of Items 2, 3 and 4. In Experiment B, 'S' was replaced by 'Q' as a few students thought that 'S' was an element, either a metal or sulphur. Thus it was also elaborated that Q was a compound containing a cation and an anion which was possibly chloride. The statement 'The white solid remains' was added to the observations for step (b) for clarity. For step (c), the description of the reaction was revised to 'White solid disappears and a colourless solution is formed'. This was to prevent any misunderstanding that some white solid still remained in step (c).

Item 5 was revised and the first-tier options were derived from the answers that the students wrote in the previous version. Two other first-tier options were included in Item 6, again based on the answers students filled in for option C in the previous versions. Though there were five options in the first-tier of Item 6, this author believed that for this item, the first-tier options were satisfactorily served by the five second-tier reasons because students often gave similar reasons for different options. For example, the option 'Nitric(V) acid is a good solvent' in the second-tier could be a reason for options C and E in the first-tier.

There were no changes to the stem or first-tier options of Items 7, 8 and 9. Item 10 was rewritten to cut down the number of first-tier options, otherwise there had to be more than five reasons to satisfactorily cover all the first-tier options. The stem of Item 11 was revised slightly to make it more grammatical. There were no changes to the stem or first-tier options of Item 12. Items 13, like Item 10, was revised to keep the second-tier options to a minimum.

The results from the administration of the first version of the two-tier multiple choice diagnostic instrument and the development of the second version of the diagnostic instrument

The first version of the two-tier multiple choice diagnostic instrument on qualitative analysis was administered in July 1999 to 73 students (two classes) in School R and 55 students (two classes) in School S. These classes were chosen by the liaison teacher in each school. The students were told that if they did not think that any of the options given was appropriate, they could write their answers at the back of their answer sheets, and six did. The students were also given a data sheet (Appendix A) to refer to during the test. Evidence of an alternative conception was established by considering student selection of incorrect content choice and/or incorrect reason choice (Peterson et al, 1989). In this study, the criterion used for considering an alternative conception significant was that 10% or more of the sample had chosen it (Peterson, 1986). The items in the instrument (Table 6.4 and Appendix K) and the results obtained (Table 6.5) will be referred to in the following discussions. The result for an item will not add up to 100% if there are students who did not select a response to both parts of an item, or who selected an answer combination which is beyond the options given in the item.

Item 1. It can be seen that both the content distracters worked as 37.3% believed that a displacement reaction occurred and 16.1% believed that a redox reaction occurred. This author's intention was to discard any distracter which attracted less than 5% of the sample provided there was a minimum of two options for content, and four for reasons. Two reason distracters attracted less than 5% of the sample. Distracter (1) was discarded as only 2.5% of the sample chose it, while distracter (2) (4.2%) was retained to make up the fourth distracter. As in the second version of the free response test, the main alternative conception in this test is that a displacement reaction occurred (37.3%), specifically because the sodium ion is more reactive than the zinc ion (A4, 28.0%). Another significant alternative conception is that a redox reaction occurred because sodium hydroxide lost oxygen but gained chlorine in forming sodium chloride while zinc chloride gained oxygen but lost chlorine in forming zinc hydroxide (C3, 12.7%). Distractor (3) was reworded in the next version to exclude the loss and gain of chlorine to narrow its focus to the loss and gain of oxygen as students learn that oxygen is lost from a compound in an oxidation reaction but is gained in a reduction reaction.

Item 2. Reason option (4) was discarded in the next version of the test as only 1.7% chose it. Many students (79.7%) believed that the precipitate dissolved in the excess aqueous sodium hydroxide. However, out of the many students who chose content option A, half of them chose reason option (5), the

Table 6.5: Results obtained from the administration of the first version of the two-tier instrument on qualitative analysis

Item	Content option	Reason option				
		(1)	(2)	(3)	(4)	(5)
1	A	1.7	0	3.4	28.0	3.4
	B	.8	3.4	5.9	2.5	**33.1***
	C	0	.8	12.7	1.7	.8
2	A	12.7	13.6	10.2	1.7	39.8
	B	.8	1.7	5.9	0	**11.9***
3	A	0	0	2.5	**27.1***	14.4
	B	24.6	13.6	10.2	.8	5.9
4	A	5.1	5.1	11.0	9.3	33.1
	B	.8	3.4	5.1	6.8	**20.3***
5	A	0	0	0	0	-
	B	15.3	**44.9***	.8	15.3	-
	C	1.7	.8	10.2	2.5	-
	D	3.4	0	.8	1.7	-
6	A	11.9	0	2.5	1.7	29.7
	B	.8	**24.6***	2.5	.8	0
	C	5.1	.8	0	2.5	.8
	D	.8	0	2.5	0	.8
	E	.8	1.7	0	0	1.7
7	A	4.2	0	19.5	0	0
	B	5.1	**50.8***	0	13.6	6.8
8	A	33.9	16.9	15.3	0	-
	B	4.2	0	2.5	**22.0***	-
9	A	7.6	5.9	13.6	6.8	12.7
	B	15.3	9.3	**15.3***	5.1	3.4
10	A	1.7	25.4	0	.8	0
	B	21.2	5.1	**27.1***	5.1	9.3
11	A	4.2	**12.7***	1.7	.8	5.1
	B	5.1	1.7	34.7	29.7	3.4
12	A	21.2	.8	1.7	.8	0
	B	.8	.8	**27.1***	4.2	9.3
	C	8.5	0	0	0	20.3
13	A	17.8	0	0	**29.7***	-
	B	.8	15.3	34.7	.8	-

Note: The figures in reason option columns refer to percentages of students who chose a particular option.

correct reason. This could indicate that the students understood the processes occurring but did not differentiate between the terms 'dissolve' and 'react', or ignored the reaction forming the soluble product. This author did not want use the word 'reacts' in reason option (5) to indicate specifically than a reaction had taken place but he would make the option less attractive for dissolution in the next version by rewording it to indicate that a new compound was formed.

Option A3 (10.2%) seemed like a nonsensical choice as displacement was a reaction, but the students could have ignored the part about reaction and concentrated on the dissolution of a soluble product from the reaction. Other significant specific alternative conceptions were that the precipitate dissolved because more solvent was added (A1, 12.7%), and that the disappearance of a solid when no new reagent was added indicated no reaction (A2, 13.6%).

Item 3. All options worked. The only changes to be made were to reword reason option (5) to replace the word 'precipitate' with 'white solid' and specify, in the stem, that the solvent dissolved the white solid in step (b). The major alternative conceptions were that the acid removed the solvent for the white solid resulting in its reappearance (A5, 14.4%), a new substance was formed because different reagents were used (B1, 24.6%), and the new substance formed was sodium nitrate(V) (B2, 13.6%) or zinc nitrate(V) (B3, 10.2%).

Item 4. All options worked. As in Item 2, the similar option A5 in Item 4 attracted many students (33.1%). The same explanation given in Item 2 that the students could have understood the processes occurring but did not differentiate between dissolution and reaction or ignored the reaction forming the soluble product applied here as well. Reason option (5) was reworded in the second version to indicate that a new compound was formed. Almost the same number of students believed that no reaction occurred because no new reagent was added and the solid only disappeared (A3, 11.0%) in this item and in Item 2 (A2, 13.6%). Twice the number of students were able to decide that a reaction has occurred in this case (B5, 20.3%) compared to Item 2 (B5, 11.9%).

Item 5. Content option A was deleted in the next version as nobody chose it. All the other options worked. More students were able to state that silver combined with the chloride ions (B2, 44.9%) in this item than that zinc combined with hydroxide ions in Item 1 (B5, 33.1%). The number of students who stated that a displacement reaction occurred because of a reactive ion displacing a less reactive ion in Item 5 (B1, 15.3% and B4, 15.3%) is similar to that of Item 1 (A4

28.0%). It was interesting to note, as mentioned in an earlier section, that this 'ion displacing ion' alternative conception for anions did not appear in the student interviews in Study One. The other significant alternative conception was that the white solid was zinc chloride because the white solid disappeared in aqueous ammonia (C3, 10.2%). Q could be zinc chloride as it would give similar results as stated in Experiment B, but the white solid could not be zinc chloride. Thus, the students ignored the fact that the white precipitate was formed when aqueous silver nitrate(V), not aqueous ammonia, was added; they seemed to attend only to the fact that the white solid disappeared in aqueous ammonia.

Item 6. Content options D (4.2%) and E (4.2%) was discarded in the next version as few students chose them. The word 'dilute' was inserted before 'nitric(V) acid' in reason options 3 and 4 in the second version to make them more specific. Some students believed that dilute nitric(V) acid was added to acidify the mixture because all nitrate(V) salts were soluble (A1, 11.9%); this author took it to mean that the addition of dilute nitric(V) acid would not result in the formation of a precipitate. Nearly 30% (A5) of the students believed that the mixture had to be acidified to allow Q to react 'properly' with silver nitrate(V), possibly showing that they did not know the purpose of acidification. A student wrote that the nitric(V) acid should be added before silver nitrate(V); it did not matter as a chloride would give the same results, and a carbonate or sulphate(IV) would react with the acid liberating a gas which could be identified, indicating the ion present.

Item 7. All options worked. The word 'already' was inserted before 'present' in reason option (1) and 'dilute' was inserted before 'hydrochloric acid' in reason options (3), (4) and (5) in the next version. Reason option 3 was modified to specify that dilute hydrochloric acid had the same properties and reactions as dilute nitric(V) acid. About 20% (A3) of the students believed that dilute hydrochloric acid could be used because it had similar properties as dilute nitric(V) acid and 13.6% (B4) stated that dilute hydrochloric acid could not be used because it would not react with the white solid. The actual reason for not using hydrochloric acid was that it contained chloride ions which would react with any excess silver ions to give a precipitate and complicate the situation.

Item 8. All options worked, with 68.6% of the students choosing content option A, believing that ammonium chloride was formed. The main specific alternative conception was that ammonium chloride was formed because the white solid disappeared and ammonium chloride was a soluble salt (A1, 33.9%). Two other significant specific alternative conceptions were that chloride ions still present in solution reacted with the aqueous ammonia to form ammonium chloride (A2, 16.9%) and that the ammonium ion displaces the silver ion to form ammonium chloride (A3, 15.3%).

Item 9. All options worked and apart from the insertion of a comma between the words 'element' and 'silver' in reason option 5, no other changes were made to the item. Almost half of the students chose content option A, believing that hydrogen ions reduced the silver ions, with 12.7% (A5) stating that the white solid is silver. It was not clear why students chose option A3 (13.6%) as the content option did not agree with the reason option. One student wrote 'Acid does not react with a metal below hydrogen in the reactivity series' as her reason for choosing content option B. This is true but inapplicable in this item. Another student wrote 'white solid is formed from reaction between cation and acid'; the student could have thought that the cation from the unknown sample reacted with the dilute nitric(V) acid.

Item 10. All options worked. The significant alternative conceptions are that ionic compounds containing carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen, respectively (A2, 25.4%), and that ionic compounds will not decompose on heating because they have strong bonds (B1, 21.2%). This possibly showed that the students did not know what reactions could occur when compounds were heated. In Study One, many students commented that the testing of gases was difficult; if they did not understand what reactions could occur when compounds were heated, then the testing of gases certainly would be very difficult for them. Reason option (2) was made more specific in the next version by the insertion of the word 'those' before 'ionic compound'. Option (3) also was revised slightly to read that hydrogen would never be liberated when any ionic compound was heated, and option (4) was corrected for a grammatical error, 'compound' instead of 'compounds'. Two students wrote that 'not all ionic compounds contain hydrogen or carbonate ions' as their reason for not testing for the gases. However, there was no way of knowing that the unknown compound given does not contain a carbonate until one tests for it. One student wrote 'It depends whether the compound is molten or aqueous. Aqueous solution would liberate hydrogen'. When some ionic compounds are heated, they also can melt or dissolve in their water of crystallisation, but hydrogen is not liberated. This author was uncertain what the student really meant by her statement, but he would specify in the next version that the ionic compound was in a powder form.

Item 11. All options worked with the major alternative conceptions being that carbonate ions could not be detected using the procedure given because it was strictly to test for the presence of sulphate(VI) (B3, 34.7%). About 30% (B4) of the students believed that the acid had to be added directly to the unknown to test for the presence of carbonate ions; adding it after the addition of barium nitrate(V) would not do. This item revealed that many students (87.3%) did not understand the underlying reasons for this common procedure in qualitative analysis. The only change that was made to this item was the insertion of the word 'dilute' before 'nitric(V) acid' in reason option (2).

Item 12. To make the stem more specific, it was reworded in the second version as 'Instead of dilute nitric(V) acid, can the student add dilute sulphuric(VI) acid (H_2SO_4) after the addition of barium nitrate(V) in Item 11?'. Reason option (2) would be deleted as only 1.7% of the students chose it. Content option C was meant to go along with reason option (5) but content option C might be open to other interpretations and become an unwanted distraction, so it was deleted. The word 'dilute' was inserted before 'sulphuric(VI) acid in reason option (4) and reason option (5) was revised to explain the word 'invalidates' in case students were not familiar with the term. A significant alternative conceptions was that dilute sulphuric(VI) acid could be used because it had similar properties and reactions as dilute nitric(V) acid (A1, 21.2%). The percentage of students who chose a similar option in Item 7 (A3, 19.5%) is also very similar. Another significant alternative conception is that the addition of barium nitrate(V) invalidates the test for carbonate ions (reason option 5, 29.7%), showing that the students did not understand this common procedure in qualitative analysis.

Item 13. All options worked and no changes would be made to the item. The alternative conceptions were that it was not necessary to test for oxygen when an unknown solid was heated because oxygen was only produced when acids react with compounds containing oxygen (B2, 15.3%) and because oxygen would be used rather than produced during heating (B3, 34.7%). Another one was that that all gases must be tested when a substance was heated (A1, 17.8%). This item also showed students' lack understanding of reactions caused by heating.

Additional items for the second version of the two-tier multiple choice instrument

The number of items in the second version was increased to 19 as the author believed that there was a need for additional items to test and confirm the consistent existence of students' alternative conceptions of reactivity, displacement, and procedures involving the use of dilute acids. The items in the second version are given in Appendix L with Items 13 to 18 being the additional items.

Reactions involving copper(II) ions and aqueous ammonia (Items 13 and 14) did appear in Part 2 of the first version of the free response test (Appendix I2) but were not included in the second version of the free response test because there were too many items in the test. Items 13 to 16 will establish the consistency of students' alternative conceptions determined in Items 1 to 4 as the reactions involved are similar. Students should be familiar with the setting as steps (a) and (b) in Experiment C appeared in the 1997, 1994 and 1990 O-level practical examinations. Step (c) in Experiment C is similar to step (c) in Experiment A. In the same way, Items 17 and 18 will establish the consistency of students' alternative conceptions determined in Items 5 and 6. The procedure in Experiment D has not appeared in any recent practical examination but the procedure is in the syllabus, so students are required to know that it is used to detect the presence of iodide ions. The specifications of the additional items are given in Table 6.6.

For layout purposes, Item 10 in version one was moved to Item 19 in version two, and Item 13 in version one was moved to Item 10 in version two.

Administration of the second version of the two-tier multiple choice diagnostic instrument and the development of the Qualitative Analysis Diagnostic Instrument

The second version of the two-tier multiple choice diagnostic instrument was reviewed by three teachers, and was administered in August 1999 to 33 students (one class) in School B, 25 students in School R (one class) and 53 students (two classes) in School S. These classes were chosen by the liaison teacher in each school. The students took an average of fifty minutes to complete the test.

Teachers' comments on the second version of the diagnostic instrument

Mrs. Goh teaches in a church-affiliated government aided school with students of average academic ability. When she reviewed the second version of the diagnostic instrument (Appendix L), she commented that she had covered all the content required for the test except for formation of complex ammines. However, she felt that her students would not be able to apply the knowledge that they had learnt to answer the items as she explained:

Table 6.6: Table of specifications for the additional items in the second version of the two-tier multiple choice diagnostic instrument

No	Items, reasons and their sources	Areas of alternative conception
13	What happens when aqueous ammonia is added to aqueous copper(II) sulphate(VI) in step (a)? A Displacement B Precipitation C Redox (1) Aqueous ammonia gains oxygen in forming ammonium sulphate(VI) but copper(II) sulphate(VI) loses oxygen in forming copper(II) hydroxide. *Similar to reason (1) of Item 1.* **(2) Copper(II) ions combine with the hydroxide ions.** (3) Copper(II) ion is more reactive than ammonium ion. *Similar to reason (3) of Item 1.* (4) Copper(II) ion is less reactive than the ammonium ion. *Similar to reason (3) of Item 1.*	displacement, reactivity series, double decomposition, redox
14	In step (b), why does the light blue solid disappear? A It dissolves in aqueous ammonia. B It reacts with aqueous ammonia. (1) Ammonium ion displaces the cation from the light blue solid. *Similar to reason (3) of Item 2.* (2) More solvent is added so there is more volume for the light blue solid to dissolve in. *Similar to reason (1) of Item 2.* (3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added. *Similar to reason (2) of Item 2.* **(4) There is a chemical reaction between the light blue solid and excess ammonia forming product(s) which is/are soluble.**	dissolution, displacement, complex salt formation, reactivity series, what constitutes a reaction
15	The light blue solid obtained in step (a) and in step (c) is the same. A True B False *(1)* Different reagents were used. *Similar to reason (1) of Item 3.* (2) The acid reacts with the copper(II) compound to form copper(II) suphate (VI) which appears as the light blue solid. *Similar to reason (3) of Item 3.* **(3) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).** (4) The acid removes the solvent which dissolves the light blue solid in step (b), so the light blue solid reappears. *Similar to reason (5) of Item 3*	dissolution properties and reactions of acid

Note: **The correct reason is in bold.**

Table 6.6 (continued): Table of specifications for the additional items in the second version of the two-tier multiple choice diagnostic instrument

No	Items, reasons and their sources	Areas of alternative conception
16	Excess dilute sulphuric(VI) acid acts as a solvent for the light blue solid in step (c). A True B False (1) Adding more acid dilutes the mixture. *Similar to reason (1) of Item 4.* (2) Hydrogen is more reactive than the cation in the light blue solid, so it displaces the cation from the solid. *Similar to reason (2) of Item 4.* (3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added. *Similar to reason (3) of Item 4.* (4) The acid contains hydrogen ions which reduce the light blue solid. *Similar to reason (4) of Item 4.* **(5) The acid reacts with the light blue solid to form a new soluble compound.**	dissolution, displacement, reactivity series, redox, what constitutes a reaction
17	The purpose of adding the dilute nitric(V) acid in step (a) is to A acidify the mixture. B determine if R reacts with the acid. C remove impurities. (1) All nitrate(V) salts are soluble. *Similar to reason (1) of Item 6.* (2) Dilute nitric(V) acid is a strong oxidising agent. *Similar to reason (3) of Item 6.* (3) Dilute nitric(V) acid is a good solvent. *Similar to reason (4) of Item 6.* (4) So that R can react properly with lead(II) nitrate(V). *Similar to reason (5) of Item 6* **(5) The acid will react with any carbonate or sulphate(IV) (SO_3^{2-}) ion if they are present in R.**	properties and reactions of acids, what constitutes a reaction, redox
18	How is the yellow solid formed? A Displacement B Precipitation (1) The lead(II) ion is more reactive than the cation from R. *Similar to reason (4) of Item 5* (2) The lead(II) ion is less reactive than the cation from R. *Similar to reason (4) of Item 5* **(3) The lead(II) ions combine with iodide ions.** (4) The iodide ions are more reactive than the nitrate(V) ions. *Similar to reason (4) of Item 5* (5) The iodide ions are less reactive than the nitrate(V) ions. *Similar to reason (4) of Item 5*	displacement, reactivity series, double decomposition

> For the practical examinations, they are not required to know the reasons for the procedures. They just need to be able to carry out the procedures, record their observations and make inferences from the observations. They are not required to know the reactions involved.

Hence she felt most of her students would be lost and demoralised if they took the test and declined to have the test administered to her students.

Mr. Ho, who teaches in a government secondary school, also made very similar comments about not teaching the reasons for the procedures and the reactions involved. He highlighted that his students would know that acid was added to acidify a mixture, but would not know why the mixture needed to be acidified in the first instance. He also said that he did not cover complex salt formation with his students so they might not be able to answer items involving the reaction. Both Mrs. Goh and Mr. Ho indicated that they had to follow the requirements of the syllabus and examinations very closely because they were working with less academically able students who found chemistry difficult. Their comments mirrored comments in Chapter 3 from Mrs Ang who also taught students of similar ability.

In contrast, Mr. Jo, who teaches in an above average academically achieving church-affiliated government-aided boys' school, believed that his students should be able to answer all items, except those which involved the reversal of complex salt formation because he did not teach it. The difference between what was taught in qualitative analysis in different schools, first raised in Chapter 3, was again evident here. Teachers in schools with less academically able students tended to teach only what was required in the syllabus, while those in better schools tended to teach so that students could understand what actually happened in the various reactions. The academically less able students, supposedly, were unable to understand the additional content, but the author believes that these teachers' may be putting their students at a further disadvantage by not teaching in a way to help them understand qualitative analysis.

Results and discussion

The results obtained are given in Table 6.7. The significant alternative conceptions (above 10%) determined from the administration of the second version of the diagnostic instrument are summarised in Table 6.8. If a higher minimum value, say 25%, was chosen, this would possibly eliminate some valid alternative conceptions from the results.

This author decided not to consider as an alternative conception students stating that a precipitate dissolved in a reagent because it formed a soluble compound with the reagent. This was because this author believed that the students understood what had occurred leading to the disappearance of the precipitate, and he agreed with Brosnan (1999) that understanding of the phenomenon in this case was more important than the terms used to categorise the phenomenon. Thus, the options A4 (25%), A5 (32%), A4 (10%) and A5 (17%) in Items 2, 4, 14 and 16, respectively, were not considered as alternative conceptions. This author also considered options B1 (10%) in Item 13 and A2 (13%) in Item 15 as examples of non-conception rather than alternative conceptions as the options do not make sense. It is difficult to see how precipitation is related to the gain and loss of oxygen in Item 13; in Item 15, it is nonsensical to state that the original precipitate is copper(II) sulphate(VI) when it was clearly stated in Experiment C that the precipitate was formed when aqueous ammonia was added to copper(II) sulphate(VI) solution. Another option which will not be considered as an alternative conception is option A5 in Item 17. This was because stating that acid is added to acidify the mixture so that it will react with any carbonate or sulphate(IV) ions present is still acceptable and shows understanding of the purpose of adding the acid and the reactions involved.

The alternative conceptions identified and the results obtained for items 13, 14, 15, 16, 17 and 18 are not very different from those obtained for items 1, 2, 3, 4, 6 and 5, respectively. The only change made was that option C in Item 17 would not appear in the final version of the instrument as only 3.6% chose it.

Table 6.7: Results obtained from the administration of the second version of the two-tier instrument on qualitative analysis

Item	Content option	Reason option				
		(1)	(2)	(3)	(4)	(5)
1	A	0	2.7	33.3	3.6	-
	B	5.4	7.2	6.3	**32.4***	-
	C	0	8.1	.9	0	-
2	A	28.8	20.7	4.5	25.2	-
	B	1.8	.9	2.7	**15.3***	-
3	A	.9	.9	.9	**23.4***	25.2
	B	11.7	13.5	17.1	.9	5.4
4	A	8.1	3.6	18.9	9.9	32.4
	B	2.7	2.7	.9	1.8	**18.0***
5	A	17.1	**45.9***	3.6	16.2	-
	B	5.4	.9	.9	1.8	-
	C	6.3	0	.9	0	-
6	A	6.3	4.5	5.4	6.3	34.2
	B	1.8	22.5*	0	0	1.8
	C	8.1	.9	1.8	4.5	0
7	A	1.8	0	12.6	4.5	.9
	B	.9	**55.0***	.9	11.7	9.0
8	A	46.8	5.4	15.3	0	-
	B	7.2	1.8	.9	**21.6***	-
9	A	9.9	4.5	9.0	4.5	7.2
	B	11.7	11.7	**27.9***	8.1	.9
10	A	19.8	3.6	0	**35.1***	-
	B	0	11.7	27.0	1.8	-
11	A	2.7	**16.2***	0	2.7	6.3
	B	6.3	0	20.7	38.7	1.8
12	A	24.3	.9	1.8	.9	-
	B	0	**31.5***	7.2	30.6	-
13	A	5.4	0	5.4	14.4	-
	B	9.9	**32.4***	4.5	3.6	-
	C	21.6	.9	.9	.9	-
14	A	2.7	30.6	20.7	9.9	-
	B	3.6	.9	.9	**29.7***	-
15	A	0	12.6	**31.5***	26.1	-
	B	5.4	18.0	3.6	2.7	-
16	A	7.2	4.5	17.1	5.4	17.1
	B	2.7	11.7	3.6	7.2	**21.6***
17	A	8.1	9.0	5.4	49.5	11.7
	B	0	0	1.8	.9	**9.0***
	C	0	0	0	2.7	.9
18	A	14.4	10.8	2.7	7.2	5.4
	B	2.7	2.7	**42.3***	6.3	4.5
19	A	0	0	.9	.9	24.3
	B	30.6	6.3	**27.9***	4.5	.9

Table 6.8: Alternative conceptions determined from the administration of the second version of the diagnostic instrument

Alternative conception	Choice combination	Percentage of students with the alternative conception
Displacement		
1. A more reactive ion displaces a less reactive ion in a double decomposition/precipitation mixture.	Q1 (A3) Q5 (A1& A4) Q13 (A4) Q18 (A1&A2)	33 33 14 25
2. A more reactive ion displaces a less reactive ion in complex salt formation.	Q8 (A3)	15
3. A more reactive ion displaces a less reactive ion in a neutralisation reaction.	Q16 (B2)	12
Redox		
A redox reaction occurs in a double decomposition reaction involving the use of alkalis.	Q13 (C1)	22
Dissolution		
1. A precipitate is formed when a reagent is added to an unknown solution. On further addition of excess reagent, the precipitate disappears.		
a. More excess reagent means more space/volume for the precipitate to dissolve.	Q2 (A1) Q14 (A2)	29 31
b. The precipitate is considered to have dissolved in the excess reagent as no further reaction is seen except its disappearance and no new reagent is added.	Q2 (A2) Q4 (A3) Q14 (A3) Q16 (A3)	21 19 21 17
2. Ammonium chloride is formed when aqueous ammonia is added to silver chloride resulting in the formation of a complex ammine because ammonium chloride is formed because it is a soluble salt.	Q8 (A1)	47
3. When acid is added to a mixture containing excess alkali and a complex salt (eg. ammine, zincate or aluminate), it removes the solvent (alkali) which dissolved the precipitate in the first instance.	Q3 (A5) Q15 (A4)	25 26

Table 6.8 (continued): Alternative conceptions determined from the administration of the second version of the diagnostic instrument

Alternative conception	Choice combination	Percentage of students with the alternative conception
Addition of acid before/after the addition of silver nitrate(V), barium chloride/nitrate(V) or lead(II) nitrate(V) to an unknown.		
1. Acid is needed to acidify the mixture so that reaction can proceed properly.	Q6 (A5) Q17 (A4)	34 50
2. Any acid can be used because all acids have the same properties and reactions.	Q7 (A3) Q12 (A1)	13 24
3. Hydrochloric acid cannot be added because it will not react with the silver chloride precipitate.	Q7 (B4)	12
4. Carbonate ions cannot be determined if acid is added after the addition of barium nitrate(V).		
a. The acid must be added directly to the unknown.	Q11 (B4) Q12 (B4)	39 31
b. The procedure is strictly a test for sulphate(VI).	Q11 (B3)	21
Reappearance of original precipitate on the addition of acid to a mixture containing excess alkali and a complex salt.		
1. A different solid from the original precipitate is formed.	Q3 (B1,B2 & B3) Q9 (B2) Q15 (B2)	42 12 18
2. The acid decomposes the ammonium chloride formed to liberate the chloride ions which react with the silver ions present to reform the precipitate.	Q9 (B1)	12
Heating		
1. All gases have to be tested when a substance is heated.	Q10 (A1)	20
2. Oxygen cannot be produced when a substance is heated.		
a. It is only produced when acids react with compounds containing oxygen.	Q10 (B2)	12
b. It cannot be produced when a substance is heated because it is used up during heating.	Q10 (B3)	27
3. Compounds containing hydrogen and hydroxide ions will liberate hydrogen on heating.	Q19 (A5)	24
4. Ionic compounds have strong bonds and do not decompose on heating.	Q19 (B1)	31

On further thought, it was difficult to decide whether points 2 and 3 under 'Dissolution', and 1 and 2 under the 'Reappearance of original precipitate...' were examples of alternative conceptions or non-conceptions. As discussed in Chapter 3, the procedures involved were very common in qualitative analysis practical work, but some teachers might not explicitly teach the reactions involved in the procedures, for example, complex salt formation (ammines in particular) and reactions. Thus, students would not know the correct answers and had to make guesses. This author finally decided to keep items as alternative conceptions to highlight what student thought had occurred in the procedures involving complex salt formation and reactions. It was hoped that the results obtained would persuade teachers to reconsider teaching the reactions to their students.

Twenty-five of the 32 significant alternative conceptions determined in the first version of the diagnostic instrument also appeared in the second version. One new significant alternative conception in Item 9 was determined in the second version, that is, when nitric(V) acid is added to a mixture of aqueous ammonia and a silver ammine complex, the nitric(V) acid reacts with aqueous ammonia to produce a new insoluble compound. The difference in the results from the two versions could be attributed to the different samples of students as none of the items involved were significantly revised. Other new significant alternative conceptions in the second version were determined from the additional six items, Items 13 to 18.

Students' comments

Students were briefed that if they disagreed with the options given in an item, they could write down their answers at the back of the answer sheet. Nine students responded. One wrote that the reason why hydrogen ions reduce silver ions in Item 9 was that 'hydrogen is higher on the reactivity series'; he did not realise that there are no more electrons left in hydrogen ions to donate to silver ions. For Item 10, a student commented that compounds containing oxygen may not necessarily liberate oxygen upon heating, hence it may not be necessary to test for oxygen when heating an unknown compound. She did not realise that one must test for oxygen when heating an unknown compound because one cannot be sure that oxygen would not be liberated. She also wrote that there were two possible answers in Item 11 which explained why the procedure could not test for carbonate ions; the barium carbonate precipitate was unlikely to react with nitric(V) acid (option 5), so the acid had to be added directly to the unknown for carbon dioxide to be produced (option 4).

Three students commented on Item 12. One wrote that both acids could not be used because both do not contain carbonate ions, the second student stated that carbonates could only be determined through heating while the third wrote that sulphate(VI) ions would react with barium ions to give an insoluble salt. The first two students did not seem to understand the reactions involved. The third student knew that there would be a reaction between sulphuric(VI) acid and barium ions but seemed to find the wording of option 2 unclear or unacceptable. Another student commented on two other items, 16 and 19. She wrote that the function of the sulphuric(VI) acid in Item 16 was to neutralise the excess aqueous ammonia to form back the deep blue solution; the deep blue solution could not be reformed in this particular procedure. However, to prevent further misinterpretation, the word ‘light’ was inserted before ‘blue solution’ in Experiment C step (c) in the third version of the test. She also wrote that very high temperatures are required to break the bonds between ionic compounds so they are unlikely to produce any gases on heating (Item 19).

It could be seen that giving students the option of writing their reasons down if they disagree with those given in the item uncovered a few more alternative conceptions, albeit minor ones as the small numbers indicated. If a large sample was used, it might not be feasible to look through all the answer sheets to determine whether any student wrote their reasons as only a small number of students may respond and their alternative conceptions may be minor.

Summary of Phase 2

In Phase 2, the first two versions of the two-tier multiple choice diagnostic instrument on qualitative analysis were developed, administered to students and revised based on the results obtained from the respective trials. The next section describes the development of the final version of the diagnostic instrument based on the data obtained in Phase 2.

THE QUALITATIVE ANALYSIS DIAGNOSTIC INSTRUMENT

The final version of the diagnostic instrument, the Qualitative Analysis Diagnostic Instrument (QADI) is given in Appendix M. The specifications of each of the 19 items in the instrument is given in Table 6.9 which shows the items, the propositions assessed, the areas of alternative conception involved, as well as, the specific alternative conceptions in each item and the source(s) from which the specific alternative conceptions were determined.

The matching of the items with the propositions assessed indicated that more than one proposition was tested in all but four of the items, and five pairs of items test the same propositions, respectively, but in different contexts or experimental settings. The propositions most frequently assessed were 1, 2, 9, 10, 14, 15, 6, 13, 4 and 14 (in order of decreasing frequency). These are propositions on properties and reactions of acids, bases and amphoteric oxides, double decomposition and precipitation, and formation of ammines, propositions which students most frequently encounter in qualitative analysis. Except for the formation and reaction of complex salts which some teachers do not teach, these propositions are taught to the students, required in the examinations, and within the ability of the students to understand. Thus, more importance was placed on these propositions and more items were written based on them.

Table 6.9: Specifications of the items in the Qualitative Analysis Diagnostic Instrument

No	The items, specific alternative conceptions and their sources	Propositional knowledge statements	Areas of alternative conception
1	What happens when aqueous sodium hydroxide is added to aqueous zinc chloride resulting in the white solid? A Displacement B Precipitation C Redox (1) The solution is too concentrated with sodium chloride so the sodium chloride comes out of the solution as a solid. (D,2) (2) Sodium hydroxide loses oxygen in forming sodium chloride and zinc chloride gains oxygen in forming zinc hydroxide. (2) (3) Sodium ion is more reactive than zinc ion. (I,D,2) **(4) Zinc ions combine with the hydroxide ions.**	9,10,14,15	displacement, double decomposition, reactivity series, redox
2	In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide. A dissolves in B reacts with (1) More solvent is added so there is more space for the white solid to dissolve. (I,2) (2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added. (2) (3) Sodium ion displaces the cation from the white solid. (I) **(4) The white solid forms a new soluble compound with the excess sodium hydroxide.**	9,10,12	complex salt formation, dissolution, displacement, reactivity series, what constitutes a reaction
3	A student concludes that the white solid obtained in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion? A Yes B No (1) Different reagents were used. (2) (2) The acid reacts with the excess sodium hydroxide to form sodium nitrate(V) which appears as the white solid. (2) (3) The acid reacts with the zinc compound to form zinc nitrate(V) which appears as the white solid. (D,2) **(4) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).** (5) The acid removes the solvent which dissolves the white solid in step (b), so the white solid reappears. (2)	1,2,6,9,10,12	dissolution, properties and reactions of acid
4	The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion? A Yes B No (1) Adding more acid dilutes the solution. (I,D,2) (2) Hydrogen is more reactive than the cation in the white solid, so it displaces the cation from the solid. (I) (3) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added. (2) (4) The acid contains hydrogen ions which reduce the white solid. (I) **(5) The acid reacts with the white solid to form a new soluble compound.**	1,2,12	dissolution, displacement, reactivity series, redox, what constitutes a reaction

Note:

Symbol	Source of alternative conception
I	interviews
D	first version of the free response test
2	second version of the free response test
4	second version of the two-tier multiple choice test

Table 6.9 (continued): Specifications of the items in the Qualitative Analysis Diagnostic Instrument

No	The items, specific alternative conceptions and their sources	Propositional knowledge statements	Area of alternative conception
5	What is the white solid obtained in step (a)? A AgCl B $ZnCl_2$ C $Zn(NO_3)_2$ (1) The silver ions are displaced by the more reactive cations from Q. (2) **(2) The silver ions combine with the chloride ions.** (3) The white solid disappears when aqueous ammonia is added in step c(i). (2) (4) The nitrate(V) ions are displaced by the more reactive chloride ions. (2)	14,15	displacement, reactivity series, selective attention to details
6	In step (b), the purpose of adding the dilute nitric(V) acid is to: A acidify the mixture. B determine if the sample contains carbonate ions. C dissolve the white solid. (1) All nitrate(V) salts are soluble. (2) **(2) Carbonate ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.** (3) Dilute nitric(V) acid is a strong oxidising agent.(D,2) (4) Dilute nitric(V) acid is a good solvent. (D,2) (5) So that Q can react properly with silver nitrate(V).(2)	1,2,4	dissolution, properties and reactions of acids, redox
7	In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid? A Yes B No (1) Both nitrate(V) and chloride ions are already present in the mixture. (2) **(2) Chloride ions from dilute hydrochloric acid will interfere with the test.** (3) Dilute HCl can be used as it has similar properties and reactions as dilute nitric(V) acid. (D,2) (4) Dilute HCl will not react with the white solid. (2) (5) Dilute HCl will react with the white solid. (2)	7,8	properties and reactions of acids
8	In step (c (i)), it can be concluded that the white solid disappeared because it reacted with the aqueous ammonia to form ammonium chloride. A True B False (1) Ammonium chloride is a soluble salt. (I,2) (2) Chloride ions still present in solution react with the aqueous ammonia. (2) (3) The ammonium ion is more reactive than the silver ion, so it displaces the silver ion. (I,D,2) **(4) The aqueous ammonia reacts with the white solid to produce a soluble compound which is not ammonium chloride.**	13	complex salt formation, displacement, reactivity series
9	In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid. A True B False (1) The acid decomposes the ammonium chloride to liberate chloride ions which react with the silver ions present in solution. (I,2) (2) The acid reacts with the aqueous ammonia to produce a new insoluble salt. (2) **(3) The acid reacts with the aqueous ammonia and the soluble compound in step (c (i)) to produce the same white solid as in step (a).** (4) The acid removes the ammonium ions so that silver ions can react with hydroxide ions. (I) (5) The white solid is the element, silver. (D,2)	1,2,6,9,10,13	properties and reactions of acids, redox

Table 6.9 (continued): Specifications of the items in the Qualitative Analysis Diagnostic Instrument

No	The items, specific alternative conceptions and their sources	Propositional knowledge statements	Area of alternative conception
10	Will you test for oxygen gas when you heat an unknown solid? A Yes B No (1) All gases must be tested when a substance is heated.(2) (2) Oxygen gas is produced only when acids react with compounds containing oxygen. (2) (3) Oxygen gas will not be liberated during heating, instead it would be used up. (2) **(4) Some compounds decompose on heating to give oxygen gas.**	20	oxidation, thermal decomposition
11	A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure? A Yes B No (1) An insoluble carbonate would be formed leaving no free carbonate ions in solution to react with the acid.(2) **(2) Dilute nitric(V) acid will react with both a soluble and an insoluble carbonate.** (3) The above procedure is strictly to test for the presence of sulphate(VI) only. (I,D,2) (4) The acid must be added directly to the solution to test for the presence of a carbonate. (I,D,2) (5) The unknown compound will only react with the dilute nitric(V) acid and not with the barium nitrate(V). (2)	1,2,4,14,15	double decomposition, properties and reactions of acids
12	Instead of dilute nitric(V) acid, can the student add dilute sulphuric(VI) acid (H_2SO_4) after the addition of barium nitrate(V) in Question 11? A Yes B No (1) Any acid can be used as they have similar properties and reactions. (2) **(2) Sulphate(VI) ions from dilute H_2SO_4 will interfere with the test.** (3) Dilute H_2SO_4 will react with the nitrate(V) ions.(2) (4) The addition of barium nitrate(V) has already invalidated (spoilt) the test for carbonates. (2)	7,8	properties and reactions of acids
13	What happens when aqueous ammonia is added to aqueous copper(II) sulphate(VI) in step (a)? A Displacement B Precipitation C Redox (1) Aqueous ammonia gains oxygen in forming ammonium sulphate(VI) but copper(II) sulphate(VI) loses oxygen in forming copper(II) hydroxide. (4) **(2) Copper(II) ions combine with the hydroxide ions.** (3) Copper(II) ion is more reactive than ammonium ion. (4) (4) Copper(II) ion is less reactive than ammonium ion. (4)	9,10,14,15	displacement, reactivity series, double decomposition, redox
14	In step (b), why does the light blue solid disappear? A It dissolves in aqueous ammonia. B It reacts with aqueous ammonia. (1) Ammonium ion displaces the cation from the light blue solid. (4) (2) More solvent is added so there is more volume for the light blue solid to dissolve in. (4) (3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added. (4) **(4) There is a chemical reaction between the light blue solid and excess ammonia forming product(s) which is/are soluble.**	13	complex salt formation, displacement, dissolution, reactivity series, what constitutes a reaction

Table 6.9 (continued): Specifications of the items in the Qualitative Analysis Diagnostic Instrument

No	The items, specific alternative conceptions and their sources	Propositional knowledge statements	Area of alternative conception
15	The light blue solid obtained in step (a) and in step (c) is the same. A True B False (1) Different reagents were used. (4) (2) The acid reacts with the copper(II) compound to form copper(II) suphate (VI) which appears as the light blue solid. (4) **(3) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).** (4) The acid removes the solvent which dissolves the light blue solid in step (b), so the light blue solid appears.(4)	1,2,6,9,10,13	dissolution, properties and reactions of acid
16	Excess dilute sulphuric(VI) acid acts as a solvent for the light blue solid in step (c). A True B False (1) Adding more acid dilutes the mixture. (4) (2) Hydrogen is more reactive than the cation in the light blue solid, so it displaces the cation from the solid. (4) (3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added. (4) (4) The acid contains hydrogen ions which reduce the light blue solid. (4) **(5) The acid reacts with the light blue solid to form a new soluble compound.**	1,2,6	dissolution, displacement, reactivity series, redox, what constitutes a reaction
17	The purpose of adding the dilute nitric(V) acid in step (a) is A to acidify the mixture. B to determine if R reacts with the acid. (1) All nitrate(V) salts are soluble. (4) (2) Dilute nitric(V) acid is a strong oxidising agent. (4) (3) Dilute nitric(V) acid is a good solvent. (4) (4) So that R can react properly with lead(II) nitrate(V).(4) **(5) The acid will react with any carbonate or sulphate(IV) (SO_3^{2-}) ion if they are present in R.**	1,2,4	properties and reactions of acids, redox, what constitutes a reaction
18	How is the yellow solid formed? A Displacement B Precipitation (1) The lead(II) ion is more reactive than cation from R. (4) (2) The lead(II) ion is less reactive than cation from R.(4) **(3) The lead(II) ions combine with iodide ions.** (4) The iodide ions are more reactive than nitrate(V) ions.(4) (5) The iodide ions are less reactive than nitrate(V) ions. (4)	14,15	reactivity series, displacement, double decomposition
19	A student believes that she has to test for hydrogen and carbon dioxide when she heats an unknown ionic compound (in powder form). Do you agree? A Yes B No (1) Ionic compounds have strong bonds and do not decompose on heating. (D,2) (2) Gases are only evolved when covalent compounds are heated. (2) **(3) Some carbonates decompose on heating to give carbon dioxide but hydrogen is never liberated when any ionic compound is heated.** (4) The ionic compound would react with oxygen on heating to give water and/or carbon dioxide. (D,2) (5) Those ionic compounds containing carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen on heating. (2)	18	oxidation, ionic bonding, thermal decomposition

The propositions for redox reactions, 3, 22 to 28 were not directly assessed in the instrument because the various redox reactions involved in qualitative analysis are not included in O-level chemistry. Many of these reactions are only taught at the next stage of chemical education, in A-level chemistry. Thus it was difficult to write any item based on the O-level redox content that the students learn. Propositions 16 and 21 involving the identification of ions based on their properties were indirectly assessed in the test. Proposition 17 concerning the stability of compounds to heat was indirectly assessed in Items 10 and 19. Proposition 19 on the thermal decomposition of sulphate(IV) was not assessed because it seldom occurs in O-level qualitative analysis practical work. Though the identification of sulphur dioxide is included in the syllabus, the reactions involved in its formation is not in the syllabus, so teachers may not teach it.

The QADI was reviewed by four senior secondary chemistry teachers and three tertiary chemistry professors. The secondary teachers were asked to ascertain whether the content of the test was consistent with the requirements of the O-level pure chemistry syllabus, and review the items to ensure that the wording in the items was clear and could be understood by secondary chemistry students. The teachers concurred that all the items, except 8 and 14, met the requirements of the syllabus and that the wording was acceptable. Items 8 and 14 involve the formation of ammines which is not in the syllabus, but only one of the four teachers did not teach it; the other three had no objections with the inclusion of the items. All four teachers agreed that the items could be included in the instrument based on this author's argument that students frequently encounter the reaction in their experiments, and that the understanding of the reaction was not beyond the students. The three tertiary chemistry professors mainly concentrated on the accuracy of the content in the items and agreed that there was nothing wrong with any of the items.

One reviewer commented that reference made in the stem to the white solid disappearing in item 8 should be made more explicit. Thus, this author revised the stem to read 'In step (c (i)), it can be concluded that the white solid disappeared because it reacted with the aqueous ammonia to form ammonium chloride'.

SUMMARY

This chapter focussed mainly on Research Question 4, and outlined the development of the diagnostic instrument on qualitative analysis from the free response test stage to the final version of the two-tier multiple choice instrument. Research Question 3 on the students' understanding of the concepts and propositional knowledge related to qualitative analysis also was addressed through the trials of the various test instruments. The alternative conceptions and conceptually difficult areas identified through interviews in Chapter 5 and the free response tests in this chapter were used to develop the first version of the two-tier multiple choice diagnostic instrument on qualitative analysis. Successive refinement to the instrument led to final version of the two-tier multiple choice instrument, the 19-item Qualitative Analysis Diagnostic Instrument (QADI). The next chapter describes the data obtained from the administration of the QADI to secondary students, while the focus of Chapter 8 is on the understanding of qualitative analysis of A-level students, undergraduates and graduate trainee-teachers as determined through the administration of the QADI.

CHAPTER SEVEN

GRADE 10 STUDENTS' UNDERSTANDING OF QUALITATIVE ANALYSIS

INTRODUCTION

The focus of this chapter is on Research Question 5 which seeks to determine the extent of secondary chemistry students' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as identified through the use of a diagnostic test. The administration of the Qualitative Analysis Diagnostic Instrument (QADI), the results obtained, the analysis, interpretation and discussion of the results are described in this chapter.

ADMINISTRATION OF THE DIAGNOSTIC INSTRUMENT

The QADI was administered to 915 Grade 10 students from 11 schools over the period September to October 1999. Grade 10 students were chosen because they had more qualitative analysis lessons and practical work compared to Grade 9 students. The details and distribution of the students are described in Tables 7.1 and 7.2.

Table 7.1: Age distribution of the students (n=915)

Age	Number	Percentage
15	1	.1
16	816	89.2
17	24	2.6
18	9	1.0
19	2	.2
Not stated	63	6.9

Table 7.2: Distribution of students over schools

School	Female	Male	Total
1	55	31	86
2	150	-	150
3	-	81	81
4	-	136	136
5	15	17	32
6	45	39	84
7	208	-	208
8	16	15	31
9	13	12	25
10	27	14	41
11	20	18	38
Not stated	1	1	2
Total	553 (60.4%)	361 (39.5%)	914

Note: One student did not state his/her school nor sex.

Singaporeans, in general, will be 16 years old in Grade 10 if they were not retained at any level. The older students were generally Malaysians or Indonesians. Schools 2, 3, 4 and 7 are single-sex, academically above average schools with many students taking pure chemistry.

RESULTS AND DISCUSSION

The answer sheets of the students were optically scanned, and SPSS version 9 (SPSS, 1999) was used to analyse the results. Following the procedure in Peterson (1986), each item was considered to be correctly answered if a student correctly responded to both parts of the item.

Test statistics

Some test statistics are given in Table 7.3, and the distribution of the students' scores is shown in Figure 7.1. It can be seen from both that a great majority of the Grade 10 students' had low scores with the mean score being 5.76 out of 19, and 86.8% of them scored 9 marks or less. Many students remarked that they found the QADI difficult and the low scores confirmed this.

Table 7.3: Test statistics for Grade 10 students

Variable	Statistic
No. of cases	915
No. of items	19
Alpha	.68
Mean	5.76
Standard Deviation	3.28
Median	5.00
Mode	5
Minimum	0
Maximum	18

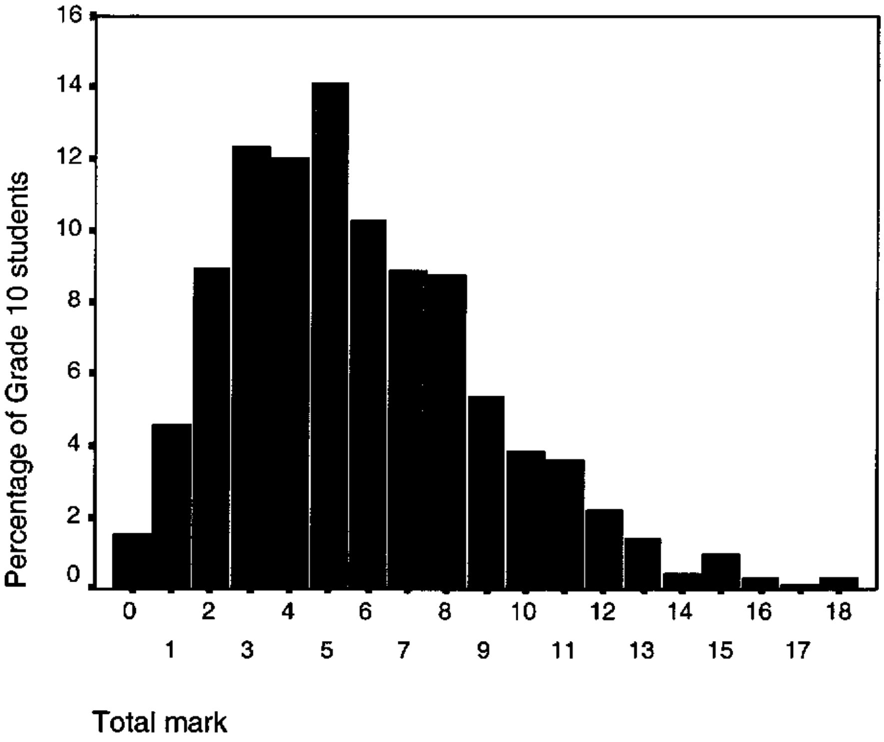

Figure 7.1: Distribution of Grade 10 students' scores

The reliability of the instrument (Cronbach coefficient alpha) is a moderate .68, consistent with the criterion-referenced nature of the test (Ross & Munby, 1991). The coefficient alpha did not change significantly when any item was deleted from the instrument; for example, maximum coefficient alpha, .69 was obtained when item 8 was deleted, an increase of only .01. Since item 8 involves the formation of complex ammines, the above result can be taken to justify its inclusion as the reliability of the test is not altered significantly. The reliability of the instrument could be affected by students guessing their answers or not giving any answer to one or both parts of an item.

Table 7.4 describes the percentage of the Grade 10 students selecting each response combination for each item in the QADI. The results for an item will not add up to 100% if there were students who did not select a response to both parts of the item, or selected an answer combination which was beyond the options given in the item. Table 7.5 gives the percentage of Grade 10 students correctly answering both the content and reason parts of each item, and the discrimination index for each item (in brackets). The percentage of those correctly answering only the content part of the items was also included to highlight the students' understanding of the propositions and concepts for the correct answer to the content part of the items.

The facility indices ranged between .17 to .48, again showing that the diagnostic test was difficult for the secondary students. However, all of the facility indices were above the level of statistical guessing, indicating that many students did know the correct answers. A comparison of the percentage of students who correctly answered the content part of the questions with that of those who correctly answered both parts of the questions suggests that students may have learned facts without an adequate understanding of the propositions and concepts involved (Peterson et al., 1989). The discrimination indices ranged between .20 to .53, with 15 items showing good discrimination (>.30).

Table 7.4: The percentage of Grade 10 students (n=915) selecting each response combination for each item in the Qualitative Analysis Diagnostic Instrument (QADI)

Item	Content option	Reason option				
		(1)	(2)	(3)	(4)	(5)
1	A	.4	1.6	*24.9*	2.7	-
	B	4.8	7.8	7.1	**40.8***	-
	C	0	5.2	.8	1.1	-
2	A	*28.6*	*15.7*	5.2	25.7	-
	B	.3	.4	2.7	**19.3***	-
3	A	.9	2.0	2.1	**16.8***	*17.5*
	B	*23.8*	*11.0*	*17.6*	2.1	3.9
4	A	6.8	4.5	*15.8*	7.2	30.1
	B	1.7	2.0	3.7	3.2	**21.7***
5	A	*20.1*	**43.3***	1.5	*17.0*	-
	B	2.4	1.4	4.4	.4	-
	C	4.3	.9	2.4	.5	-
6	A	5.2	2.3	6.8	3.3	*21.6*
	B	2.1	**33.7***	2.1	.8	2.1
	C	6.2	1.4	1.6	4.4	1.4
7	A	2.4	.8	*17.8*	2.0	1.3
	B	2.8	**48.2***	.3	*15.6*	6.1
8	A	*41.3*	*12.9*	*15.3*	2.4	-
	B	4.0	1.3	.7	**19.6***	-
9	A	*10.8*	6.4	9.9	5.0	9.7
	B	*14.6*	8.6	**18.8***	6.9	3.3
10	A	*22.7*	1.3	.7	**35.3***	-
	B	1.4	7.5	*27.4*	1.0	-
11	A	4.4	**24.0***	.9	2.8	5.4
	B	5.5	2.5	*19.7*	*25.0*	3.9
12	A	*26.4*	.7	1.1	3.0	-
	B	1.1	**38.1***	5.8	*20.4*	-
13	A	2.4	4.7	3.2	*11.6*	-
	B	5.8	**44.9***	2.3	4.0	-
	C	*13.0*	1.9	1.2	1.0	-
14	A	4.3	*24.8*	*16.4*	15.5	-
	B	3.0	1.0	2.0	**29.1***	-
15	A	1.2	*18.8*	**23.1***	*19.0*	-
	B	*14.2*	*15.2*	1.6	1.7	-
16	A	9.0	5.9	*18.8*	5.5	15.4
	B	2.0	6.2	4.2	4.5	**22.8***
17	A	7.8	5.9	4.3	*34.8*	12.8
	B	2.7	2.0	1.1	2.4	**19.8***
18	A	9.6	8.4	3.6	6.9	3.6
	B	3.8	3.4	**47.8***	4.5	2.4
19	A	1.1	1.0	3.7	3.4	*20.9*
	B	*26.0*	3.7	**29.3***	3.1	1.5

Table 7.5: Percentage of Grade 10 students (n=915) correctly answering the first part only and both parts of the items in the QADI

Item	Percentage of students correctly answering		Item	Percentage of students correctly answering	
	first part	both parts		first part	both parts
1	62	41 (.46)	11	41	24 (.45)
2	23	19 (.53)	12	67	38 (.36)
3	40	17 (.39)	13	58	45 (.46)
4	33	22 (.37)	14	35	29 (.44)
5	83	43 (.32)	15	63	23 (.29)
6	42	34 (.38)	16	41	23 (.53)
7	74	48 (.23)	17	29	20 (.35)
8	26	20 (.20)	18	63	48 (.39)
9	55	19 (.42)	19	65	29 (.37)
10	60	35 (.27)			

Note: Discrimination indices are given in brackets.

Alternative conceptions

Alternative conceptions are considered significant if they existed in at least 10% of the student sample (Peterson, 1986). If a higher minimum value, say 25%, was chosen, this would possibly eliminate some valid alternative conceptions from the results. Tables 7.6 and 7.7 summarise the significant alternative conceptions determined from the administration of the QADI to the 915 Grade 10 students. Thirty-five significant alternative conceptions were identified and grouped under the headings of 'Displacement', 'Redox', 'Addition of acid', and 'Heating' (Table 7.7). As in the second version of the diagnostic test, this author decided not to consider students stating that a precipitate dissolved in a reagent because it formed a soluble compound with the reagent as an alternative conception. Thus the options A4 (26%), A5 (30%), A4 (16%) and A5 (15%) in Questions 2, 4, 14 and 16, respectively, were not considered as alternative conceptions.

Table 7.6: Percentage of Grade 10 students with significant alternative conceptions in each item of the QADI

Item	Option	Alternative conception	Percentage of Grade 10 students
1	A3	Sodium ion displaces zinc ion because it is more reactive.	25
2	A1	Zinc hydroxide dissolves in excess sodium hydroxide because more solvent is added so there is more space for it to dissolve.	29
	A2	Zinc hydroxide dissolves in excess sodium hydroxide because no further reaction is seen except for its disappearance, and no new reagent is added.	16
3	A5	The acid removes the solvent which dissolved the white solid in the first instance.	18
	B1	A different solid is formed because different reagents were used.	24
	B2	A different solid, sodium nitrate(V) is formed from the reaction of the acid and the alkali.	11
	B3	A different solid, zinc nitrate(V) is formed from the reaction of the acid and the zinc compound present.	18
4	A3	Zinc hydroxide dissolves in acid (solvent) because no further reaction is seen except for its disappearance, and no new reagent is added.	16
5	A1	Silver chloride is formed when the silver ions are displaced by the more reactive ions from Q	20
	A4	Silver chloride is formed when the nitrate(V) ions are displaced by the more reactive chloride ions.	17
6	A5	Acid is added to acidify the mixture in order that the reaction can proceed properly.	22
7	A3	Hydrochloric acid can be added following the addition of silver nitrate(V) as it has similar properties and reactions as nitric(V) acid.	18
	B4	Hydrochloric acid cannot be added following the addition of silver nitrate(V) as it will not react with the silver chloride.	16
8	A1	Ammonium chloride is formed when aqueous ammonia is added to silver chloride because ammonium chloride is a soluble salt.	41
	A3	Ammonium chloride is formed when aqueous ammonia is added to silver chloride because the more reactive ammonium ion displaces the silver ion.	15
9	B1	Nitric(V) acid decomposes the ammonium chloride to liberate chloride ions which then react with the silver ions to form a white precipitate.	15
10	A1	Test for oxygen has to be carried out when a substance is heated because all gases have to be tested.	23
	B3	Test for oxygen need not be carried out when a substance is heated because oxygen will not be liberated during heating, instead it will be used up.	27

Table 7.6 (continued): Percentage of Grade 10 students with significant alternative conceptions in each item of the QADI

Item	Option	Alternative conception	Percentage of Grade 10 students
11	B3	It is not possible to detect the presence of carbonate ions by the addition of barium nitrate(V) followed by nitric(V) acid because the procedure is strictly a test for the presence of sulphate(VI) ions.	20
	B4	It is not possible to detect the presence of carbonate ions by the addition of barium nitrate(V) followed by nitric(V) acid because the acid must be added directly to the unknown to test for the presence of carbonate ions.	25
12	A1	Sulphuric(VI) acid can be added following the addition of barium nitrate(V) because all acids have similar properties and reactions.	26
	B4	Sulphuric(VI) acid cannot be used because the addition of barium nitrate(V) has already invalidated the test for carbonates.	20
13	A4	Ammonium ion displaces copper(II) ions because it is more reactive.	12
	C1	A redox reaction occurs when aqueous ammonia is added to copper(II) sulphate(VI) because copper(II) sulphate(VI) loses oxygen in the forming copper(II) hydroxide chloride and aqueous ammonia gains oxygen in forming ammonium sulphate(VI).	13
14	A2	Copper(II) hydroxide dissolves in excess aqueous ammonia because more solvent is added so there is more volume for it to dissolve.	25
	A3	Copper(II) hydroxide dissolves in excess aqueous ammonia because no further reaction is seen except for its disappearance, and no new reagent is added.	16
15	A4	The acid removes the solvent which dissolved the blue solid in the first instance.	19
	B1	A different solid is formed because different reagents were used.	14
	B2	A different solid, copper(II) sulphate(VI) is formed from the reaction of the acid and the soluble copper(II) compound.	15
16	A3	Copper(II) hydroxide dissolves in acid (solvent) because no further reaction is seen except for its disappearance, and no new reagent is added.	19
17	A4	Acid is added to acidify the mixture so that the unknown can react properly with lead(II) nitrate(V).	35
18	A	Lead(II) iodide is formed by a displacement reaction between R and lead(II) nitrate(V).	33
19	A5	Hydrogen and carbon dioxide must be tested when ionic compounds are heated because compounds containing carbonate, hydrogen or hydrogen ions will liberate carbon dioxide or hydrogen on heating.	21
	B1	Hydrogen and carbon dioxide need not be tested when ionic compounds are heated because ionic compounds have strong bonds and do not decompose on heating.	26

Table 7.7: Alternative conceptions determined from the administration of the QADI

Alternative conception	Choice combination	Percentage of students with the alternative conception
Displacement		
1. A more reactive ion displaces a less reactive ion in a double decomposition/precipitation mixture.	Q1 (A3) Q5 (A1& A4) Q13 (A4) Q18 (A1,A2, A4&A5)	25 37 12 29
2. A more reactive ion displaces a less reactive ion in complex salt formation.	Q8 (A3)	15
Redox		
A redox reaction occurs in a double decomposition reaction involving the use of alkalis.	Q13 (C1)	13
Dissolution		
1. A precipitate is formed when a reagent is added to an unknown solution. On further addition of excess reagent, the precipitate disappears.		
a. More excess reagent means more space/volume for the precipitate to dissolve.	Q2 (A1) Q14 (A2)	29 25
b. The precipitate is considered to have dissolved in the excess reagent as no further reaction is seen except its disappearance and no new reagent is added.	Q2 (A2) Q4 (A3) Q14 (A3) Q16 (A3)	16 16 16 19
2. Ammonium chloride is formed when aqueous ammonia is added to silver chloride because it is a soluble salt.	Q8 (A1)	41
3. When acid is added to a mixture containing excess alkali and a complex salt (eg. ammine, zincate or aluminate), it removes the solvent (alkali) which dissolved the precipitate in the first instance.	Q3 (A5) Q15 (A4)	18 19

Table 7.7 (continued): Alternative conceptions determined from the administration of the QADI

Alternative conception	Choice combination	Percentage of students with the alternative conception
Addition of acid		
1. Acid is needed to acidify the mixture so that reaction can proceed properly.	Q6 (A5) Q17 (A4)	22 35
2. Any acid can be used because acids have the same properties and reactions.	Q7 (A3) Q12 (A1)	18 26
3. Hydrochloric acid cannot be added because it will not react with the silver chloride precipitate.	Q7 (B4)	16
4. Carbonate ions cannot be identified if acid is added after the addition of barium nitrate(V).		
a. The acid must be added directly to the unknown.	Q11 (B4) Q12 (B4)	25 20
b. The procedure is strictly a test for sulphate(VI).	Q11 (B3)	20
5. When acid is added to a mixture containing excess alkali and a complex salt,		
a. a different solid from the original precipitate is formed.	Q3 (B1,B2 & B3) Q15 (B1& B2)	52 29
b. The acid decomposes the ammonium chloride formed to liberate the chloride ions which react with the silver ions present to reform the precipitate.	Q9 (B1)	15
Heating		
1. All gases have to be tested when a substance is heated.	Q10 (A1)	23
2. Oxygen cannot be produced when a substance is heated because it is used up during heating.	Q10 (B3)	27
3. Compounds containing hydrogen and hydroxide ions will liberate hydrogen on heating.	Q19 (A5)	21
4. Ionic compounds have strong bonds and do not decompose on heating.	Q19 (B1)	26

Another option which again would not be considered as an alternative conception is option A5 (13%) in Question 17 because stating that acid is added to acidify the mixture so that it will react with any carbonate or sulphate(IV) ions present is quite acceptable. As in the second version of the diagnostic test, this author also considered option A2 (19%) in Question 15 as an example of a non-conception rather than an alternative conception as the option did not make sense. This author also felt that option A2 (13%) of item 8 was not an alternative conception as the reason option did not agree with the content option. Rather, it showed students' non-conception of complex ammine formation as well as selective attention to details. Option A1 (10%) of item 9 also made no sense as the reason option, reduction of silver ions, had no relation at all to the content option, decomposition of ammonium chloride. Thus the above two options would not be considered as alternative conceptions.

Displacement

Understanding of double decomposition was low among the Grade 10 students though it is a very common reaction in qualitative analysis; students frequently use aqueous sodium hydroxide and ammonia to identify cations, and aqueous silver, barium and lead(II) nitrates (V) to identify anions. As measured by items 1, 5, 13 and 18, only between 41 to 48% of the sample could correctly state that the formation of the precipitates was due to double decomposition reactions. Between 12 to 37% of the students believed that a more reactive ion displaced a less reactive ion resulting in the formation of a precipitate. Similar findings were reported by Boo (1994, 1998) in her study of A-level students, and as discussed in Chapter 5, this alternative conception could be caused by the set effect (Hashweh, 1986) of memorising the reactivity series leading to concept interference (McDermott, 1988). Another reason could be the lack of understanding of the scientific terms (Reif & Larkin, 1991), in this case, double decomposition and displacement.

In item 8, only 20% of the students understood that silver chloride reacted with aqueous ammonia to form a complex silver ammine salt. About 15% of the students believed that displacement had taken place instead of complex salt formation. They could have reasoned that since silver was low in the reactivity series, ammonia, though not in the reactivity series, could also displace silver forming ammonium chloride. This reasoning could be due to perceptually dominated thinking (Ebenezer & Erickson, 1996; Boo & Toh, 1998); the students focussed on the fact that ammonium chloride was soluble and so it 'dissolved' leading to the disappearance of the precipitate. It is interesting to note that in item 14 which also involves complex ammine formation, about 30% of the students chose the correct option, and a similar alternative conception (option B1) only attracted 3% of the sample. The formation of the dark blue copper ammine solution is very prominent in this case compared to the less conspicuous change in the case of the silver chloride-aqueous ammonia reaction, so teachers could have discussed the reaction involved.

Redox

About 13% of the students chose option C1 in item 13, showing lack of understanding of redox. Students thought that copper(II) sulphate(VI) 'lost' oxygen and aqueous ammonia 'gained' oxygen when they reacted to form copper(II) hydroxide and ammonium sulphate(VI). Thus either the students were misled by the 'ox' in 'redox' into thinking that oxygen must be involved in any redox reaction (Schmidt, 1997), or the use of an inappropriate model, the oxygen model (Garnett & Treagust, 1992) in this instance, caused students to have this alternative conception. In this situation, the oxidation number model is superior to the other three models (Garnett et al., 1990; Herron, 1975; Ringnes, 1995; Sisler & VanderWerf, 1980) in determining that the reaction is not a redox reaction; if it were not taught, as De Jong et al. (1995) suggested, then students would be misled into thinking that a redox reaction had occurred. Oxidation number model of redox is taught in Singapore, but it is a difficult model for the beginning chemistry students to learn (De Jong et al., 1995; Ringnes, 1995). Thus, those students having difficulty understanding the oxidation number model of redox could have favoured one of the other three models.

Dissolution

This author believed that the alternative conceptions on dissolution were mainly due to the lack of understanding of complex salt formation and reaction rather than lack of understanding of dissolution per se. This was because the alternative conceptions were determined mainly from items 2, 3, 14 and 15, which involved complex salt formation and reaction; the students did not know why the precipitate disappeared when aqueous ammonia or sodium hydroxide was added, or why it reappeared when dilute acid was added to the mixture of the complex salt and excess alkali. Thus, lacking the required knowledge and overlooking the fact that the precipitate actually appeared when the 'solvent' was first added, they would logically conclude, based on perceptually dominated thinking (Ebenezer & Erickson, 1996; Boo & Toh, 1998), that the precipitate 'dissolved' in the excess alkali because more 'solvent' was added (A1 in item 2 and A2 in item 14) or that no new reagent was used or no further reaction was seen (A2, and A3 in items 2 and 14, respectively). Ribeiro et al. (1990) also reported that if students did not see a new substance being formed, they tended not to refer to the change as a reaction, while Novick and Nussbaum (1978) found that students thought mixtures were formed when no external means such as heating or electricity were used. This alternative conception might have been unwittingly reinforced in the 'Notes for use in qualitative analysis' (Appendix A) where, for example, 'white precipitate, soluble in excess giving a colourless solution' was used to describe the reaction to test for zinc ions using aqueous sodium hydroxide (Tan & Koh, 1999). In Chapters 2 and 5, the triviality of the definition of dissolution, provided students knew what went on in the micro-level, was discussed. However, if students did not have the necessary knowledge, then, as Tan and Koh (1999) pointed out, use of the term 'dissolve' would create alternative conceptions as students considered that only a physical change had taken place. Thus, this author believed that the term 'soluble' should not be used in the 'Notes for use in qualitative analysis'. If the students believed that the precipitate 'dissolved' in the alkali, then it was reasonable, in items 3 (A5) and 15 (A4), to believe that dilute acid reacted with the alkali, removing the 'solvent', giving rise to this alternative conception. It is interesting to note that the percentage of students holding this alternative conception was less than half of those believing that the alkali dissolved the precipitate. This finding could indicate that many students had no clear idea what was involved in the questions.

The alternative conception that the dilute acid dissolves the solid because no further reaction is seen and no new reagent is added in items 4 (A3) and 16 (A3) is very similar to that in items 2 and 14. Again if the students did not understand or know that an acid-base reaction was involved, based on perceptually dominated thinking and overlooking the fact that the solid appeared when the acid was first added, it would be reasonable to think that the solid 'dissolved' when the 'acid-solvent' was added. In item 8 (A1), 41% of the students believed that soluble ammonium chloride was formed when silver chloride reacted with aqueous ammonia. This was most likely due to lack of understanding or knowledge of complex ammine formation. The use of perceptually dominated thinking could lead students to conclude that ammonium chloride was formed because it is soluble and the white solid disappeared when aqueous ammonia was added.

Addition of acid

Many students in the sample had an instrumental understanding (Skemp, 1976) of qualitative analysis, of 'doing without knowing why'. This was very clearly shown in their responses for items 6, 7, 11, 12 and 17. For example, 20% (item 11, B3) of the students believed that the addition of aqueous barium nitrate(V) followed by dilute nitric(V) acid was to test for sulphate(VI) only, another 25%

(item 11, B4) believed that to test for a carbonate, acid had to be added directly to the unknown sample, and in item 12, 20% (B4) believed that the addition of barium nitrate(V) invalidated the test for carbonates. These responses showed that students did not understand the reactions behind the procedures, the reasons why barium nitrate(V) and nitric(V) acid were added. Further examples were given in item 6 (A5, 22%) and 17 (A4, 35%) where students thought that acid had to be added so that the unknown substances could react 'properly' with silver nitrate(V) and lead(II) nitrate(V), respectively, without having a clue as to what 'properly' meant. If they did not understand the role of acids in the identification of anions, then the reasons for the selection of specific acids in the tests would not be understood. Thus in items 7 (A3, 18%) and 12 (A1, 26%), students did not realise that the acids would produce precipitates with the silver and barium ions, respectively, and thought that any acid could be used because all acids have similar properties and reactions (item 7 (A3), 18% & item 12 (A1), 26%) or that hydrochloric acid would not react with the silver chloride precipitate (item 7 (B4), 16%).

Students' lack of understanding of complex salt formation and reactions was again apparent in their inability to work out what would happen if dilute acid was added to a mixture containing the complex salt and excess base. In items 3 (B1, B2 & B3, 52%) and 15 (B1 & B2, 29%), students could not figure out that the dilute acid would neutralise the excess alkali and react with the complex salt to produce the original hydroxide precipitate; they believed that a different substance was formed. In item 9, 15% (B1) believed that the acid 'decomposes' the 'ammonium chloride' formed, freeing the chloride ions which then 'react' with silver ions present in solution; a rather creative attempt, in the light of insufficient knowledge, at working out what had happened in the procedure. Van Driel, de Vos and Verloop (1999) suggest that the concept of reversibility of reactions may be difficult for students because they have to revise their initial ideas that reactions only proceed in one direction and to completion. This might be why students did not consider that the addition of acid reversed the complex salt formation.

Heating

More evidence of instrumental understanding can be seen from the results of items 10 and 19. It is apparent that many students did not understand the role of heating in qualitative analysis or the reactions that take place during heating. For example, in item 10, 23% (A1) stated that all gases had to be tested when a substance was heated. Many students stated in the interviews (Chapter 3) that one of the biggest difficulties they had in qualitative analysis was the testing for gases because they did not know which gas to test for during heating; this resulted in the random testing of gases. If all ionic compounds do not decompose on heating, then what is the purpose of heating in qualitative analysis? Unfortunately the above thought did not occur to the 26% who chose B1 in item 19. Other examples of 'doing without knowing why' or 'doing without being aware' could be seen in the choice of B3 (27%) in item 10 and A5 (21%) in item 19. Students would have heated nitrate(V) salts several times in the course of their practical work, and would have obtained positive results for oxygen. If oxygen was never produced when a substance was heated, then what relighted the glowing splint? On the other hand, it was extremely unlikely that they ever had a positive test for hydrogen when heating a solid. The results seemed to indicate that the students could not remember or process what they do in the laboratory sessions.

Problems

A number of reasons for the students' apparent inability to learn qualitative analysis meaningfully were discussed in Chapters 2 and 5. These included the lack of understanding of the purpose and critical features of the experiments (Tasker & Freyberg, 1985), lack of appropriate frameworks (Duit & Treagust, 1995), lack of cognitive strategies (Gunstone, 1994; Wittrock, 1994), the content of qualitative analysis (White, 1994), motivational beliefs and learning contextual factors (Pintrich et al., 1993; Rop, 1999), passive view of learning (Treagust et al., 1996), cognitive overloading (Johnstone, 1999; Johnstone & Wham, 1982) and lack of mastery of process skills (Goh et al., 1987; Herron, 1996). Based on this author's teaching experiences, and interactions with students and teachers, another factor that should to be considered was the lack of explicit teaching in qualitative analysis. For example, there should be more explicit links between theory and practical work, more explicit teaching of the chemical terms used, the relevant content which is not included in the syllabus, for example, complex salt formation, and the strategies and process skills required. Teachers also should monitor more closely their students' understanding of the content involved and their acquisition of the process skills required in qualitative analysis. The lack of explicit teaching and close monitoring could have compounded all the other difficulties that students have in qualitative analysis.

Limitations

Two important limitations of the results from the administration of the QADI need to be highlighted. The first is that it was uncertain whether the lack of conceptual understanding of qualitative analysis was due to students having alternative conceptions or due to students having no conceptions at all (Birk & Kurtz, 1999). This author believed that the latter was more applicable to many of the students because understanding was generally not stressed in the teaching and learning of qualitative analysis; rather, teachers and students concentrated on getting the 'right' answers. Thus most upper secondary students only had an instrumental understanding (Skemp, 1976) of qualitative analysis, and the results from the administration of the QADI showed this very clearly. The other consideration is that the extent to which guessing answers and not selecting answers (leaving blanks) affected the test statistics could not be accurately determined.

Generalisation of the findings to all secondary chemistry students in Singapore taking the O-level pure chemistry also must be considered with caution because of the selected number of concepts and propositional knowledge statements tested, the limited size of the sample (915 students), the number of schools involved (11), and the number of teachers teaching the students in the sample.

SUMMARY

The discussion of the results from the administration of the QADI to Grade 10 students answered Research Question 5, which is concerned with the extent of secondary chemistry students' understanding and alternative conceptions of the concepts and propositions related to qualitative analysis. It was evident from the results that many Grade 10 students in the sample did not understand the concepts and propositions tested by the QADI.

The alternative conceptions identified were grouped under the areas of 'Displacement', 'Redox', 'Dissolution', 'Addition of acid' and 'Heating'. These alternative conceptions provided information on the Grade 10 students' lack of understanding of the concepts in qualitative analysis, and the incorrect associations made by the students between the various concepts in their attempts to understand the topic. Limitations of the results obtained from the administration of the QADI instrument also were discussed.

The QADI also was administered to junior college students, chemistry undergraduates and graduate trainee-teachers, and their understanding and alternative conceptions of the concepts and propositions related to qualitative analysis are discussed in the next chapter. Recommendations to help students learn qualitative analysis more effectively is discussed in Chapter 9, where the development of a teaching package on qualitative analysis is elaborated.

CHAPTER EIGHT

A CROSS-AGE STUDY OF CHEMISTRY STUDENTS' UNDERSTANDING OF QUALITATIVE ANALYSIS

INTRODUCTION

The focus of this chapter is on Research Question 6 which seeks to determine the extent of junior college (Grade 11 and 12) students', undergraduates' and graduate trainee-teachers' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as measured by the QADI compared to the Grade 10 students. This comparison was conducted to examine the retention of the alternative conceptions on qualitative analysis over time and to determine if and when the alternative conceptions disappear (Birk & Kurtz, 1999). Cross-age studies are subjected to the error of comparing nonequivalent populations, but are more easily accomplished and have been used in previous studies on student understanding of science concepts (Abraham et al., 1994; Birk & Kurtz, 1999).

ADMINISTRATION OF THE DIAGNOSTIC INSTRUMENT

The QADI was administered in October 1999 to 360 junior college students (16 to 20 years old) in three junior colleges, and 38 undergraduates and 56 graduate trainee-teachers (July 2000 intake) from one university. Table 8.1 describes the distribution of the junior college students, undergraduates and trainee-teachers. Students in the junior college were mainly 17 to 18 years old while the ages of the undergraduates in the four different years of the Bachelor of Science (BSc) programme in the National Institute of Education (NIE) ranged between 19 to 26 years. The ages of the trainee-teachers in the Postgraduate Diploma in Education (PGDE) programme in the NIE ranged between 22 years to late thirties.

Table 8.1: Distribution of subjects to whom the QADI was administered

Level	Female	Male	Total
JC1	46	44	90
JC2	125	128	253
U1	5	4	9
U2	6	0	6
U3	8	2	10
U4	11	1	12
TT	32	23	55
Not stated			19

Note: JC1 denotes the first year of junior college where the average age of students is 17.
JC2 denotes the second year of junior college where the average age of students is 18.
U 1, 2, 3 and 4 denotes the first, second, third and fourth years of the undergraduate programme respectively.
TT denotes trainee-teachers.

RESULTS AND DISCUSSION

The results from the various groups of subjects in the cross-age study were subjected to similar treatment as in Chapter 7. The answer sheets of the students were optically scanned and SPSS version 9 (SPSS, 1999) was used to analyse the results. A student's answer to an item was considered correct if the student selected both the content and reason options correctly.

Test statistics

Test statistics are given in Table 8.2, where the first and second year junior college students were treated as one group, and the undergraduates of the four year levels were also treated as one group. The distribution of the scores of each group is given in Figure 8.1.

A one-way analysis of variance (ANOVA) was carried out on the mean total score to determine the effect of educational level on the scores, and the results (Table 8.3) show that the mean total scores across educational levels are statistically significantly different (p<.001). A post hoc pairwise multiple comparisons analysis (Tamhane) was conducted (Table 8.4) to determine the mean total scores of which educational levels differ significantly.

Table 8.2: Descriptive statistics for the four educational level groups to whom the QADI was administered

	Sec 4	JC	U	TT
No. of cases	915	360	38	56
No. of items	19	19	19	19
Alpha Reliability	.68	.72	.55	.79
Mean	5.76	8.14	6.42	9.18
Standard Deviation	3.28	3.69	2.75	4.15
Median	5.00	8.00	6.00	9.00
Mode	5	9	6	11
Minimum	0	1	1	2
Maximum	18	18	12	19

Note: Sec 4 refers to the group of Grade 10 students

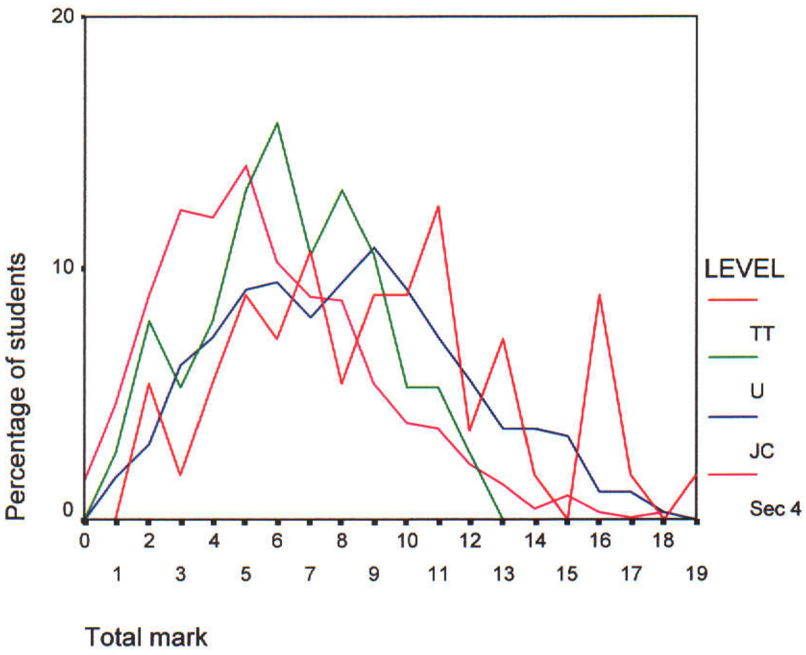

Figure 8.1: Distribution of scores of the four educational levels of students

Table 8.3: Comparison of the different educational level groups for mean scores on the QADI using an analysis of variance

	Sum of Squares	df	Mean Square	F value	p value
Between Groups	1861.76	3	620.587	53.118	<.001
Within Groups	15947.54	1365	11.683		
Total	17809.30	1368			

Table 8.4: Post hoc pairwise multiple comparisons (Tamhane) on mean scores on the QADI for the four educational level groups

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	p value
TT	U	2.76*	.72	.001
	JC	1.04	.49	.399
	Sec 4	3.41*	.47	.000
U	TT	-2.76*	.72	.001
	JC	-1.72*	.58	.005
	Sec 4	.66	.57	.647
JC	TT	-1.04	.49	.399
	U	1.72*	.58	.005
	Sec4	2.37*	.21	.000
Sec 4	TT	-3.41*	.47	.000
	U	-.66	.57	.647
	JC	-2.37*	.21	.000

Note: * The mean difference between the two groups is significant at the .05 level.

The important results from Table 8.4 were that there was no statistically significant difference in mean total scores between the junior college students and the trainee-teachers, and that the undergraduates' mean total score was statistically significantly lower than that of the junior college students and trainee-teachers, but not significantly different from the secondary students. Consequently, based on these results, it was not possible to conclude that understanding of basic qualitative analysis concepts as measured by the QADI increases with educational level unless the results of the undergraduates were considered an aberration. The graduate trainee-teachers would have a minimum of seven years of chemical education, the undergraduates between five to eight years, the junior college students between three to four years, and two years for the Grade 10 students. Thus, based on the number of years of chemical education, this author expected that the results of the undergraduates and trainee-teachers would be similar but better than that of the junior college students, and that the results of the junior college students would be better than that of the secondary students (TT~U > JC > Sec 4 (Grade 10)). Possible reasons for the poorer performance of the undergraduates as compared to the junior college students could be the small sample size (n=38) and nature of undergraduate group. All the undergraduates were students of one of the two Singapore universities offering tertiary chemistry, while the trainee-teachers were graduates of the other Singapore university or of universities abroad, so this could have important implications on the study. In addition, the majority of the undergraduates, though taking chemistry at tertiary level, were most likely to be teaching at the primary level, so they might not have been serious in doing the test or putting much thought into it. The standard deviation of the scores of the undergraduates was smaller than those of the junior college students and trainee-teachers, and the undergraduates' scores were distributed mainly at the middle to lower end of the scale. This gave the undergraduate group a lower mean compared to the junior college and trainee-teacher groups which had wider range of scores and more high scorers.

In the analysis of alternative conceptions in later sections of this chapter, it could be seen that the undergraduates did not perform as badly as their mean total score seemed to indicate. The undergraduates' attitude during the test could also have influenced the results, as well as, their understanding and knowledge of basic qualitative analysis. The coefficient alpha value for the undergraduates was the lowest among the four groups. It seemed logical to assume that the greater the exposure to chemical education, the lesser the likelihood of guessing and leaving any question or part of a question unanswered. However, the low coefficient alpha value could indicate that the many of the undergraduates in the sample did not take the test seriously and/or resorted to guessing when answering the questions.

If the performance of the undergraduates was considered as anomalous, the result that there was no statistically significant difference between the performance of the junior college students and trainee-teachers, and that the junior college students performed significantly better than the Grade 10 students could indicate that understanding of basic qualitative analysis did not require more than junior college (A-level) chemistry; whether junior college students understood the chemistry taught is another matter, as seen by their low mean score of 43% (8.14/19). In junior college, students study more inorganic chemistry as compared to secondary students, and learn in greater details the reactions of transition metals with ligands to form complexes. This should be sufficient for students to understand the basic qualitative analysis concepts assessed by the QADI, and the results of the junior college students compared to those of the secondary students and trainee-teachers seemed to support this hypothesis.

Table 8.5 gives the probability of various levels of subjects correctly answering only the content part of each item, only the reason part, and both the content and reason parts of each item. The finding that subjects obtained the content and the reason parts correct much less frequently than the content part alone is consistent with other studies (Peterson et al., 1989; Voska & Heikkinen, 2000). The extent that the student's correct content answer was associated with the correctness of the chosen reason, and vice versa, was determined using conditional probability (Voska & Heikkinen, 2000), and is also illustrated in Table 8.5. As an example, for Item 1, the probability that a junior college student selected the correct content option regardless of whether the correct reason was chosen was p = .81. As expected, for junior college students who chose the correct reason for the item, the probability of a correct answer increased, p = .95. Furthermore, for students providing incorrect reason on the item, the probability of choosing the correct content option decreased, p = .48. As Voska and Heikkinen pointed out, these relative probability showed that students who possessed correct conceptions were more likely to choose the correct content option and those who did not were more likely to choose the incorrect content option.

Table 8.5: Probability of subjects' mean content answers with the reasons

	Sec 4	JC	U	TT
Item 1				
P(C)	.62	.81	.63	.70
P(R)	.45	.71	.53	.73
P(C∩R)	.41	.68	.47	.64
P(C/R)	.91	.95	.90	.88
P(C/R')	.38	.48	.33	.20
P(R/C)	.66	.83	.75	.92
P(R'/C')	.90	.81	.86	.71
Item 2				
P(C)	.23	.32	.40	.50
P(R)	.45	.69	.74	.64
P(C∩R)	.19	.30	.37	.46
P(C/R)	.43	.43	.50	.72
P(C/R')	.07	.06	.10	.10
P(R/C)	.84	.94	.93	.93
P(R'/C')	.67	.43	.39	.64
Item 3				
P(C)	.40	.74	.66	.63
P(R)	.19	.49	.47	.54
P(C∩R)	.17	.46	.40	.46
P(C/R)	.89	.95	.83	.87
P(C/R')	.28	.55	.50	.35
P(R/C)	.42	.62	.60	.74
P(R'/C')	.96	.90	.77	.81
Item 4				
P(C)	.33	.43	.47	.50
P(R)	.52	.57	.63	.66
P(C∩R)	.22	.27	.29	.34
P(C/R)	.42	.47	.46	.51
P(C/R')	.24	.37	.50	.47
P(R/C)	.66	.63	.61	.68
P(R'/C')	.55	.48	.35	.36

Note: P(C) is the probability of a subject selecting the correct content option.
P(R) is the probability of a subject selecting the correct reason.
P(C∩R) is the probability of a subject selecting the correct content option and reason.
P(C/R) is the probability of a subject selecting the correct content option given that he/she chosen the correct reason in that item.
P(C/R') is the probability of a subject selecting the correct content option given that he/she chosen an incorrect reason in that item.
P(R/C) is the probability of a subject selecting the correct reason option given that he/she chosen the correct content option in that item.
P(R'/C') is the probability of a subject selecting an incorrect reason option given that he/she chosen an incorrect content option in that item.

Table 8.5 (continued): Probability of subjects' mean content answers with the reasons

	Sec 4	JC	U	TT
Item 5				
$P(C)$	.83	.92	.87	.93
$P(R)$	.45	.52	.47	.68
$P(C \cap R)$	.43	.52	.47	.66
$P(C/R)$	.95	.99	1.00	.97
$P(C/R')$	.73	.86	.75	.83
$P(R/C)$	.52	.56	.55	.71
$P(R'/C')$	.87	.92	1.00	.75
Item 6				
$P(C)$	.42	.42	.34	.27
$P(R)$	.37	.46	.39	.21
$P(C \cap R)$	.34	.39	.32	.20
$P(C/R)$	.90	.85	.80	.92
$P(C/R')$	.14	.06	.04	.09
$P(R/C)$	.80	.93	.92	.73
$P(R'/C')$	.94	.89	.88	.98
Item 7				
$P(C)$	.74	.78	.82	.86
$P(R)$	.49	.61	.74	.68
$P(C \cap R)$	.48	.61	.74	.68
$P(C/R)$	.98	1.00	1.00	1.00
$P(C/R')$	.51	.45	.30	.56
$P(R/C)$	.65	.77	.90	.79
$P(R'/C')$	.97	1.00	1.00	1.00
Item 8				
$P(C)$	.26	.45	.26	.38
$P(R)$	.22	.38	.32	.32
$P(C \cap R)$	.20	.37	.26	.32
$P(C/R)$	.89	.98	.83	1.00
$P(C/R')$	.08	.12	.00	.08
$P(R/C)$	.75	.83	1.00	.86
$P(R'/C')$	.97	.98	.93	1.00
Item 9				
$P(C)$	.55	.72	.82	.82
$P(R)$	.29	.51	.68	.59
$P(C \cap R)$	.19	.41	.61	.57
$P(C/R)$	.66	.79	.88	.97
$P(C/R')$	.51	.64	.67	.61
$P(R/C)$	.34	.57	.74	.70
$P(R'/C')$	.78	.63	.57	.90
Item 10				
$P(C)$	.60	.71	.42	.55
$P(R)$	.36	.44	.26	.34
$P(C \cap R)$	.35	.43	.24	.30
$P(C/R)$	.97	.98	.90	.89
$P(C/R')$	.39	.51	.25	.38
$P(R/C)$	.58	.60	.56	.55
$P(R'/C')$	.98	.96	.95	.92

Table 8.5 (continued): Probability of subjects' mean content answers with the reasons

	Sec 4	JC	U	TT
Item 11				
P(C)	.41	.28	.45	.50
P(R)	.27	.22	.26	.38
P(C∩R)	.24	.17	.24	.36
P(C/R)	.90	.77	.90	.95
P(C/R')	.23	.14	.29	.23
P(R/C)	.59	.60	.53	.71
P(R'/C')	.96	.93	.95	.96
Item 12				
P(C)	.67	.75	.61	.71
P(R)	.39	.44	.40	.46
P(C∩R)	.38	.44	.40	.46
P(C/R)	.98	.99	1.00	1.00
P(C/R')	.47	.56	.35	.47
P(R/C)	.57	.58	.65	.65
P(R'/C')	.98	.99	1.00	1.00
Item 13				
P(C)	.58	.76	.66	.77
P(R)	.51	.66	.63	.75
P(C∩R)	.45	.61	.53	.64
P(C/R)	.87	.92	.83	.86
P(C/R')	.28	.43	.36	.50
P(R/C)	.77	.81	.80	.84
P(R'/C')	.84	.80	.69	.54
Item 14				
P(C)	.35	.53	.53	.59
P(R)	.45	.65	.68	.61
P(C∩R)	.29	.48	.53	.46
P(C/R)	.65	.73	.77	.76
P(C/R')	.11	.17	.00	.32
P(R/C)	.82	.89	1.00	.79
P(R'/C')	.76	.63	.67	.65
Item 15				
P(C)	.63	.83	.87	.82
P(R)	.25	.51	.68	.63
P(C∩R)	.23	.50	.66	.61
P(C/R)	.93	.98	.96	.97
P(C/R')	.53	.67	.67	.57
P(R/C)	.37	.60	.76	.74
P(R'/C')	.96	.94	.80	.90
Item 16				
P(C)	.41	.54	.63	.71
P(R)	.38	.47	.47	.57
P(C∩R)	.23	.31	.37	.48
P(C/R)	.60	.66	.78	.84
P(C/R')	.29	.43	.50	.54
P(R/C)	.56	.58	.58	.68
P(R'/C')	.74	.65	.71	.69

Table 8.5 (continued): Probability of subjects' mean content answers with the reasons

	Sec 4	JC	U	TT
Item 17				
P(C)	.29	.33	.26	.32
P(R)	.33	.38	.29	.38
$P(C \cap R)$	.20	.25	.21	.25
P(C/R)	.61	.65	.73	.67
P(C/R')	.14	.13	.07	.11
P(R/C)	.68	.76	.80	.78
P(R'/C')	.82	.80	.89	.82
Item 18				
P(C)	.63	.73	.74	.79
P(R)	.52	.60	.61	.73
$P(C \cap R)$	.48	.56	.58	.73
P(C/R)	.93	.94	.96	1.00
P(C/R')	.32	.41	.40	.20
P(R/C)	.76	.77	.79	.93
P(R'/C')	.90	.86	.90	1.00
Item 19				
P(C)	.65	.66	.71	.86
P(R)	.33	.43	.61	.55
$P(C \cap R)$	.29	.39	.50	.54
P(C/R)	.89	.89	.83	.97
P(C/R')	.53	.47	.53	.72
P(R/C)	.45	.59	.70	.63
P(R'/C')	.90	.86	.64	.88
Average				
P(C)	.51	.62	.59	.64
P(R)	.38	.51	.52	.55
$P(C \cap R)$	.30	.43	.43	.48
P(C/R)	.81	.84	.83	.88
P(C/R')	.33	.39	.35	.39
P(R/C)	.62	.71	.75	.76
P(R'/C')	.86	.81	.79	.82

On closer examination, the probability that a student chose the correct answer given that he/she chose the correct reason was low (about $p = .50$) for Items 2 and 4 for all the four groups, and to a lesser extent (about $p = .70$) for Items 14, 16 and 17. For Items 2, 4, 14 and 16, uncertainty over the definition of 'dissolution' was most probably the cause of the problem, and this was discussed in Chapters 6 and 7. For item 17, to say that dilute nitric(V) acid is added to acidify the reaction mixture so that it will react with any carbonate or sulphate(IV) ion present can be considered as correct, though less acceptable than the actual answer. Thus the analysis of conditional probability is effective in highlighting any anomaly in the items.

The correctness or incorrectness of a student's reason was also found to be associated with the correctness or incorrectness of the student's content option. For example, in Item 1, the probability that a junior college student chose the correct reason given that the student has made the correct content choice P(R/C) is high ($p = .83$), while the probability that a junior college student chose the wrong reason given that he/she made the wrong content option choice P(R'/C') is also high ($p = .81$). Except for Items 2, 4, 14 and 17, P(C/R) was greater than P(R/C) for the items in the test. Getting the content option correct did not mean that a student would chose the correct reason; he/she might have learnt by rote specific chemistry content or processes (Peterson, 1986). However, if a student had the correct conception, he/she was more likely to choose the correct content option, as shown by the higher P(C/R) values. The anomalous results for Items 2, 4, 14 and 17 were most likely due to differences in understanding of 'dissolve' and 'acidify', as mentioned in the previous paragraph.

It can be seen from Table 8.5 that on the average, values of P(C), P(R), $P(C \cap R)$, P(C/R) and P(R/C) were the highest for the trainee-teachers and lowest for the Grade 10 students. This was to be expected as the trainee-teachers had the greatest exposure to chemical education while the Grade 10 students had the least. These results agreed with the results in Tables 8.2 and 8.4 that the trainee-teachers obtained the best scores on the QADI, and that the Grade 10 students had the lowest scores. However, on the average, the junior college, undergraduate and trainee-teacher group had very little differences between them (see Table 8.5). Thus the undergraduate group did not performed as badly as the results in Tables 8.2 and 8.4 would imply.

The percentages (10% or more) of Grade 10 students, junior college students, undergraduates and trainee-teachers selecting response combination for each item in the QADI is shown in Table 8.6.

Table 8.6: The percentage (10% or more) of Grade 10 students / junior college students / undergraduates / trainee-teachers selecting response combination for each item in the QADI

Item	Content option	Reason option				
		(1)	(2)	(3)	(4)	(5)
1	A	~	~	*25/12/26/21*	~	-
	B	~	~	~	**41/68/47/64**	-
	C	~	~	~	~	-
2	A	*29/11/24/20*	*16/11/~/~*	~	26/39/37/18	-
	B	~	~	~	**19/30/37/46**	-
3	A	~	~	~	**17/46/40/46**	*18/26/26/16*
	B	*24/~/~/~*	*11/~/~/~*	*18/11/~/11*	~	~
4	A	~	~	*16/13/~/~*	~	30/30/34/32
	B	~	~	~	~	**22/27/29/34**
5	A	*20/13/21/18*	**43/52/47/66**	~	*17/21/13/~*	-
	B	~	~	~	~	-
	C	~	~	~	~	-
6	A	~	~	*~/~/11/16*	~	*22/22/24/18*
	B	~	**34/39/32/20**	~	~	~
	C	*~/~/~/13*	~	~	~	~
7	A	~	~	*18/15/16/~*	~	~
	B	~	**48/61/74/68**	~	*16/10/~/~*	~
8	A	*41/34/45/38*	13/~/11/~	*15/12/13/14*	~	-
	B	~	~	~	**20/37/26/32**	-
9	A	11/~/~/~	~	~	~	~
	B	*15/~/~/~*	~	**19/41/61/57**	*~/14/~/~*	~
10	A	*23/27/18/25*	~	~	**35/43/24/30**	-
	B	~	~	*27/19/40/36*	~	-
11	A	~	**24/17/24/36**	~	~	*~/~/13/13*
	B	*~/~/~/16*	~	*20/24/21/~*	*25/33/21/23*	
12	A	*26/22/34/25*	~	~		-
	B	~	**38/44/40/46**	~	*20/26/18/14*	-
13	A	~	~/~/11/~	~	*12/~/~/~*	-
	B	~	**45/61/53/64**	~	~	-
	C	*13/~/11/~*	~	~	~	-
14	A	~	*25/11/21/16*	*16/~/~/~*	16/18/16/14	-
	B	~/~/~/11	~	~	**29/48/53/46**	-
15	A	~	19/~/11/~	**23/50/66/61**	*19/25/11/16*	-
	B	*14/~/~/~*	*15/~/~/~*	~	~	-
16	A	*~/~/11/~*	~	*19/13/~/~*	~	15/16/11/~
	B	~	*~/~/11/~*	~	*~/~/11/~*	**23/31/37/48**
17	A	~	*~/~/~/13*	~	*35/38/50/36*	13/13/~/13
	B	~	~	~	~	**20/25/21/25**
18	A	*~/~/11/~*	~	~	*~/10/~/~*	~
	B	~	~	**48/56/58/73**	~	~
19	A	~	~	~	~	*21/22/18/11*
	B	*26/21/11/23*	~	**29/39/50/54**	~	

Note: ~ represents less than 10%
Figures in italics represent alternative conceptions
Figures in bold represent the correct answer

Alternative conceptions

The significant alternative conceptions of the four levels of students in each item in the QADI are shown in Table 8.7. Figures below 10% are not presented as the alternative conceptions are considered significant only if they existed in at least 10% of a given sample (Peterson, 1986).

Table 8.7: Comparison of the significant alternative conceptions among the four educational levels of students

No.	Option	Alternative conception	Percentage of students with the alternative conception			
			Sec 4	JC	U	TT
1	A3	Sodium ion displaces zinc ion because it is more reactive	25	12	26	21
2	A1	Zinc hydroxide dissolves in excess sodium hydroxide because more solvent is added so there is more space for it to dissolve.	29	11	24	20
	A2	Zinc hydroxide dissolves in excess sodium hydroxide because no further reaction is seen except for its disappearance, and no new reagent is added.	16	11	~	~
3	A5	The acid removes the solvent which dissolved the white solid in the first instance.	18	26	26	16
	B1	A different solid is formed because different reagents were used.	24	~	~	~
	B2	A different solid, sodium nitrate(V) is formed from the reaction of the acid and the alkali.	11	~	~	~
	B3	A different solid, zinc nitrate(V) is formed from the reaction of the acid and the zinc compound present.	18	11	~	11
4	A3	Zinc hydroxide dissolves in acid (solvent) because no further reaction is seen except for its disappearance, and no new reagent is added.	16	13	~	~
5	A1	The more reactive ions from Q displace the silver ion to form silver chloride.	20	13	21	18
	A4	The more reactive chloride ions displace the nitrate(V) ions to form silver chloride.	17	21	13	~

Note: ~ denotes that the figure is below 10%, thus insignificant.

Table 8.7 (continued): Comparison of the significant alternative conceptions among the four educational levels of students

No.	Option	Alternative conception	Percentage of students with the alternative conception			
			Sec 4	JC	U	TT
6	A3	Dilute nitric(V) acid is used to acidify the mixture because it is a strong oxidising agent.	~	~	11	16
	A5	Acid is added to acidify the mixture in order that the reaction can proceed properly.	22	22	24	18
	C1	Dilute nitric(V) acid is used to dissolve the white solid because all nitrate(V) salts are soluble.	~	~	~	13
7	A3	Hydrochloric acid can be added following the addition of silver nitrate(V) as it has similar properties and reactions as nitric(V) acid.	18	15	16	~
	B4	Hydrochloric acid cannot be added following the addition of silver nitrate(V) as it will not react with the silver chloride.	16	10	~	~
8	A1	Ammonium chloride is formed when aqueous ammonia is added to silver chloride because ammonium chloride is a soluble salt.	41	34	45	38
	A3	Ammonium chloride is formed when aqueous ammonia is added to silver chloride because the more reactive ammonium ion displaces the silver ion.	15	12	13	14
9	B1	Nitric(V) acid decomposes the ammonium chloride to liberate chloride ions which then react with the silver ions to form a white precipitate.	15	~	~	~
	B4	Nitric(V) acid removes the ammonium ions so that silver ions can react with hydroxide ions.	~	14	~	~
10	A1	Test for oxygen has to be carried out when a substance is heated because all gases have to be tested.	23	27	18	25
	B3	Test for oxygen need not be carried out when a substance is heated because oxygen will not be liberated during heating, instead it will be used up.	27	19	40	36

Table 8.7 (continued): Comparison of the significant alternative conceptions among the four educational levels of students

No.	Option	Alternative conception	Percentage of students with the alternative conception			
			Sec 4	JC	U	TT
11	A5	Carbonate ions will only react with the acid and not the barium nitrate(V).	~	~	13	13
	B1	Insoluble carbonate will not react with dilute nitric(V) acid.	~	~	~	16
	B3	It is not possible to detect the presence of carbonate ions by the addition of barium nitrate(V) followed by nitric(V) acid because the procedure is strictly a test for the presence of sulphate(VI) ions.	20	24	21	~
	B4	It is not possible to detect the presence of carbonate ions by the addition of barium nitrate(V) followed by nitric(V) acid because the acid must be added directly to the unknown to test for the presence of carbonate ions.	25	33	21	23
12	A1	Sulphuric(VI) acid can be added following the addition of barium nitrate(V) because all acids have similar properties and reactions.	26	22	34	25
	B4	Sulphuric(VI) acid cannot be used because the addition of barium nitrate(V) has already invalidated the test for carbonates.	20	26	18	14
13	A4	Ammonium ion displaces copper(II) ions because it is more reactive.	12	~	~	~
	C1	A redox reaction occurs when aqueous ammonia is added to copper(II) sulphate(VI) because copper(II) sulphate(VI) loses oxygen in the forming copper(II) hydroxide chloride and aqueous ammonia gains oxygen in forming ammonium sulphate(VI).	13	~	11	~
14	A2	Copper(II) hydroxide dissolves in excess aqueous ammonia because more solvent is added so there is more volume for it to dissolve.	25	11	21	16
	A3	Copper(II) hydroxide dissolves in excess aqueous ammonia because no further reaction is seen except for its disappearance, and no new reagent is added.	16	~	~	~
	B1	Ammonium ions displaces the cation from the light blue solid.	~	~	~	11

Table 8.7 (continued): Comparison of the significant alternative conceptions among the four educational levels of students

No.	Option	Alternative conception	Percentage of students with the alternative conception			
			Sec 4	JC	U	TT
15	A4	The acid removes the solvent which dissolved the blue solid in the first instance.	19	25	11	16
	B1	A different solid is formed because different reagents were used.	14	~	~	~
	B2	A different solid, copper(II) sulphate(VI) is formed from the reaction of the acid and the soluble copper(II) compound.	15	~	~	~
16	A1	Adding more solvent (dilute sulphuric(VI)) acid causes the light blue solid to dissolve.	~	~	11	~
	A3	Copper(II) hydroxide dissolves in acid (solvent) because no further reaction is seen except for its disappearance, and no new reagent is added.	19	13	~	~
	B2	The acid reacts with the blue solid because the more reactive hydrogen ion from the acid added displaces the cation in the light blue solid.	~	~	11	~
	B4	The hydrogen ions in the acid reduces the light blue solid.	~	~	11	~
17	A2	Dilute nitric(V) acid is used to acidify the mixture because it is a strong oxidising agent.	~	~	~	13
	A4	Acid is added to acidify the mixture so that the unknown can react properly with lead(II) nitrate(V).	35	38	50	36
18	A	Lead(II) iodide is formed by a displacement reaction between R and lead(II) nitrate(V).	33	25	26	21
	A1	Lead(II) ion displaces the unknown cation in R because it is more reactive.	~	~	11	~
	A4	The iodide ion displaces the nitrate(V) ions because it is more reactive.	~	10	~	~
19	A5	Hydrogen and carbon dioxide must be tested when ionic compounds are heated because compounds containing carbonate, hydrogen or hydrogen ions will liberate carbon dioxide or hydrogen on heating.	21	22	18	11
	B1	Hydrogen and carbon dioxide need not be tested when ionic compounds are heated because ionic compounds have strong bonds and do not decompose on heating.	26	21	11	23

As discussed in Chapters 6 and 7, as well as in the section on conditional probability earlier in this chapter, options A4, A5, A4, A5 and A5 in Questions 2, 4, 14, 16, and 17 respectively, were not considered as alternative conceptions. Option A2, A1, A2 of items 8, 9 and 15 respectively, were considered as non-conceptions as they made no sense or the reason chosen did not agree with the content answer. In item 13 (A4), 11% of the undergraduates believed that a displacement reaction occurred when aqueous ammonia was added to aqueous copper(II) sulphate(VI), giving the reason that copper(II) ions combine with the hydroxide ions. This author found it difficult to pinpoint the alternative conception, whether the undergraduates equated 'displace' with 'replace', or whether they thought that a displacement reaction had occurred prior the combination of the ions. Thus, he decided not to consider this option an alternative conception.

This author's supervisor commented that there were many alternative conceptions in Table 8.9, for example, options B1 and B2 in Item 3, B1 and B4 in Item 9, and B1 and B2 in Item 15, seemed only to occur with one level of students, in most cases, the secondary students. He questioned whether these were really alternative conceptions in that could they be addressed by additional learning. This was also brought up by Birk and Kurtz (1999) who questioned whether the lack of conceptual understanding shown by beginning chemistry students indicated that they had alternative conceptions or that it was because they had no concept at all. Items 3, 9 and 15 involved the reversal of complex salt formation. As discussed in Chapters 6 and 7, it was very likely that the secondary students had no idea of the reactions involved because few teachers would discuss them. The low $P(C \cap R)$ values for the three items (.17 to .23) compared to that of the more advanced students (between .40 to .66) supported this author's supervisor's belief that the secondary students' lack of understanding of the reactions involved in Items 3, 9 and 15 could be addressed by additional learning. Another issue appeared – what did it mean if the alternative conception was insignificant among the secondary students but was prominent among the more advanced chemistry students, for example, option A3 and C1 in Item 6, and A1, B2, and B4 in Item 16? This would be brought up in the discussion of the results in Table 8.8.

The alternative conceptions identified from the results of the administration of the QADI to the Grade 10 and junior college students, undergraduates and trainee-teachers were grouped under the same headings of 'Displacement', 'Redox', 'Addition of acid', and 'Heating' in Table 8.8. As with the cross-age study by Abraham et al. (1994), there were no predictable patterns in the frequency of significant alternative conceptions with respect to educational levels in this study. There were clear decreases in alternative conceptions with increasing educational levels, for example, a higher percentage of advanced students know that acids did not react with silver chloride or ammonium chloride (3 and 7b respectively under 'Addition of acid' in Table 8.8) compared to the Grade 10 students. Another example of this trend was with the alternative conception that a precipitate was considered to have dissolved in excess reagent if no further reaction was seen and no new reagent was added (1b under 'Dissolution'). The increasing $P(C \cap R)$ values (albeit low values) for Items 2, 4, 14 and 16 (Table 8.5) for the various education levels of students indicated that with increasing exposure to chemical instruction, more students were likely to know that complex salts were formed in Items 2 and 14 and that the acids reacted with the insoluble bases in Items 4 and 16. The decrease in the number of students selecting the options indicating the alternative conception on dissolution could be attributed to more students knowing the correct answer for the questions with increasing chemical education, or less students having the alternative conception with increasing chemical education, or both. Thus, it could not be determined with certainty why less students had this alternative conception on dissolution with increasing chemical education unless they answered a question based on dissolution without the complex salt formation context.

There were also unexpected increases in alternative conceptions with increasing educational levels, for example, that dilute nitric(V) acid was added to acidify mixtures because it is a strong oxidising agent (4 in 'Addition of acid').

Table 8.8: Alternative conceptions of the four educational levels of students

Alternative conception	Choice combination	Percentage of students with the alternative conception			
		Sec 4	JC	U	TT
Displacement					
1. A more reactive ion displaces a less reactive ion in a double decomposition/ precipitation mixture.	Q1 (A3)	25	12	26	21
	Q5 (A1,A4)	37	35	34	27
	Q13 (A3,A4)	15	11	13	~
	Q18 (A1,A2, A4&A5)	29	21	24	21
2. A more reactive ion displaces a less reactive ion in complex salt formation.	Q8 (A3)	15	12	13	14
	Q14 (B1)	~	~	~	11
3. The more reactive hydrogen ion in an acid displaces the less reactive cation in a base in an acid-base reaction.	Q16 (B2)	~	~	11	~
Redox					
1. A redox reaction occurs in a double decomposition reaction.	Q13 (C1)	13	~	11	~
2. The hydrogen ion in an acid is a reducing agent.	Q16 (B4)	~	~	11	~
Dissolution					
1. A precipitate is formed when a reagent is added to an unknown solution. On further addition of excess reagent, the precipitate disappears.					
a. More excess reagent means more space/volume for the precipitate to dissolve.	Q2 (A1)	29	11	24	20
	Q14 (A2)	25	11	21	16
	Q16 (A1)	~	~	11	~
b. The precipitate is considered to have dissolved in the excess reagent as no further reaction is seen and no new reagent is added.	Q2 (A2)	16	11	~	~
	Q4 (A3)	16	13	~	~
	Q14 (A3)	16	~	~	~
	Q16 (A3)	19	13	~	~
2. Ammonium chloride is formed when aqueous ammonia is added to silver chloride because it is a soluble salt.	Q8 (A1)	41	34	45	38
3. When acid is added to a mixture containing excess alkali and a complex salt it removes the solvent (alkali) for the precipitate.	Q3 (A5)	18	26	26	16
	Q15 (A4)	19	25	11	16

Note: ~ represent a figure which is less than 10%

Table 8.8(continued): Alternative conceptions of the four educational levels of students

Alternative conception	Choice combination	Percentage of students with the alternative conception			
		Sec 4	JC	U	TT
Addition of acid					
1. Acid is needed to acidify the mixture so that reaction can proceed properly.	Q6 (A5) Q17 (A4)	22 35	22 38	24 50	18 36
2. Any acid can be used because acids have the same properties and reactions.	Q7 (A3) Q12 (A1)	18 26	15 22	16 34	~ 25
3. Hydrochloric acid cannot be added because it will not react with the silver chloride precipitate.	Q7 (B4)	16	10	~	~
4. Dilute nitric(V) acid is added to acidify mixtures because it is a strong oxidising agent.	Q6 (A3) Q17 (A2)	~ ~	~ ~	11 ~	16 13
5. Aqueous carbonate ions will only react with acid and not barium nitrate(V).	Q11 (A5)	~	~	13	13
6. Carbonate ions cannot be identified if acid is added after the addition of barium nitrate(V).					
a. The acid must be added directly to the unknown.	Q11 (B4) Q12 (B4)	25 20	33 26	21 18	23 14
b. The procedure is strictly a test for sulphate(VI).	Q11 (B3)	20	24	21	~
c. Insoluble carbonates will not react with acid.	Q11 (B1)	~	~	~	16
7. When acid is added to a mixture of a complex salt and excess alkali,					
a. a different solid from the original precipitate is formed.	Q3 (B1,B2 & B3) Q15 (B1& B2)	52 29	21 12	19 11	25 14
b. the acid decomposes the ammonium chloride formed to liberate the chloride ions which react with the silver ions present to reform the precipitate.	Q9 (B1)	15	~	~	~
c. the acid reacts with the ammonium ion.	Q9 (B4)	~	14	~	~
8. Nitric(V) acid is added after the addition of silver nitrate(V) to dissolve the precipitate formed as all nitrate(V) is soluble.	Q6 (C1)	~	~	~	13

Table 8.8(continued): Alternative conceptions of the four educational levels of students

Alternative conception	Choice combination	Percentage of students with the alternative conception Sec 4	JC	U	TT
Heating					
1. All gases have to be tested when a substance is heated.	Q10 (A1)	23	27	18	25
2. Oxygen cannot be produced when a substance is heated because it is used up during heating.	Q10 (B3)	27	19	40	36
3. Compounds containing hydrogen and hydroxide ions will liberate hydrogen on heating.	Q19 (A5)	21	22	18	11
4. Ionic compounds have strong bonds and do not decompose on heating.	Q19 (B1)	26	21	11	23

The more advanced students could have forgotten some of their qualitative analysis knowledge, or the knowledge that they learned at higher levels could have led them astray. For example, they could have learned more about the oxidising properties of nitric(V) acid and this could have influenced their choices in Items 6 and 17. The undergraduates and trainee-teachers also had problems with reactions of carbonates with barium nitrate(V) and acid (5 and 6c in 'Addition of acid') which few junior college and Grade 10 students had. In this case, it seemed more likely that the undergraduates and trainee-teachers had forgotten their facts or they could have learned qualitative analysis by rote in their earlier years and paid no further attention to it. One undergraduate remarked:

> I remembered that I wasn't taught in secondary school what really happened during the experiments. I understood my qualitative analysis a bit more in my junior college days but now I can't really remember my facts, so I don't think all my answers are correct. I can't really work out the answers.

Thus, there was no predictable trend in alternative conceptions with increasing educational level, and many alternative conceptions still existed despite exposure to further chemical education. For example, the 'reactive ion displacing a less reactive ion' alternative conception (A3 of Item 1, A1 and A4 of Item 5, A3 and A4 of Item 13, and A1, A2, A4 and A5 of Item 18) was still prevalent among the advanced chemistry students. Many of the advanced chemistry students also did not seem to understand complex salt formation and reaction as showed by the three alternative conceptions on dissolution and one on the addition of acid (7a, Table 8.8) still held by them. The purpose of adding acid after the introduction of aqueous barium or silver nitrate(V) and the reactions involved (Item 6 and 17) also were not understood by many of the advanced chemistry students. Their responses indicating a belief that acid was needed for the reaction to 'proceed properly' (A5 of Item 6 and A4 of Item 17) or that acid must be added directly to the unknown to test for carbonates (B4 of Items 11 and 12) could indicate that they had resorted to rote learning. Procedures involving heating caused as many problems for the junior college students, undergraduates and trainee-teachers as they did for the Grade 10 students. The four prevalent alternative conceptions on heating in Table 8.10 showed that many advanced students (11%-40%) still had little understanding of the reactions involved in heating processes.

The prevalence of alternative conceptions among the advanced chemistry students showed that there were common conceptions among the different educational level subjects, and that the alternative conceptions were retained (Abraham et al., 1994; Birk & Kurtz, 1999; Osborne & Cosgrove, 1983; Palmer, 1999; Posner et al., 1982; Watson et al., 1997). These findings could indicate that many of the advanced chemistry students still had an instrumental understanding of the procedures in qualitative analysis, or were unable to apply their additional knowledge compared to the Grade 10 students, to the understanding of qualitative analysis procedures and reactions as measured by the QADI. Alternative explanations could include that the advanced chemistry students had forgotten some of their basic chemistry knowledge, that their learning of advanced chemistry interfered with their choices in the QADI, or that little effort was made to think about the procedures and reactions during the test.

Consistency of alternative conceptions

A statistical analysis was carried out to determine the consistency of the alternative conceptions (Birk & Kurtz, 1999). For example, the alternative conception ‘a more reactive ion displaces a less reactive ion in a double decomposition reaction/precipitation mixture’, under the heading ‘Displacement’ in Table 8.8, had four questions with content-reason pairs pertaining to it. The extent to which students believed each alternative conception was determined by calculating percentages based on the number of times each student picked a content-reason combination that supported that alternative conception. Thus only alternative conceptions which appeared in more than one question were analysed. This ruled out all of the alternative conceptions under the categories ‘Redox’ and ‘Heating’, and a few in the other categories. The percentage of subjects who selected content-reason pairs supporting each alternative conception 75% of the time or more (Birk & Kurtz, 1999) is shown in Table 8.9.

It can be seen from Table 8.9 that with one exception, only a small extent (0-18%) of the students in the four groups consistently hold an alternative conception as compared to the results in Table 8.8 which shows responses for individual items. For example, only 0% to 2% of the students in the four groups consistently had the alternative conception that a more reactive ion displaces a less reactive one in complex salt formation. In general, the secondary students had a higher percentage of consistent alternative conceptions compared to the more advanced chemistry students. The consistent alternative conception most widely held (23%) by the Grade 10 students was that a new solid was formed when an acid was added to a mixture of a complex salt and excess alkali. The students’ lack of knowledge of complex salt formation and reaction could account for this result, and as discussed in an earlier section in this chapter, this could be considered as a non-conception rather than alternative conception as it is likely to be alleviated by additional learning. However it should be noted that between 5% to 13% of the advanced chemistry students also consistently held the same alternative conception, indicating than additional learning does not

Table 8.9: Consistent alternative conceptions of the four educational levels of students

Alternative conception	Choice combination	Percentage of students selecting pairs supporting alternative conception >75% of the time			
		Sec 4	JC	U	TT
Displacement					
1. A more reactive ion displaces a less reactive ion in a double decomposition/precipitation mixture.	Q1 (A3) Q5 (A1,A4) Q13 (A3,A4) Q18 (A1,A2, A4&A5)	11	5	16	5
2. A more reactive ion displaces a less reactive ion in complex salt formation.	Q8 (A3) Q14 (B1)	1	1	0	2
Dissolution					
1. A precipitate is formed when a reagent is added to an unknown solution. On further addition of excess reagent, the precipitate disappears.					
a. More excess reagent means more space/volume for the precipitate to dissolve.	Q2 (A1) Q14 (A2) Q16 (A1)	4	1	5	4
b. The precipitate is considered to have dissolved in the excess reagent as no further reaction is seen and no new reagent is added.	Q2 (A2) Q4 (A3) Q14 (A3) Q16 (A3)	8	5	3	4
2. When acid is added to a mixture containing excess alkali and a complex salt it removes the solvent (alkali) for the precipitate.	Q3 (A5) Q15 (A4)	9	15	8	11
Addition of acid					
1. Acid is needed to acidify the mixture so that reaction can proceed properly.	Q6 (A5) Q17 (A4)	14	14	18	13
2. Any acid can be used because acids have the same properties and reactions.	Q7 (A3) Q12 (A1)	8	7	13	4
3. Dilute nitric(V) acid is added to acidify mixtures because it is a strong oxidising agent.	Q6 (A3) Q17 (A2)	3	1	5	11
4. Carbonate ions cannot be identified if acid is added after the addition of barium nitrate(V) as the acid must be added directly to the unknown.	Q11 (B4) Q12 (B4)	10	14	5	7
5. When acid is added to a mixture of a complex salt and excess alkali, a different solid from the original precipitate is formed.	Q3 (B1,B2 & B3) Q15 (B1& B2)	23	9	5	13

totally remove this alternative conception. The alternative conception that this author believed stood out above the others in Table 8.9 was that acid needed to acidify a mixture so that reaction could proceed properly. Between 13% to 18% of the students in all four groups consistently held this alternative conception. This showed that, even with additional chemistry learning, a number of students did not understand the common procedure of adding dilute acid when silver or lead(II) solutions were used to identify anions. This might indicate the students carried out qualitative analysis mechanically, without understanding, and supports a good argument for the use of the teaching package on qualitative analysis developed by this author (discussed in Chapter 9).

The lack of consistency of alternative conceptions held by the students could point to students having more than one conception for a particular concept and "different conceptions can be brought into play in response to different problem contexts" (Palmer, 1999, p. 639). Palmer proposes that his "personal propositions" (p. 649) model provides an explanation for students' inconsistencies in science and the prevalence of such inconsistencies even right through tertiary level. He believes that the student has a collection of scientific concepts and alternative conceptions and that the student's knowledge structures or personal propositions guide the student on which to use in any given situation. He contends that there is no inconsistency from the viewpoint of the student because the responses will be "a true reflection of the 'if...then' nature of their understanding" (p. 650). Taber (1999b) also found in his study using a diagnostic instrument on ionisation energy that "apparently related items do not always receive a consistent level of support from the students" (p. 103). He agrees with Palmer that students "may have several alternative explanatory schemes that can be applied to a particular context" (p. 103). The study by Voska and Heikkinen (2000) on student conceptions in chemical equilibrium also revealed that only a small proportion of students showed consistency in their thinking. Finally, the lack of consistency could also be due to students not having adequate understanding of the topic and resorting to guessing.

There was also no predictable pattern in the consistency of the alternative conceptions with respect to increasing educational level and this could indicate that the alternative conceptions were retained even with increasing chemical education. The findings of this study are supported by the results of a similar cross-age study by Birk and Kurtz (1999), using the two-tier diagnostic instrument developed by Peterson and Treagust (1989), on the effect of experience on the retention and elimination of alternative conceptions on molecular structure and bonding.

Limitations

The sampling and the sample sizes of the various groups, especially the trainee-teacher and undergraduate groups, might have affected this cross-age study. This might be particularly so with the undergraduate group, giving rise to the 'unexpected or anomalous' data. Two important factors could be students forgetting what they had learned in qualitative analysis and the attitude of the students towards the test. A number of trainee-teachers and undergraduates could have forgotten their qualitative analysis concepts as they could have last encountered it in A-level chemistry many years ago. Qualitative analysis is included in the syllabi of the O-level and A-level chemistry, so the Grade 10 and junior college students had incentive to be serious when doing the QADI. The trainee-teachers also incentive to be serious about the test as they would be teaching qualitative analysis in secondary schools or junior colleges when they finish their one-year PGDE course. However, the majority of the undergraduates, though taking chemistry at the tertiary level, were most likely to be teaching at the primary school level, so they might not have been serious in doing the test or put much thought into it. Another factor, which could have important implications on the study, could be that all the undergraduates were students of one of the two Singapore universities offering tertiary chemistry while the trainee-teachers were graduates of the other Singapore university or of universities abroad.

SUMMARY

The cross-age study described in this chapter responded to Research Question 6 which sought to determine the extent of junior college students', undergraduates' and graduate trainee-teachers' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as compared to the Grade 10 students. In general, all levels of students did not perform well on the QADI, with the trainee-teacher group having the highest mean score of only 48% (9.18/19) and the Grade 10 group having the lowest mean score of 30% (5.76/19). The ANOVA results showed that there was a statistically significant difference in total overall mean scores across educational levels. However, a post-hoc multiple comparison analysis showed that there was no statistically significant difference between the junior college and trainee-teacher groups and that the junior college students performed significantly better than the undergraduates. This could imply that exposure to A-level chemistry was sufficient/necessary for the understanding of basic qualitative analysis concepts as measured by the QADI, and that sampling problems of the undergraduates might have implications on the study. The cross-age study also showed that many of the alternative conceptions were prevalent among the different groups and that the alternative conceptions were "robust enough to have survived schooling" (Palmer, 1999, p. 648). However, these alternative conceptions were consistently held by only a small number of students (0-23%) across all contexts examined in the QADI, indicating that the subjects might have more than one conception for a particular concept or had little understanding of qualitative analysis and resorted to guesswork.

Conditional probabilities showed the strong association between the content option and reason. The students were more likely to select the correct content option when they provided the correct reason than when they provided the incorrect reason ($P(C/R) > P(C/R')$). Getting the content option correct also did not mean that a subject was likely to choose the correct reason but if a subject made the correct reason choice, he/she was more likely to select the correct option choice (P(C/R) > P(R/C)). This suggested that the subject's reasoning was more indicative of the correctness or incorrectness of subject's understanding than was the content option that he/she selected (Voska & Heikkinen, 2000).

The next chapter describes a teaching package on qualitative analysis which this author designed, the trial of the teaching package on two classes of Grade 9 students in 1999, and the results obtained when the QADI was administered to the students when they were in Grade 10 in 2000.

CHAPTER NINE

DEVELOPMENT AND EVALUATION OF THE QUALITATIVE ANALYSIS TEACHING PACKAGE

INTRODUCTION

The focus of this chapter is on Research Question 7 which seeks to develop a teaching package on qualitative analysis, and on Research Question 8 which seeks to determine the impact of the teaching package on students' understanding of the concepts and propositional knowledge related to qualitative analysis as determined through the administration of the Qualitative Analysis Diagnostic Instrument (QADI). The development of the Qualitative Analysis Teaching Package (QATP), its trial in November 1999 in one secondary school, the observers' comments, and the results of the administration of the QADI, in March 2000, to the students involved in the trial are described in this chapter.

It should be made clear at this point that the trial of the qualitative analysis teaching package was not intended to do more that to indicate its feasibility. Thus, within the constraints of this study, the requirement was to demonstrate whether it was possible to increase students' understanding of the conceptions and propositional knowledge related to qualitative analysis using the designed teaching package. Extensive trials of the teaching package focussing on its effects on students' understanding and performance in qualitative analysis practical sessions, students' attitude towards the practical sessions, the acquisition of process skills such as manipulative, observational and inferential skills, and the acquisition of metacognitive strategies required in qualitative analysis could be the focus of future studies.

DEVELOPMENT OF THE TEACHING PACKAGE

The following sections describe how studies in the literature and findings, thus far, of this study on students' understanding of qualitative analysis guided the development of the QATP.

Reasons why qualitative analysis is difficult

A summary of the reasons why students find qualitative analysis difficult, as discussed in Chapter Two, is given below.

1. Students may not know that they are required to make links between theory and practical work, or they may not know how to make these links.
2. Students may not know the purpose of the experiments and procedures, so they simply follow instructions with little thought, and try to get the 'right' answer.
3. The content of qualitative analysis is extensive, abstract and complex. It involves the application of knowledge from different topics and also process skills such as manipulative and inferential skills, as well as metacognitive strategies.
4. Students' working memory may be overloaded when they carry out qualitative analysis experiments. They need to read instructions, carry them out, prepare additional tests to identify gases that are liberated, observe, record and interpret their results, as well as be mindful of the time left to complete their experiments and reports. The resulting cognitive overload leaves little space for thought and learning.
5. Students may lack mastery of the skills required in qualitative analysis. Many students may not know how to carry out the procedures in the correct manner, leading to erroneous results. Unfortunately, teachers do not spend time helping students develop such procedural skills. Students

also may not know what to observe and what valid inferences to make because they do not understand the theory behind the procedures.

6. Students do not need to understand what they do in the experiments in order to do well in the practical examinations. Teachers concentrate on 'drill and practice' rather than understanding for the same reason. Thus, there is little incentive to expend the effort on thinking deeply into the topic and understanding it.

The usual way of doing qualitative analysis

Teachers normally begin teaching qualitative analysis by reviewing the reactions involved and demonstrating some procedures that the students need to carry out. Using commercially available workbooks or teacher-prepared worksheets, usually adapted from commercially available workbooks or past-year examination papers, students then do a series of tests for the various cations, anions, gases, oxidising and reducing agents as specified in the syllabus (UCLES, 1996). After they are familiar with the tests, students are given past years' examination questions to determine the unknown ions present in the given samples. Throughout the series of practical sessions, students merely follow instructions given in the worksheets, and are seldom required to think about and understand they are doing. This way of doing qualitative analysis did not seem to help students understand the concepts and propositions involved in qualitative analysis as discussed in Chapters 5 to 8, neither did it help them to acquire the necessary process skills (Goh et al., 1987; Tsoi, 1994). Thus, there is a need to find a better way of conducting qualitative analysis practical work to enable students to understand the concepts and propositional knowledge involved, as well as, acquire the process skills and thinking required for the practical work.

Theoretical foundations of the package

The theoretical foundations of the teaching package centred mainly on the studies by Woolnough and Allsop (1985), Driver and Oldham (1986), Goh et al. (1987, 1989), Volet (1991), Pintrich et al. (1993), and Johnstone and Wham (1982). The key factors underpinning the design and development of the teaching package are described below.

1. Experience

   To allow students to have tacit knowledge of the phenomena, reagents and apparatus, and to construct explanations of the phenomena.
2. Exercise

   To allow students to be proficient in manipulative, observational and inferential skills.
3. Application

   To allow students to apply what they have learnt to plan, execute and evaluate experiments to identify unknown samples.
4. Metacognitive skills

   To allow students to learn the thinking required in qualitative analysis, to observe how an expert (the teacher) analyses worksheets and carries out the procedures, and to model the teacher.

Contents of the teaching package

The QATP consisted of a teacher's guide (Appendix N1), a workbook (Appendix N2), and answers to the questions in the workbook (Appendix N3). The teacher's guide spelt out the rationale for each activity in the workbook as well as the aspects of theory and/or process skills involved. It also contained a list of reagents that the school's laboratory technician needed to prepare for the various activities in the teaching package.

The workbook was divided into four main chapters, 'Cations', 'Gases', 'Anions' and 'Strategies'. This author felt that the identification of cations was the easiest to start with as it involved mainly double decomposition and precipitation, while the identification of anions was the most difficult because it also involved the identification of gases. Thus, the chapter on gases preceded the chapter on anions. The activities in each chapter were generally in the following sequence 'Experience', 'Exercise', 'Applications' (Woolnough & Allsop, 1985) and 'Strategies' (Pintrich et al., 1993; Volet, 1991). The students would experience a certain chemical phenomenon and learn the theory and reactions behind it. Subsequently, they proceeded to practise the manipulative skills required to carry out the procedures involved, learn what to observe and how to record their observations. They also were introduced to the thinking or strategies involved in doing qualitative analysis experiments. Finally, students were given opportunities to apply the knowledge, skills and strategies that they had acquired by planning and carrying out experiments to identify ions in unknown samples.

One aim of the Experience sections in each of the chapters was to provide the experimental context (Gabel, 1989; McDermott, 1988) for the learning of qualitative analysis, thereby enabling students to use their senses to assimilate the phenomena (Costa, 1991) during reactions such as colour changes, formation of precipitates, effervescence, colours and odours of gases evolved. Another aim was to explicitly introduce to the students the reactions behind common procedures, the reactions that the students had actually learned in previous lessons but might not have known that they were relevant to qualitative analysis. The inability to relate theory to practical work seemed to be the main weakness of many students, and this showed up in the interviews (described in Chapter 5) and results of the administration of the various versions of the qualitative analysis diagnostic tests (described in Chapters 6 to 8). By explicitly targeting the more abstract reactions behind the procedures and results, this author hoped to encourage students' mental model construction (Greca & Moreira, 2000; Williamson & Abraham, 1995), to interpret and understand qualitative analysis, and develop knowledge structures more closely resembling that of expert chemists (Wilson, 1998).

In the chapter on cations, computer animation sequences depicting dissolution, double decomposition and precipitation at the micro-level were shown to students to help promote greater understanding of the processes. Garnett et al. (1995) and Harrison and Treagust (1998) believe that the use of multimedia simulations can provide students with concrete micro-level representations of chemical structures and reactions, and Dechsri, Jones and Heikkinen (1997) noted that images were more easily recalled than words and could act as an "easily recalled conceptual peg for abstract concepts" (p. 892). Kozma and Russell (1997) described the advantages of using micro-level animations in learning chemical equilibrium, and Gabel and Bunce (1994) commented that correct conceptional understanding might have to be provided through technology because many teachers have the same incorrect conceptions as their students. This position was supported by Muthukrishna, Carnine, Grossen and Miller (1993) who argued that use of instructional media could provide clear explanations which fostered understanding of concepts because clear explanations were inconsistent with any misinterpretations. However, Williamson and Abraham (1995) cautioned that the use of instructional media, like all teaching strategies, also could create and even reinforce alternative conceptions; for example, the animations themselves may have errors in them, or the students may gain only a partial understanding of the concepts.

The orientation, elicitation of ideas and restructuring of idea sequences proposed by Driver and Oldham (1986) were followed in the Experience sections. Students were given ample opportunities to think about the chemical phenomena, to write down their thoughts and to discuss them with their classmates. This was to enable them to apply what they had learned in earlier topics to explain the phenomena, justify their own ideas, listen to their classmates' thoughts, test the feasibility of the various explanations and resolve any disagreements (Hodson, 1993). Herron and Nurrenbern (1999) contend that cooperative learning experiences help students move away from rote memorisation to meaningful learning as students tend to use more metacognitive strategies and higher level reasoning in cooperative learning, and assume more responsibility for their own learning. The teacher's guidance was important in this stage as students might need help to make the links between the theory taught in the classroom and the experiments in the laboratory. The students also would listen to the teacher's explanations (to be treated as one of the alternatives and not 'the whole truth') carefully, compare them with their own ideas and try to resolve any differences or any areas that they do not understand (Hodson, 1993). It was intended that students would develop relational understanding (Skemp, 1976) or fundamental understanding (Gott & Johnson, 1999) of qualitative analysis through the cooperative thinking activities (Costa, 1991) and negotiation of knowledge (Hodson, 1993). Hogan (1999), however, cautioned that the teacher needed to monitor the collaborative activities as students "tend to focus their tasks procedurally rather than intellectually" (p. 1086) and ideas may be poorly communicated or understood.

In the Exercise sections, students were allowed to carry out procedures as many times as necessary until they were proficient in them. They also were asked questions on why certain procedures had to be carried out in a certain way, for example, why they were supposed to add only two drops of aqueous sodium hydroxide initially in the test for cations. These questions were to ensure that they understood the procedures so that they would take care to adhere to the procedures. Bryce and Robertson (1985) warned that many students did not master the basic skills required in practical work. Thus, checklists were used to highlight the skills and the important procedures in qualitative analysis that the students needed to practise and master, and to allow students to evaluate themselves and their peers. Self- and peer-evaluation was important as an average class in Singapore school would consist of 35-42 students, so the teacher might not have time to check on all the students.

In the Application sections, students were instructed to determine the unknown species without any instructions given, except in the chapter on gases. This was because students needed to be told how to generate the gas, but no instruction was given on how to test for the gases. Thus, in planning the sequence of tests needed to be carried out, students would hopefully increase their confidence in the viability of the knowledge and skills that they had acquired in the Experience and Exercise sections, and make meaningful use of what they had learnt (Marzano & Pickering, 1991). Schauble et al. (1991) believe that students would start to try to understand the relevant concepts involved in experiments instead of merely focussing on results when they become aware that the experiments require analytic or extended reasoning; the aim of the application activities was to provide such opportunities.

Metacognitive strategies (Pintrich et al., 1993; Volet, 1991) were introduced before the Application sections in 'Gases' and 'Anions' because the identification of gases and anions were more difficult and require more preparation than identification of cations. Students must know which ion/gas to test, when to test for it and why. Since normal qualitative analysis practical work and examinations in Singapore involved following given procedures, students were taught how to 'interpret' these procedures, that is, how to determine what the objectives of the procedure were, what precautions to take, and what results to expect. This analysis of procedures was to help students to better organise the way they engage in the required specific thinking processes (Swartz, 1991) and provide "procedural supports for helping them to regulate their knowledge construction processes" (Hogan, 1999, p. 1087). All the metacognitive strategies were then summarised in the last chapter on strategies. The teacher also was expected to show students how they would analyse a worksheet or practical examination paper and how the analysis guided the execution of the procedures; students would see the metacognitive strategies put into practice by an expert and this provided a model for them to emulate. The students were required to analyse some worksheets or past years' examination questions in a similar way to give them more practice in the use of the metacognitive strategies and to allow them to reflect on their thinking. In the future, they also were expected to analyse the worksheets or examination questions before starting on the experiments.

IMPLEMENTATION OF THE QUALITATIVE ANALYSIS TEACHING PACKAGE

The trial of the QATP was conducted in one secondary school in November 1999, during the end-of-school-year holidays, over six days, three-and-a-half hours daily. Mrs. Ang, who had participated in the review of propositional statements and concept maps as well as the development and administration of the QADI, also was involved in the development and trial of the QATP. Four chemistry teachers and two tertiary science education professors observed some of the lessons and gave their feedback on the teaching package. The QADI was administered to the students involved in the trials in March 2000.

Pre-trial discussions – some issues

Before the trials were conducted, Mrs. Ang and this author met thrice in August/September 1999 to discuss the contents of the teaching package, scheduling of the various activities, the preparation of reagents and apparatus, and other administrative matters involved. Mrs. Ang reviewed the teaching package and contributed practical suggestions which were used to revise a few activities and worksheets in the package.

However, Mrs. Ang had some reservations about her students. She believed that the teaching package involved a great deal of discussion, and feared that her students would not participate actively because they were not used to talking about concepts and expressing their ideas.

> When I first took them I told them that they are really a dumb [as in could not speak] class. I really have to prompt and prompt them to

> answer questions. I need to call them by name as nobody will volunteer an answer. As you are a stranger to them, they will be even more quiet. They are very conscious of themselves and they feel that if they say something wrong they will lose face.

'Fear of exposing their ignorance' or 'losing face' was also highlighted by Osborne (1997) as the reason for students' reluctance to engage in discussions. Mrs. Ang's words proved to be true. When this author asked a question, there usually was a murmur of voices discussing the question but nobody volunteered an answer. This author had to either call a student by name to answer the question or threatened to stop lessons unless someone first gave an answer.

Mrs. Ang also expressed concern that students might not be able to carry out certain activities such as preparing their own insoluble salts in the worksheet on cations, saying that "I hope they will be able to think...it is typical of them to only follow instructions. They will be asking each other how to do it." Johnstone and Letton (1991) also commented that students brought up on set experiments had a "confidence barrier to surmount" (p. 83) when they had to think for themselves. However, this concern was unfounded. Most students were generally able to think their way through the activities and carried them out satisfactorily, though there were a few who did not follow the procedures and, at the end of the last session, asked Mrs. Ang if they could repeat the whole package again!

The third concern of Mrs. Ang was the time required to complete the teaching package. She felt that in normal school circumstances, she could not spare the time doing all the activities in the teaching package. Insufficient curriculum time was a serious constraint as it affected the way teachers carry out practical work (Hodson, 1993). The whole package took about 21 hours to complete during the trials and that translated to 18 weeks of normal once a week 70 minutes long practical sessions. Few teachers could afford to spend so much time just on the basics of qualitative analysis. This author agreed with Mrs. Ang that time was a constraint, and suggested that teachers use the whole package during the holidays, or part of it during holidays and the remainder during normal school days; otherwise, teachers could use only parts of the package which they consider important. In Singapore, it is an established practice for schools to conduct remedial or extra lessons during the school holidays, usually at the beginning, so students, parents and teachers expect and make allowances for such lessons.

The fourth concern of Mrs. Ang was on the writing of observations. Her worry was that in the reaction involving amphoteric hydroxides and sodium hydroxide, the O-level examiners expected students to write that the 'precipitate dissolves in excess reagent' but the students were taught in the trials that a reaction was involved. If the examiners had to follow a strict marking scheme, then leaving out the words 'dissolve in excess reagent' might result in a deduction of marks. She suggested that the students be taught complex salt formation but told to write 'dissolve in excess reagent' when doing worksheets and past years' practical examination papers; at least they learned what actually happened when the precipitate disappeared. Another similar situation was the reaction of carbonate or sulphate(IV) precipitates with dilute acid where students would be told to write the precipitate 'dissolves' in the acid added when it actually reacted with the acid.

The trial of the QATP

Two intact classes, each with 45 Grade 9 students (14 to 16 years old) taking pure chemistry at the O-level were involved in the trial of the QATP. These students had completed their Grade 9 studies and would proceed to Grade 10 on 2 January 2000, the start of the new school year. Mrs. Ang requested that both her pure chemistry classes undergo the QATP as she considered the experience useful for both classes. Since there were no other pure chemistry classes in this school, no control group could be assigned for this trial. Implications of the lack of a control group are discussed in the section on the results from the administration of the QADI. This author took one class while Mrs. Ang taught the other class in another laboratory at the same time.

The worksheets on cations were the focus of the first two days, gases on the next two days, and anions and metacognitive skills on the fifth and sixth days. Students carried out reactions to experience the results of the reactions, and were asked to explain the results. Mrs. Ang and this author tried to explicitly link the procedures and results with the knowledge that the students had learned in class. They also monitored the students practising the manipulative skills and thinking required for the experiments. On the sixth day, Mrs. Ang and this author carried out a past year examination question and showed the students how to analyse the procedures and predict possible outcomes, as well as, how to carry out the procedures.

RESULTS AND DISCUSSION

Feedback on trial of the QATP was given by Mrs. Ang, four teacher-observers and two science education professors. As mentioned previously, Mrs. Ang was involved in teaching during the trials. Two of the teacher-observers were present throughout the first four days, while the other two teachers who belonged in the school, only sat in when they were free from other duties in the school. The two science education professors together observed one session. The students' performance in the QADI, which was administered in March 2000 four months after the trials, also was taken into consideration in the evaluation of the teaching package.

The teachers' comments

The teachers found the teaching package very structured, detailed and comprehensive. They said that it would help the more academically able students gain a deeper understanding of the theory involved in qualitative analysis. One teacher commented that "If you have the time, it is very good. It is very detailed...actually gives the students a very good idea on what is happening behind the procedures, and they can appreciate them better." The teachers liked the computer animation and felt that it will help students to understand solubility and precipitation. They also felt that the checklists were useful for students to evaluate their mastery of the manipulative skills required.

Combined Science students

Each of the teachers commented that for the less academically able students, especially the combined science students, the package was too detailed and the reactions discussed might be too difficult to understand. One teacher commented that "The more I tell them the more confused they get. Don't need to go into details because they will not understand."

In Singapore, secondary students study chemistry either as a subject by itself (pure chemistry) or as part of a combined science subject (biology/chemistry) or (chemistry/physics). Secondary students sit for a streaming examinations in Grade 8 (13 to 15 years old), and their results determine the subjects they will take at the O-levels. The less academically inclined students study combined science and constitute the majority of the students in many schools. These students do not need to study as much content as students taking pure chemistry, and thus, the teachers felt that the teaching package was more for the pure chemistry students than the combined science students. This was indeed the case as this author designed the package specifically to cater for the pure chemistry syllabus. However, the teachers also would like to be able to use a similar package, but with a reduction in content, for the combined science students. The teachers felt that students doing combined science would not be able to understand the extra content. They also did not want to spend too much time on qualitative analysis as it accounted for, at the most, 7.5% of the total marks for combined science. The above points were summarised by a teacher:

> For the combined science students, we don't go into detail. We concentrate on the observations. If you explain too much, they will be confused. Sometimes they will complain that the material is not structured towards the examinations. Besides, the practical does not count for that much in combined science, so you have to balance things.

Time

The teachers felt that it was not feasible, time-wise, to implement the whole teaching package. Mr. Ho said that taking more than seven hours to complete the worksheets on cations was too long and tedious, and that the less academically inclined students might become bored and restless. Seven hours was equivalent to six weeks' worth of practical work in normal curriculum time. Mrs. Khoo commented that doing the teaching package continuous for six days was advantageous because the materials would be 'fresh in the students' minds'. However, she felt that it would be ineffective in the normal school situation where practical work was scheduled once a week because students might have forgotten most of what was done during the previous lessons. She also mentioned that getting the less academically inclined students back during vacation time to do the package was very difficult as they were not as motivated as the pure chemistry students to come back to school during their holidays for lessons.

Observations

Following the implementation of the QATP, three teachers considered that some students still did not record their observations effectively; they did not know how to write the 'required' observations, and needed more practice in this aspect. Mr.

Ho went round the laboratory observing the students, and spotted many illogical or incorrect statements and commented that "I think the students may be better prepared in terms of understanding...but the writing of observations is still problematic."

Students' lack of competence in writing observations showed up in the worksheets which this author marked. For example, several students could not differentiate between the terms 'clear', 'colourless' and 'white' when they described colourless solutions. Many students wrote incomplete observations; for example, they did not describe the colours of the solutions formed when precipitates 'dissolve', as well as, the tests for gases evolved. From the omissions of certain details in their observations, this author believed that many students did not use litmus paper to test for gases, used negative tests as evidence for the presence of nitrate(V) ion, and did not add dilute acid when using barium or silver solutions to identify anions. Hodson (1992) pointed out that the lack of expertise in laboratory skills could hinder learning in practical work. Thus, more practice was required for students to master the skills required in qualitative analysis

Teacher H also felt that this author was inexact in his use of the term 'liquid'.

> I feel that the use of liquid is a bit too loose because the students already have difficulty in understanding liquid and aqueous solution. In today's session, you used liquid many times, so I'm afraid students may be confused that sodium chloride solution is actually a liquid. We teach our students that a liquid is formed when a solid melts at its melting point...[at room temperature] only water is a liquid and mercury is a liquid metal.

However, from this researcher's perspective, an aqueous solution has a fixed volume and no fixed shape, the characteristics of a liquid. Though it is a mixture, it also should be considered as a liquid as strictly defining a liquid as a pure substance is incorrect.

In summary, the five teachers believed that the QATP was very structured, detailed and comprehensive, but they had concerns about the time required to carry it out. They also commented that it was more suited for students taking pure chemistry rather than students taking combined science – the group which formed the majority of their students. Finally, the teachers wanted more emphasis to be placed on the writing of observations in the teaching package.

The tertiary science education professors' comments

The two tertiary science education professors together observed one session on heating and testing of gases and concentrated on the manipulative skills of the students. They found that students had problems in heating substances and testing for carbon dioxide, commenting that in one activity, more copper(II) oxide was needed in the sample containing a mixture of charcoal powder and copper(II) oxide so that copper metal can be visible after heating. They provided this author with a written account of their observations (Figure 9.1).

Results from the administration of QADI

Mrs. Ang administered the QADI, in March 2000, to the 90 students involved in the piloting of the QATP. This author had arranged with Mrs. Ang to administer the QADI in March or later to allow students to do more qualitative analysis experiments so that they had more time to understand and apply what they had learned in the trials. The four months also should provide a sufficient interval to minimise memory effects that could have occurred if the QADI was administered immediately after the QATP trial was conducted. This author believed that students' answers to the QADI in March 2000 would more likely reflect their understanding of qualitative analysis rather than what they remembered from their experiences in November 1999.

Comments on QA Project

1.
   - The researcher instructed the students quite effectively and controlled their time quite satisfactorily.
   - Most students engaged in the activities conscientiously.
   - They enjoyed doing the experiments and were curious about the reasons for doing this type of experiments.
   - When we asked the students about their learning with respect to this practical work, they commented favourably even though the time taken was rather long for them.

2.
   - Students did not have many problems with the tests for Cl^- and I^-.
   - The experiment on sublimation of ammonium chloride was quite obvious and easily done.

3. On the test for nitrate using action of heat,
   - most students were able to observe the evolution of NO_2 gas from the nitrate, but
   - students appeared to have difficulty in carrying out this test, because of

     (a) the need of applying strong heating – which is not familiar to students.
     (b) unexpected results – e.g. heating of sodium nitrate should not give NO_2 gas but it did probably due to some impurities present.
     (c) their skills in conducting the test for O_2 evolved.

4.
   - For the action of heat, the students were aware that the test tubes used must be clean and dry.
   - For testing of CO_2 gas, the sample used needed very high temperature to decompose. However, the researcher had provided help by constantly reminding students to keep on heating. In addition, some students appeared to have difficulty in acquiring the testing technique for this experiment. Hence, some of them had difficulty in getting positive results.
   - The students' handling of test tubes was not appropriate and some of the design of the delivery tubes was not too appropriate. As a result, some students had faced the suck back problem.
   - The researcher could have asked students to prepare fresh limewater (if time is allowed).

5.
   - The action of heat on a mixture of carbon and copper(II) oxide is an interesting one. Perhaps the ratio of C : CuO could be more appropriate in order to ensure the expected outcome. Here again, strong heating is a problem for most students.
   - The colour of the copper residue produced was not too obvious because of the inappropriate ratio of C : CuO.

Figure 9.1: The observations of the two tertiary science education professors

The descriptive statistics for the 90 students (denoted as S4) to whom the QADI was administered are given in Table 9.1. As discussed earlier, Mrs. Ang insisted that both her classes be given the same treatment in the trials to be fair to all her students, so no control group could be assigned for the trial of the QATP. Thus, the S4 group was compared with the 915 students (denoted as Sec 4) to whom the QADI was administered in 1999. This author realised there were many confounding variables such as the nature of the students and their teachers, the very different number of students in the two samples, the modes of instruction, and the length of time given to qualitative analysis instruction to the students in the two groups, so the comparison of results of the two groups could only gave an indication of the feasibility of the QATP.

It can be seen from Table 9.1 and Figure 9.2 that the S4 group performed better than Sec 4 group. The mean and median scores of the S4 group were higher, and a higher percentage of students in the S4 group had better total scores compared to the Sec 4 group. A one-way ANOVA carried out on the mean total scores of the two groups (Table 9.2) showed that the mean total scores were statistically significantly different ($p = .015$), these being 35% (6.66/19) and 30% (5.76/19) respectively for the S4 group which had experienced the QATP and the comparison Sec 4 group. These percentages are relatively low and the calculated effect size is $(6.66-5.76)/3.28 = 0.27$, which is a small effect but not trivial (Kirk, 1996).

The coefficient alpha values (Table 9.1) for the S4 group (.75) was higher than that of the Sec 4 group (.68), and was comparable to that of the junior college students (.72) and trainee teachers (.79). This could indicate that the students who had experienced the QATP relied less on guessing when they answered the items in the QADI and/or left fewer parts of the items unanswered compared to the Sec 4 group of students who had not experienced the QATP. This, together with the statistically significant higher mean total scores of the S4 group, indicates that students in the S4 group had a better understanding of qualitative analysis as measured by the QADI than the Sec 4 group.

Table 9.1: Descriptive statistics for the two groups of Grade 10 students to whom the QADI was administered

	S4	Sec 4
No. of cases	90	915
No. of items	19	19
Alpha Reliability	.75	.68
Mean	6.66	5.76
Standard Deviation	3.72	3.28
Median	6.00	5.00
Mode	8	5
Minimum	0	0
Maximum	18	18

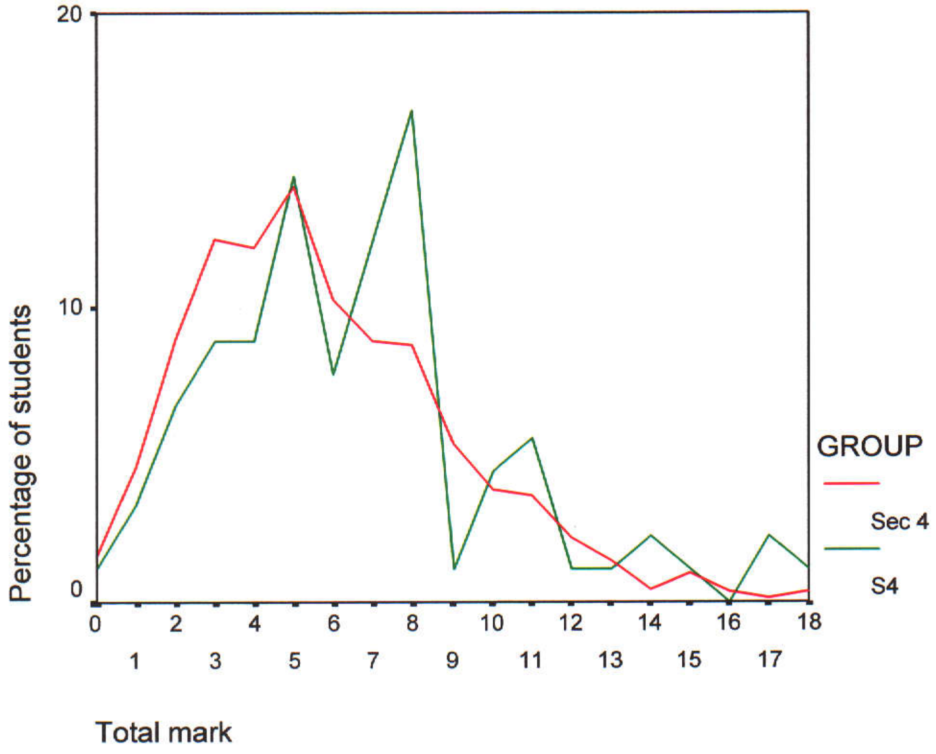

Figure 9.2: Distribution of the total scores of the two Grade 10 groups of students

Table 9.2: Comparison of the two Grade 10 groups for mean scores on the QADI using an analysis of variance

	Sum of Squares	df	Mean Square	F value	p value
Between Groups	65.14	1	65.14	5.91	.015
Within Groups	11057.33	1003	11.02		
Total	11122.47	1004			

The percentage (10% or more) of the students in the S4 and Sec 4 groups selecting each response combination for each item in the QADI is shown in Table 9.3. Except for five items – 6, 8, 9, 13 and 17 – a higher percentage of the S4 group chose the correct answer combinations on the QADI compared to the Sec 4 group. However the results were unpredictable. For example, a higher percentage of S4 students compared to the Sec 4 group knew that a precipitation reaction occurred in Item 1 (50% vs. 41%), but in Item 13 which involved the same type of reaction, a slightly lower percentage of S4 students chose the correct answer (41% vs. 45%). Similarly, in Item 2, which involved complex salt formation, the percentage of the S4 group selecting the correct answer was higher than the Sec 4 group (30% vs. 19%), but in Item 8, which involved a similar reaction, the percentage of students in the S4 group getting it correct was lower compared to the Sec 4 group (14% vs. 20%). The S4 students were explicitly taught the reactions involved in Items 1, 2, 8 and 13; thus, it could be deduced that some students still did not understand the reactions or that they have different understandings of the reactions based on the experimental contexts (Palmer, 1999).

The S4 students also were explicitly taught why dilute acids were used in the tests for anions in Items 6 and 17 but they fared worse than the Sec 4 students in the items. However, the S4 students did seem to understand thermal decomposition reactions (Items 10 and 19) better as a higher percentage of them choose the correct answer combination compared to the Sec 4 group.

Table 9.3: The percentage (10% or more) of Grade 10 students in the S4 group (n=90) / Sec 4 group (n=915) selecting response combination for each item in the QADI

Item	Content option	Reason option				
		(1)	(2)	(3)	(4)	(5)
1	A	~	~	*21/25*	~	-
	B	~	~	~	**50/41**	-
	C	~	*13/~*	~	~	-
2	A	*14/29*	*17/16*	~	28/26	-
	B	~	~	~	**30/19**	-
3	A	~	~	~	**23/17**	*18/18*
	B	*22/24*	*~/11*	*22/18*	~	~
4	A	~	~	*14/16*	~	33/30
	B	~	~	~	~	**29/22**
5	A	*13/20*	**52/43**	~	*~/17*	-
	B	~	~	~	~	-
	C	~	~	~	~	-
6	A	~	~	~	~	*11/22*
	B	~	**31/34**	~	~	~
	C	*20/~*	~	~	~	~
7	A	~	~	*~/18*	~	~
	B	~	**54/48**	~	*19/16*	~
8	A	*59/41*	~/13	*11/15*	~	-
	B	~	~	~	**14/20**	-
9	A	11/11	~	~	~	~
	B	*13/15*	~	**19/19**	~	~
10	A	*24/23*	~	~	**50/35**	-
	B	~	~	*20/27*	~	-
11	A	~	**31/24**	~	~	~
	B	~	~	*13/20*	*30/25*	~
12	A	*30/26*	~	~	~	-
	B	~	**52/38**	~	*12/20*	-
13	A	~	~	~	*21/12*	-
	B	~	**41/45**	~	~	-
	C	*18/13*	~	~	~	-
14	A	~	*12/25*	*21/16*	21/16	-
	B	~	~	~	**30/29**	-
15	A	~	26/19	**27/23**	*14/19*	-
	B	*17/14*	*~/15*	~	~	-
16	A	~	~	*14/19*	~	22/15
	B	~	~	~	~	**27/23**
17	A	*26/~*	~	~	*31/35*	~/13
	B	~	~	~	~	**18/20**
18	A	*16/~*	~	~	~	~
	B	~	~	**50/48**	~	~
19	A	~	~	~	~	*18/21*
	B	*28/26*	*10/~*	**37/29**	~	~

Note: ~ represents less than 10%
Figures in italics represent alternative conceptions
Figures in bold represent the correct answer

It has to be noted that having a higher mean score did not necessary mean that the S4 students had less alternative conceptions on qualitative analysis than the Sec 4 group. The analysis of the alternative conceptions of the two secondary groups will provide a more complete picture of the effects of the QATP on students' understanding of qualitative analysis. The significant alternative conceptions of the two groups of secondary students in each item in the QADI are shown in Table 9.4. As in the previous chapters, alternative conceptions are considered significant if they existed in at least 10% of the student sample as a higher minimum value would possibly eliminate some valid alternative conceptions from the results (Peterson, 1986). The significant alternative conceptions of the two groups of subjects determined from the administration of the QADI are classified in Table 9.5.

It can be seen from Table 9.5 that there is little difference in the types of alternative conceptions that the two groups of secondary students hold. The percentages of students having a given alternative conception did not seem to differ much as well, with a more noticeable difference in alternative conceptions 1a and 2 under 'Dissolution', and 4 and 5 under 'Addition of acid'. A lower percentage of students in the S4 group had the alternative conception that the addition of excess reagents in Items 2, 14 and 16 was to provide more 'space/volume' for the precipitate to dissolve. However, for Item 8, a higher percentage of the S4 group believed that ammonia chloride was formed when aqueous ammonia was added to silver chloride because ammonium chloride was soluble. A higher percentage of S4 students also had problems understanding the function of nitric(V) (4 and 5 under 'Addition of acid') acid in Items 6 and 17.

As pointed out in the discussion of the results in Table 9.3, a lower percentage of students in the S4 group choose the correct content-reason combination for Items 6, 8 and 17, and this was reflected in the higher percentages of S4 students having alternative conceptions related to the three items. The consistency of the various alternative conceptions that both groups had are given in Table 9.6.

Table 9.4: Comparison of the significant alternative conceptions among the students in the S4 (n=90) and Sec 4 (n=915) groups

No.	Option	Alternative conception	Percentage of students with the alternative conception	
			S4	Sec 4
1	A3	Sodium ion displaces zinc ion because it is more reactive	21	25
	C2	A redox reaction occurs because sodium hydroxide loses oxygen in forming sodium chloride and zinc chloride gains oxygen in forming zinc hydroxide.	13	~
2	A1	Zinc hydroxide dissolves in excess sodium hydroxide because more solvent is added so there is more space for it to dissolve.	14	29
	A2	Zinc hydroxide dissolves in excess sodium hydroxide because no further reaction is seen except for its disappearance, and no new reagent is added.	17	16
3	A5	The acid removes the solvent which dissolved the white solid in the first instance.	18	18
	B1	A different solid is formed because different reagents were used.	22	24
	B2	A different solid, sodium nitrate(V) is formed from the reaction of the acid and the alkali.	~	11
	B3	A different solid, zinc nitrate(V) is formed from the reaction of the acid and the zinc compound present.	22	18
4	A3	Zinc hydroxide dissolves in acid (solvent) because no further reaction is seen except for its disappearance, and no new reagent is added.	14	16
5	A1	The more reactive ions from Q displace the silver ion to form silver chloride.	13	20
	A4	The more reactive chloride ions displace the nitrate(V) ions to form silver chloride.	~	17
6	A5	Acid is added to acidify the mixture in order that the reaction can proceed properly.	11	22
	C1	Dilute nitric(V) acid is used to dissolve the white solid because all nitrate(V) salts are soluble.	20	~
7	A3	Hydrochloric acid can be added following the addition of silver nitrate(V) as it has similar properties and reactions as nitric(V) acid.	~	18
	B4	Hydrochloric acid cannot be added following the addition of silver nitrate(V) as it will not react with the silver chloride.	19	16

Note: ~ denotes that the figure is below 10%, thus insignificant.

Table 9.4 (continued): Comparison of the significant alternative conceptions among the students in the S4 (n= 90) and Sec 4 (n=915) groups

No.	Option	Alternative conception	Percentage of students with the alternative conception	
			S4	Sec 4
8	A1	Ammonium chloride is formed when aqueous ammonia is added to silver chloride because ammonium chloride is a soluble salt.	59	41
	A3	Ammonium chloride is formed when aqueous ammonia is added to silver chloride because the more reactive ammonium ion displaces the silver ion.	11	15
9	B1	Nitric(V) acid decomposes the ammonium chloride to liberate chloride ions which then react with the silver ions to form a white precipitate.	13	15
10	A1	Test for oxygen has to be carried out when a substance is heated because all gases have to be tested.	24	23
	B3	Test for oxygen need not be carried out when a substance is heated because oxygen will not be liberated during heating, instead it will be used up.	20	27
11	B3	It is not possible to detect the presence of carbonate ions by the addition of barium nitrate(V) followed by nitric(V) acid because the procedure is strictly a test for the presence of sulphate(VI) ions.	13	20
	B4	It is not possible to detect the presence of carbonate ions by the addition of barium nitrate(V) followed by nitric(V) acid because the acid must be added directly to the unknown to test for the presence of carbonate ions.	30	25
12	A1	Sulphuric(VI) acid can be added following the addition of barium nitrate(V) because all acids have similar properties and reactions.	30	26
	B4	Sulphuric(VI) acid cannot be used because the addition of barium nitrate(V) has already invalidated the test for carbonates.	12	20
13	A4	Ammonium ion displaces copper(II) ions because it is more reactive.	21	12
	C1	A redox reaction occurs when aqueous ammonia is added to copper(II) sulphate(VI) because copper(II) sulphate(VI) loses oxygen in the forming copper(II) hydroxide chloride and aqueous ammonia gains oxygen in forming ammonium sulphate(VI).	18	13

Table 9.4 (continued): Comparison of the significant alternative conceptions among the students in the S4 (n= 90) and Sec 4 (n=915) groups

No.	Option	Alternative conception	Percentage of students with the alternative conception S4	Sec 4
14	A2	Copper(II) hydroxide dissolves in excess aqueous ammonia because more solvent is added so there is more volume for it to dissolve.	12	25
	A3	Copper(II) hydroxide dissolves in excess aqueous ammonia because no further reaction is seen except for its disappearance, and no new reagent is added.	21	16
15	A4	The acid removes the solvent which dissolved the blue solid in the first instance.	14	19
	B1	A different solid is formed because different reagents were used.	17	14
	B2	A different solid, copper(II) sulphate(VI) is formed from the reaction of the acid and the soluble copper(II) compound.	~	15
16	A3	Copper(II) hydroxide dissolves in acid (solvent) because no further reaction is seen except for its disappearance, and no new reagent is added.	14	19
17	A2	Dilute nitric(V) acid is used to acidify the mixture because all nitrate(V) salts are soluble.	26	~
	A4	Acid is added to acidify the mixture so that the unknown can react properly with lead(II) nitrate(V).	31	35
18	A	Lead(II) iodide is formed by a displacement reaction between R and lead(II) nitrate(V).	36	33
	A1	Lead(II) ion displaces the unknown cation in R because it is more reactive.	16	~
19	A5	Hydrogen and carbon dioxide must be tested when ionic compounds are heated because compounds containing carbonate, hydrogen or hydrogen ions will liberate carbon dioxide or hydrogen on heating.	18	21
	B1	Hydrogen and carbon dioxide need not be tested when ionic compounds are heated because ionic compounds have strong bonds and do not decompose on heating.	28	26
	B2	Hydrogen and carbon dioxide need not be tested when ionic compounds are heated because gases are only evolved when covalent compounds are heated.	10	~

Table 9.5: Alternative conceptions of the S4 and Sec 4 groups of students

Alternative conception	Choice combination	Percentage of students with the alternative conception	
		S4	Sec 4
Displacement			
1. A more reactive ion displaces a less reactive ion in a double decomposition/ precipitation mixture.	Q1 (A3)	21	25
	Q5 (A1,A4)	21	37
	Q13 (A3,A4)	21	15
	Q18 (A1,A2, A4&A5)	35	29
2. A more reactive ion displaces a less reactive ion in complex salt formation.	Q8 (A3)	11	15
	Q14 (B1)	~	~
Redox			
1. A redox reaction occurs in a double decomposition reaction.	Q1 (C2)	13	~
	Q13 (C1)	18	13
Dissolution			
1. A precipitate is formed when a reagent is added to an unknown solution. On further addition of excess reagent, the precipitate disappears.			
a. More excess reagent means more space/volume for the precipitate to dissolve.	Q2 (A1)	14	29
	Q14 (A2)	12	25
	Q16 (A1)	~	~
b. The precipitate is considered to have dissolved in the excess reagent as no further reaction is seen and no new reagent is added.	Q2 (A2)	17	16
	Q4 (A3)	14	16
	Q14 (A3)	21	16
	Q16 (A3)	14	19
2. Ammonium chloride is formed when aqueous ammonia is added to silver chloride because it is a soluble salt.	Q8 (A1)	59	41
3. When acid is added to a mixture containing excess alkali and a complex salt it removes the solvent (alkali) for the precipitate.	Q3 (A5)	18	18
	Q15 (A4)	14	19
Heating			
1. All gases have to be tested when a substance is heated.	Q10 (A1)	24	23
2. Oxygen cannot be produced when a substance is heated because it is used up during heating.	Q10 (B3)	20	27
3. Compounds containing hydrogen and hydroxide ions will liberate hydrogen on heating.	Q19 (A5)	18	21
4. Ionic compounds have strong bonds and do not decompose on heating.	Q19 (B1)	28	26
5. Gases are only evolved when covalent compounds are heated.	Q19 (B2)	10	~

Note: ~ denotes that the figure is below 10%, thus insignificant.

Table 9.5 (continued): Alternative conceptions of the S4 and Sec 4 groups of students

	Alternative conception	Choice combination	Percentage of students with the alternative conception	
			S4	Sec 4
	Addition of acid			
1.	Acid is needed to acidify the mixture so that reaction can proceed properly.	Q6 (A5)	11	22
		Q17 (A4)	31	35
2.	Any acid can be used because acids have the same properties and reactions.	Q7 (A3)	~	18
		Q12 (A1)	30	26
3.	Hydrochloric acid cannot be added because it will not react with the silver chloride precipitate.	Q7 (B4)	19	16
4.	Dilute nitric(V) acid is added to acidify mixtures because it is a strong oxidising agent.	Q6 (A3)	~	~
		Q17 (A2)	26	~
5.	Since all nitrate(V) salts are soluble, dilute nitric(V) acid is added to			
a.	dissolve solids.	Q6 (C1)	20	~
b.	acidify mixtures.	Q17 (A2)	26	~
6.	Carbonate ions cannot be identified if acid is added after the addition of barium nitrate(V).			
a.	The acid must be added directly to the unknown.	Q11 (B4)	30	25
		Q12 (B4)	12	20
b.	The procedure is strictly a test for sulphate(VI).	Q11 (B3)	13	20
7.	When acid is added to a mixture of a complex salt and excess alkali,			
a.	a different solid from the original precipitate is formed.	Q3 (B1,B2 & B3)	54	52
		Q15 (B1& B2)	26	29
b.	the acid decomposes the ammonium chloride formed to liberate the chloride ions which react with the silver ions present to reform the precipitate.	Q9 (B1)	13	15

Table 9.6: Consistent alternative conceptions of the S4 and Sec 4 groups of students

Alternative conception	Choice combination	Percentage of students selecting pairs supporting alternative conception >75% of the time	
		S4	Sec 4
Displacement			
1. A more reactive ion displaces a less reactive ion in a double decomposition/ precipitation mixture.	Q1 (A3) Q5 (A1,A4) Q13 (A3,A4) Q18 (A1,A2, A4&A5)	10	11
2. A more reactive ion displaces a less reactive ion in complex salt formation.	Q8 (A3) Q14 (B1)	1	1
Redox			
1. A redox reaction occurs in a double decomposition reaction.	Q1 (C2) Q13 (C1)	6	2
Dissolution			
1. A precipitate is formed when a reagent is added to an unknown solution. On further addition of excess reagent, the precipitate disappears.			
a. More excess reagent means more space/volume for the precipitate to dissolve.	Q2 (A1) Q14 (A2) Q16 (A1)	3	4
b. The precipitate is considered to have dissolved in the excess reagent as no further reaction is seen and no new reagent is added.	Q2 (A2) Q4 (A3) Q14 (A3) Q16 (A3)	7	8
2. When acid is added to a mixture containing excess alkali and a complex salt it removes the solvent (alkali) for the precipitate.	Q3 (A5) Q15 (A4)	10	9
Addition of acid			
1. Acid is needed to acidify the mixture so that reaction can proceed properly.	Q6 (A5) Q17 (A4)	9	14
2. Any acid can be used because acids have the same properties and reactions.	Q7 (A3) Q12 (A1)	1	8
3. Dilute nitric(V) acid is added to acidify mixtures because it is a strong oxidising agent.	Q6 (A3) Q17 (A2)	1	3
4. Carbonate ions cannot be identified if acid is added after the addition of barium nitrate(V) because the acid must be added directly to the unknown.	Q11 (B4) Q12 (B4)	3	10
5. When acid is added to a mixture of a complex salt and excess alkali, a different solid from the original precipitate is formed.	Q3 (B1,B2 & B3) Q15 (B1& B2)	22	23

It can be seen from Table 9.6 that, with one exception, only a small extent (0-23%) of the students in the two secondary groups consistently hold an alternative conception more than 75% of the time as compared to the results in Table 9.5. The consistent alternative conception most widely held (22%) by the S4 students, which was similar for the Sec 4 group, was that a new solid was formed when an acid was added to a mixture of a complex salt and excess alkali. Though complex salt formation and reaction was explicitly taught to the S4 group, some students still had problems in understanding the information. From a chemical point of view, students' lack of understanding of chemistry concepts could be solved by providing students with more and better explanations, but this did not seem to work (van Keulen, Mulder, Goedhart & Verdonk, 1995). Indeed, van Keulen et al. found that students show every sign of understanding during the explanations but somehow fail to apply the knowledge during their experiments. Many secondary students seemed to be unable to create mental models (Greca & Moreira, 2000; Williamson & Abraham, 1995) of complex salt formation and reactions even with explicit teaching of these reactions, prompting this author's supervisor to comment that "successful teaching does not equal successful learning" – a teacher might feel that he/she had planned and taught a lesson well but, in reality, his/her students might not have understood the lesson. The students themselves need to be able to make sense of what is taught. The fact that explicit teaching could not overcome the problem, and that the junior college students did not seem to be affected by the alternative conception to the same extent seemed to suggest that some secondary students have not reached the stage of cognitive development to be able to understand complex salt formation and reactions. Complex salt formation required understanding of ligands, solvation and co-ordination about a metal ion, and reactions of the complex salts in qualitative analysis involves competing reactions as well as the concept of equilibrium. Thus, as the name suggested, complex salt formation and reactions were rather difficult to understand, and the secondary students might need more time or more cognitive development to understand them.

In summary, the statistically significant difference between the mean scores of the secondary students in the S4 and Sec 4 indicated that the QATP seemed to have a positive effect on the S4 students understanding of qualitative analysis. There was a greater variation of results in the S4 groups with a higher percentage of students having higher scores. However, there was generally little difference between the types, levels and consistency of alternative conceptions between the two groups of students. This seemed to indicate that the effect of the QATP might not be uniform; that is, some students might have benefitted from the QATP and some might not. The concepts and reactions taught in the QATP might still be too abstract or difficult for the majority of students to understand.

LIMITATIONS

To determine the effectiveness of a specific laboratory instructional package on students' learning, the cognitive, affective and psychomotor aspects of the instructional package should be investigated (Dechsri et al., 1997). Thus, the QATP should be evaluated on whether or not it helped students to understand the reactions involved in qualitative analysis, made practical work more rewarding – for example, more interesting, more enjoyable and less frustrating – as well as whether or not it facilitated laboratory skill performance. Unfortunately, the constraints of this study only allowed the trial of the QATP to be evaluated on the students' understanding of the concepts and propositional knowledge related to qualitative analysis. A more extensive study on the QATP focussing on all three dimensions of learning should be the focus of future studies. These studies also need to minimise confounding factors, for example, by having equivalent control and experimental groups, allocating equal amount of time for qualitative analysis instruction to both groups and having professional development for teachers to conduct the QATP.

SUMMARY

This chapter addressed Research Questions 7 and 8. The theoretical foundations of the QATP centred mainly on the studies by Woolnough and Allsop (1985), Driver and Oldham (1986), Goh et al. (1987, 1989), Volet (1991), Pintrich et al. (1993), and Johnstone and Wham (1982). Four key factors underpinned the design and development of the teaching package. Firstly, students should have tacit knowledge of the phenomena, reagents and apparatus, and understand the reactions involved. Secondly, they should be proficient in manipulative, observational and inferential skills required in qualitative analysis. Thirdly, the students should apply what they had learnt to plan, execute and evaluate experiments to identify unknown samples. Finally, they needed to learn and practise the thinking required in qualitative analysis.

The results from the trial of the QATP seemed to indicate that the QATP is feasible. The teachers found the QATP structured, comprehensive, and in general, suitable for students doing pure chemistry. Results from the administration of the QADI on the S4 students showed that the S4 students had higher mean total scores than the Sec 4 students but there was little difference in the types, extent and consistency of alternative conceptions between the two groups. This outcome indicates that many students in the S4 group still had difficulties understanding qualitative analysis. More studies on the QATP are required in the future to determine the extent to which such a programme of instruction can affect learning of qualitative analysis.

CHAPTER TEN

CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

INTRODUCTION

In this chapter, a brief outline on how the research questions in the study were answered is presented. The information collected during the study provides the basis for the conclusions, recommendations and discussion on the limitations of the study.

SUMMARY OF THE STUDY AND CONCLUSIONS

The eight research questions which guided this study on qualitative analysis were:

1. What are the concepts and propositional knowledge necessary for secondary chemistry students to understand the topic of qualitative analysis?
2. Are the concepts and propositional knowledge present in the two approved chemistry textbooks and two practical workbooks used by secondary chemistry students consistent with the concepts and propositional knowledge identified in the study?
3. What do secondary chemistry students understand about the concepts and propositional knowledge related to qualitative analysis?
4. What are the difficulties in developing a diagnostic test consistent with the identified concepts, propositional knowledge and known student alternative conceptions related to qualitative analysis?

5. What is the extent of secondary chemistry students' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as identified through the use of a diagnostic test?
6. What is the extent of junior college students', undergraduates' and graduate trainee-teachers' understanding and alternative conceptions of the concepts and propositional knowledge related to qualitative analysis as compared to secondary students?
7. How can a teaching package be designed to help students understand the procedures and reactions involved in qualitative analysis, as well as, acquire the process skills and thinking required in qualitative analysis?
8. What is the impact of the teaching package on secondary chemistry students' understanding of the concepts and propositional knowledge related to qualitative analysis as determined through the administration of the diagnostic test?

Research Question 1 established the content boundaries for the investigations in this study. The content framework for secondary pure chemistry qualitative analysis was described in Chapter 3 through a review of the pure chemistry syllabus, and the preparation of a concept map, a list of propositional statements, and a list of facts.

Research Question 2 was answered in Chapter 4 where two approved chemistry textbooks and two practical workbooks were analysed to determine whether the concepts and propositional knowledge present in the four texts were consistent with the concepts and propositional knowledge identified in Chapter 3. It was found that none of the texts sufficiently and explicitly highlighted all the reactions involved in qualitative analysis. This might impair the teaching and learning of qualitative analysis of teachers and students who use the two chemistry textbooks and two practical workbooks.

Research Question 3 was answered through the review of literature in Chapter 2, through laboratory observations and interviews with secondary students in Chapter 3, and through the administration of various tests, described in Chapters 5 to 7, in the development of the diagnostic instrument on qualitative analysis.

Chapter 6 described the development of the two-tier multiple choice diagnostic instrument, the QADI, which was the main focus of Research Question 4. The development of the QADI was based on the procedures described by Treagust (1986, 1988, 1995). The items in the QADI were developed based on the content framework established in Chapter 3, past years' O-level examination questions and the data collected from students in Chapters 5 and 6. The QADI was "both the outcome of a research process and an instrument for data collection [in the same study, providing data which would] triangulate the interpretation of the existing database and broaden the 'sample size'" (Taber, 2000, p. 471).

Research Question 5 was answered through the administration of the QADI to Grade 10 students, and the results, as well as the alternative conceptions identified from the analysis of the results were described in Chapter 7. It was found that the Grade 10 students had significant alternative conceptions, and these alternative conceptions were classified under the headings 'Displacement', 'Redox', 'Dissolution', 'Addition of acid', and 'Heating'. The alternative conceptions provided information on the Grade 10 students' lack of understanding of the concepts in qualitative analysis and the incorrect associations made by the students between the various concepts in their attempts to understand the topic.

Research Question 6 was answered through the administration of the QADI to junior college students, undergraduates and graduate trainee-teachers. The results obtained for the advanced chemistry students were described in Chapter 8. These results were compared with those of the Grade 10 students to examine the retention of the alternative conceptions on qualitative analysis over time and to determine if and when the alternative conceptions are less in existence (Birk &

Kurtz, 1999). The comparison showed that many of the alternative conceptions held by the Grade 10 students also were prevalent among the different groups of advanced students. However, these alternative conceptions were consistently held by only a small number of students at all educational levels (0-23%) across all contexts examined in the QADI, indicating that the students might have more than one conception for a particular concept, or had little understanding of qualitative analysis and resorted to guesswork. It also was found that there was strong association between the various groups of students' content option and reason for the items in the QADI, and that the student's reasoning was more indicative of the correctness or incorrectness of the student's understanding than was the content option selected.

The development of the teaching package on qualitative analysis, the QATP, described in Chapter 9, answered Research Questions 7. The theoretical foundations of the QATP centred mainly on the studies by Woolnough and Allsop (1985), Driver and Oldham (1986), Goh et al. (1987, 1989), Volet (1991), Pintrich et al. (1993), and Johnstone and Wham (1982). The QATP consisted of a teacher's guide (Appendix N1), a workbook (Appendix N2), and answers to the questions in the workbook (Appendix N3). In the QATP, the students would experience a certain chemical phenomenon, and learn the theory and reactions behind it. Subsequently, they proceeded to practise the manipulative skills required to carry out the procedures involved, learn what to observe and how to record their observations. They also were introduced to the thinking or strategies involved in doing qualitative analysis experiments. Finally, they were given opportunities to apply the knowledge, skills and strategies that they had acquired by planning and carrying out experiments to identify ions in unknown samples. Feedback on trial of the QATP was given by five secondary chemistry teachers and two science education professors. The teachers found the teaching package very structured, detailed and comprehensive, and said that it would help students taking pure chemistry gain a deeper understanding of the theory involved in qualitative analysis. However, they expressed concerns about the time required to carry out the QATP. They also believed that the QATP might not be suitable for combined science students as the package was too detailed and the reactions discussed might be too difficult for the combined science students to understand. This was understandable as this author had designed the QATP for pure chemistry students who learn more chemistry topics, and at a greater depth than combined science students.

The comparison of the results from the administration of the QADI to the S4 and Sec 4 groups answered Research Question 8. The mean and median scores of the S4 group were higher, and a one-way ANOVA carried out on the mean total scores of the two groups (Table 9.2) showed that the mean total scores were statistically significantly different ($p = .015$). The mean score of the S4 group was .27 standard deviations higher than that of the Sec 4 group, indicating that the effect size was small but not trivial. The coefficient alpha values (Table 9.1) for the S4 group (.75) was higher than that of the Sec 4 group (.68), and this could indicate that the students who had experienced the QATP relied less on guessing when they answered the items in the QADI and/or left fewer parts of the items unanswered compared to the Sec 4 group of students who had not experienced the QATP. This result, together with the statistically higher mean total scores of the S4 group and the effect size (.27), indicates that students had a better understanding of qualitative analysis as measured by the QADI. However, these results have to be treated with caution as there were many confounding variables such as the nature of the students and their teachers, modes of instruction, and length of time given to qualitative analysis instruction to the students. Thus, the comparison of results of the two groups can only gave an indication of the feasibility of the QATP. The results from the administration of the QADI also showed that there was little difference in the types, extent and consistency of alternative conceptions between the two groups. This outcome, together with the low mean total score of 35%, indicate that many students in the S4 group still had difficulties understanding qualitative analysis. This could be due to the complexity of some reactions in qualitative analysis, such as, complex salt formation and reactions, and the lack of cognitive development required for the understanding of the complex reactions.

RECOMMENDATIONS

Based on the findings on this study and the literature reviewed in Chapter 2, recommendations for helping students improve their understanding of qualitative analysis as well as suggestions on how to improve the teaching and learning of qualitative analysis are given in this section. It also includes recommendations for further research.

Learning and teaching qualitative analysis

Suggestions for helping students to improve their understanding of qualitative analysis, and on improving the teaching of the topic are given under the headings 'Make the knowledge base explicit', 'Understanding the reactions involved', 'Explanation of chemical terms and models', 'Qualitative analysis practical work', and 'Changing the syllabus and assessment'.

Make the knowledge base explicit

As discussed in Chapters 2 and 5, students frequently do not think for themselves and seem unaware of what they should be doing in the laboratory sessions (Berry, Mulhall, Gunstone, & Loughran, 1999). However, teachers assume their students do know what to do during experiments, and thus, seldom emphasise or make explicit the purpose of and the theory behind the procedures (Tasker & Freyberg, 1985). Left to themselves, students have "difficulty establishing any meaningful overall purpose [in the experiments, so] their purpose and actions degenerate to simply following instructions" (Tasker & Freyberg, 1985, p. 72); hence the tasks of assembling apparatus and making required observations or measurements become the focus of student action (Gunstone, 1991). Students also see no relationship between practical work and theory, and without theory to guide their experiments, it is likely that they will not know what to think about and what to take note of in the experiments (Hodson, 1992). Thus, the concepts and propositions involved in qualitative analysis, the manipulative and inferential skills, and the thinking required in qualitative analysis practical work should be highlighted to the students, and teachers too. This could guide students in their learning of the theory required, and make them aware of the skills and thinking that they need to acquire. Making the knowledge base explicit could also help teachers, especially beginning teachers and teachers who did not major in chemistry but are teaching chemistry. By knowing exactly what is required for qualitative analysis, teachers would be able to plan and carry out their lessons more effectively.

Understanding the reactions involved

The reactions involved in qualitative analysis are fundamentally important to the understanding of qualitative analysis practical work. Unfortunately, as discussed in Chapter 4, the reactions are not emphasised in textbooks and workbooks, and teachers also may not highlight the reactions. In addition, students might find the reactions difficult to understand as they involve "abstract and formal explanations of invisible interactions between particles at a molecular level" (Carr, 1984, p. 97). Nakhleh and Krajcik (1994) believe that to engage in chemical reasoning, the student may need to constantly shift between four representational systems, the macroscopic, microscopic, symbolic and algebraic, and this causes further difficulties. This is true in qualitative analysis as the student has to reconcile the procedure that he/she carries out with the results obtained and the theory learned. The student has to recall chemical equations to fit the results obtained, understand what the equations mean, as well as, what happens at the micro-level. Teachers need to allow students to experience the reactions, bring in the relevant equations, and perhaps use analogy to describe what happens at the micro-level. The use of multi-media animations also could facilitate the understanding of the reactions at the micro-level (Garnett et al., 1995; Harrison & Treagust, 1998). The reactions involved in qualitative analysis are taught in different topics such as 'Acids, Bases and Salts', 'Reactivity of Metals', 'Periodicity' and 'Redox', so teachers need to link all the reactions taught in the different topics together in qualitative analysis. The use of concept mapping would be most helpful for this task.

Explanation of chemical terms and models

The special language of chemistry poses problems to the learners (Fensham, 1994; Boo, 1998; Gabel, 1999). Andersson (1986b) stressed that careful choice of language is very important in the teaching of chemistry as students, lacking the appropriate framework, may misinterpret the words of teachers and textbook authors giving rise to alternative conceptions. As discussed in Chapter 5, Reif and Larkin (1991) believe that scientific terms are commonly taught to students, but the use of these terms are rarely explicitly elaborated by teachers or practised by students. Thus, students do not fully understand the meaning of the terms, are unable to explain the use of the terms explicitly and cannot use them correctly. Thus, teachers need to carefully explain the chemical terms that they use, especially if the terms have different meaning in everyday use, and ensure that the students understand the meaning of the terms when used in chemistry. Such terms include 'displace', 'dissolve', 'reduce' and 'oxidise'.

It was found in this study that students seemed to have problems determining what constitutes a reduction or oxidation reaction. For example, several students thought that redox was involved in neutralisation reactions because of the 'loss' and 'gain' of oxygen. Ringnes (1995) believes that the way redox is taught in secondary school does not promote understanding because students are taught four different definitions of redox, the chemical terms used are in conflict with their everyday usage, and the historical development of the concepts are seldom given. Herron (1975), Sisler and VanderWerf (1980), Garnett et al. (1990), and Ringnes (1995) believe that the oxidation number model helps students most in understanding and identifying redox reactions. Thus, teachers should emphasise this model of redox when they teach the topic even though the concept of oxidation number is difficult to teach (De Jong et al., 1995).

Qualitative analysis practical work

The usual way of carrying out qualitative analysis practical work in Singapore, that is, using commercially available workbooks, or teacher-prepared worksheets does not seem to help students understand the concepts and propositions involved, as discussed in Chapters 5 to 8, nor help them to acquire the necessary process skills (Goh et al., 1987, 1989; Tsoi, 1994). Students need to have tacit knowledge of the phenomena involved in qualitative analysis, reagents and apparatus, and to construct explanations of the phenomena. They need to acquire manipulative, observational and inferential skills, and their progress has to be monitored closely. Teachers also should allow students to practise the thinking required in qualitative analysis, and to apply what they have learnt to plan, execute and evaluate experiments to identify unknown samples. However, the usual way of doing qualitative analysis demands little cognitive effort as it mainly requires students to follow instructions and write the required observations, and the acquisition of process skills is left to chance. Thus, better ways of conducting qualitative analysis practical work are required and using the QATP may be a step in this direction. However, in Chapter 9, the five teachers who observed the lessons conducted using the QATP were concerned with the amount of time required for the QATP lessons. This raises questions about the value of teaching qualitative analysis in secondary schools if there is inadequate time in the school curriculum for learners to understand what they are doing in qualitative analysis.

Changing the syllabus and assessment

This author believes that the O-level pure chemistry syllabus should include the reactions of acids with sulphate(IV) salts, the formation of complex ammines, and the heating of nitrate(V) and sulphate(IV) salts as these reactions commonly occur in O-level qualitative analysis experiments. For example, students are expected to test for sulphur dioxide but they are not required to know how this gas could be formed, so how would they know when to test for the gas if they do not know when the gas would be evolved? This would result in students randomly testing for the gas. This author had argued in Chapter 3 (pp. 84 & 87) that it was undesirable to instruct students to carry out procedures and get results without understanding what had occurred and why they had obtained such results. This approach would result in the procedures being meaningless to students, and produce gaps in their knowledge and understanding.

Under the present assessment system, students mainly need to write the 'right' answer, that is, record the required observations to do well in the O-level practical examinations. To teach students the 'right' answers, drill and practice is very effective. Thus, it is no surprise that Goh et al. (1987) found that drill and practice was prevalent in qualitative analysis practical work. The words of Mrs. Ang are again used to illustrate the practice in secondary schools:

> I only gear them towards observations because the O-level practical examininations only require them to write the correct observations...so I gear them towards recording the correct observations, how to carry out the tests, how to get marks from the report...so I'm very focussed...

Knowing how to carry out tests, recording observations correctly and writing reports accurately are important, but so is the understanding of what one is doing. Thus, it would seem that "[the present] assessment procedures distort and narrow instruction" (Treagust, 1995, p. 327) in qualitative analysis. Since drill and practice brings good results, it is difficult to persuade teachers and school administers, who are mindful of their schools' academic ranking, to change the way qualitative analysis is taught. As discussed in Chapter 2, "there are significant sociocultural incentives and pressures [in Singapore] that support traditional school performances than for deep understandings of chemistry" (Rop, 1999, p. 222), and "many factors in this school milieu conspire against practices that would encourage meaningful learning" (Novak, 1996, p. 38).

Therefore, in order to improve the teaching and learning of qualitative analysis, the assessment of practical work should be changed. Fortunately, the Ministry of Education, Singapore, is aware of the situation and is introducing a new system of assessing practical work, starting from 2004. In this new assessment system, practical work is assessed within the school, and teachers have to assess their students on four skills, namely, manipulative, observational and recording, interpretation of results, and planning of experiments. It can be seen that the understanding of the concepts and propositions involved in qualitative analysis, as well as, the acquisition of the relevant process skills and thinking required will be important under the new assessment system. This augurs well for the meaningful learning of qualitative analysis. Better ways of teaching practical work will be needed, and the QATP could serve as an example for teachers to prepare their students for the new practical assessment system.

Recommendations for further research

Recommendations for further research are given under the headings 'Students' conceptions of qualitative analysis' and 'Qualitative analysis instruction'.

Students' conceptions of qualitative analysis

More secondary students could be interviewed to identify further alternative conceptions related to the content tested by the individual items in the diagnostic instrument, as well as to further validate the findings of results determined in this study (Peterson, 1986). Any further alternative conceptions identified could replace the reason options which few students choose. Students also could be interviewed after taking the test to find out whether they understood what the items were asking, and the reasons why they made certain choices in the test; an interview protocol could be developed based on the QADI. This could help confirm the validity of the results and give further clues to help teachers understand the causes of students' alternative conceptions. Replication studies using the QADI should also be conducted with "other samples of learners, particularly in different types of institutions, or even in different education systems" (Taber, 2000, p. 481) to determine its relevance to a wider context.

The cross-age study of junior college students', undergraduates' and trainee-teachers' understanding of qualitative analysis was conducted only through the administration of the QADI. The more advanced students also could be interviewed using an interview protocol based on the QADI to probe their understanding of qualitative analysis to help confirm the validity of the results from the cross-age study conducted in this study. It also would be useful to see how the S4 group perform on the QADI after a longer period of 'regular' qualitative analysis practical work to determine if the QATP had any long term effect on the S4 students. In addition, longitudinal studies with the same Grade 10 students through junior college and university could provide more information on changes to students' conceptions of qualitative analysis with increasing chemical education. This could further help confirm the validity of the results of the cross-age study conducted in this study.

Qualitative analysis instruction

The trial of the qualitative analysis teaching package was not intended to do more than to indicate its feasibility. Thus, more extensive trials of the teaching package should be conducted in the future, focussing on its effects on students' understanding of qualitative analysis and performance in the practical sessions, students' attitude towards the practical sessions, the acquisition of process skills such as manipulative, observational and inferential skills, and the acquisition of metacognitive strategies required in qualitative analysis. The learning environment in the chemistry laboratory where lessons are conducted using the QATP also can be studied and compared with the learning environment in the chemistry laboratory using traditional methods of teaching qualitative analysis. More work could be done to improve the QATP, for example, including flowcharts and drawings to help students understand and carry out experimental procedures (Deschri et al., 1997; McDowell & Waddling, 1985; Robinson, 1998) and dividing it up into many shorter worksheets with each worksheet designed to be completed in a 70-minute practical session. The latter would enable teachers to better incorporate the QATP into normal curriculum time.

LIMITATIONS

Seven limitations have been identified in this study. These are the content on qualitative analysis taught by teachers, the selected number of concepts and propositions tested in the QADI, the limited size and nature of the sample used in this study, the problems associated with pencil-and-paper tests, the lack of follow-up interviews, the small number of textbooks and workbooks analysed, and the lack of a well-defined control group in the trial of the QATP.

The content taught

One major limitation of the study is that some teachers may not have taught their students all the reactions involved in the O-level qualitative analysis. For example, teachers may not have taught their students the formation and reactions of complex salts as well as the thermal decomposition of nitrate(V) and sulphate(IV) salts because they are not included in the O-level pure chemistry syllabus. However, these 'extra' reactions are common in the experiments that students do, and are considered by this author as well as Mrs. Boon, Chen and Deng, who reviewed the concept map on qualitative analysis and the lists of propositional knowledge statements and facts, to be within the ability of the students to understand. Some teachers also may not have explicitly highlighted the reactions involved in the practical work, so their students, being novices in chemistry, may be unaware of the important reactions involved. These omissions will affect the study as students might not be able to answer some items in the QADI not because they do not understand the reactions involved, but because they have little or no knowledge of the reactions.

Internal validity of the diagnostic instrument

An external examiner of this thesis argued that the QADI does not have internal validity because items 6 and 11 did not include the reaction of sulphate(IV) with acid in addition to the reaction of carbonate with acid. He believed that this author expected students to answer items 6 and 11 without any knowledge of the behaviour of sulphate(IV) in the presence of acid, and that the students were deemed to have an incorrect concept if they know more than what the O-level pure chemistry syllabus required.

This author did include sulphate(IV) in several items in the first version of the free response test (Appendix I) but removed it from the second version of the free response test (Chapter 6, p. 178) because the students showed little knowledge of sulphate(IV) reactions in the first version, and because sulphate(IV) reactions were not included in the O-level syllabus. He argued earlier in this chapter that it was undesirable to omit reactions such as the reactions of acids with sulphate(IV) and the formation of complex ammines. Even though these reactions were not in the O-level pure chemistry syllabus, they were pertinent to qualitative analysis and were included in the list of propositional knowledge statements (Chapter 3, pp. 85-86). However, teachers in school, for example, Mrs. Ang, might not teach the reactions as she follows the syllabus closely because she felt that her students would be overwhelmed by too many details (see Chapter 3, pp. 78-80).

This author also contended that items 6 and 11 were still valid for Singapore Grade 10 students without any mention of sulphate(IV). Students in Singapore were very likely to have knowledge of the carbonate-acid reaction alone or both carbonate-acid and sulphate(IV)-acid reactions than to know sulphate(IV)-acid reactions only without any knowledge of carbonate-acid reactions. Thus, if students have knowledge of both carbonate-acid and sulphate(IV)-acid reactions, they should be able to choose the options in items 6 and 11 indicating carbonate-acid reaction even though sulphate(IV)-acid reaction was not mentioned. Hence they would not be penalised knowing both reactions. Having mentioned this, this author agreed with the external examiner that wording of the items could be improved to make them clearer and for the QADI to be applicable outside the Singapore O-level pure chemistry context. Thus, this author suggested the following changes (in bold italic) to items 6 and 11 (Figure 10.1).

A more general version of the QADI, which includes the revised items 6 and 11, is given in Appendix O. The author believed that both versions (in Appendices M and O) could be used in Singapore with the version in Appendix O being more suitable for other educational systems.

The same external examiner brought out another point of contention – he believed that in item 4, the option A5 was as correct as the option B5 and it was inappropriate to count option A5 as incorrect in the analysis of the item. He contended that this author was incorrect in calling the mislabelling of a phenomena – the dissolution of zinc hydroxide in nitric(V) acid – as a misconception, quoting the work of Clerk and Rutherford (2000). This author agreed with the examiner that 'mislabels', 'dissolve' in this case, do not indicate the presence of an alternative conception as choosing A5 meant that the students understood the reaction which occurred. Thus, this author did not consider

6. In step (b), the purpose of adding the dilute nitric(V) acid is to:

A acidify the mixture.
B determine if the sample contains carbonate ***or sulphate(IV) (SO_3^{2-})*** ions ***after identifying the gas evolved (if any).***
C dissolve the white solid.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Carbonate ***and sulphate(IV)*** ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.
(3) Dilute nitric(V) acid is a strong oxidising agent.
(4) Dilute nitric(V) acid is a good solvent.
(5) So that Q can react properly with silver nitrate(V).

11. A student is given a solution which may contain carbonate ***or sulphate(IV) (SO_3^{2-})*** ions. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether carbonate ***or sulphate(IV)*** ions are present when she carries out the above procedure ***followed by the identification of the gas involved (if any)***?

A Yes B No

Reason/Justification

(1) An insoluble carbonate ***or sulphate(IV)*** would be formed leaving no free carbonate ***or sulphate(IV)*** ions in solution to react with the acid.
(2) Dilute nitric(V) acid will react with both a soluble and an insoluble carbonate ***or sulphate(IV).***
(3) The above procedure is strictly to test for the presence of sulphate(VI) (SO_4^{2-}) only.
(4) The acid must be added directly to the solution to test for the presence of a carbonate ***or sulphate(IV).***
(5) The unknown compound will only react with the dilute nitric(V) acid and not with the barium nitrate(V).

Figure 10.1: Revised items 6 and 11

option A5 as an alternative conception (pp. 202 & 229). However, he believed that it was inappropriate to consider option A5 as correct because there were doubts on whether the students understand what 'dissolve' meant.

The concepts and propositions assessed

Not all concepts and propositions related to O-level qualitative analysis were measured by the QADI. Therefore, the conclusions refer specifically to the concepts and propositions examined by the test items.

Size and nature of the sample

The sample consisted of 915 Grade 10 students from 11 secondary schools, 360 students from three junior colleges, and 38 undergraduates and 56 trainee-teachers from one university. Although the Grade 10 and junior college samples are small compared to the total number of Grade 10 and junior college students, there is no reason to suggest that the samples are not representative of a normal distribution of Grade 10 and junior college students in Singapore. However, the very small samples of trainee-teachers and undergraduates, particularly the undergraduate sample, might have affected the cross-age study carried out by this researcher.

The attitude of the students towards the test also could affect the results obtained in the cross-age study. As mentioned in Chapter 8, qualitative analysis is included in the syllabi of the O-level and A-level chemistry, so the Grade 10 and junior college students had incentive to be serious in doing the QADI. The graduate trainee-teachers would be assigned to secondary schools or junior colleges teach O-level or A-level chemistry after they complete their one-year PGDE course, thus they were anxious to find out how much they understood about qualitative analysis, and were serious about doing the QADI. However, the majority of the undergraduates, though taking chemistry at the tertiary level, were most likely to be teaching at the primary school level, so they might not have been serious in doing the test or put much thought into it. This issue might have resulted in the 'anomalous' results of the undergraduates as discussed in Chapter 8.

Problems associated with pencil-and-paper tests

There are problems associated with the pencil-and-paper tests. For example, multiple choice tests "make some demands on the reading/comprehension skills of the respondents" (Taber, 1999a, p. 99), and students do not "always perceive and interpret test statements in the way that test designers intend" (Hodson, 1993, p. 97). Students may not understand or may misinterpret the questions and options in the QADI, and since they have little recourse for clarification, this may affect the validity and reliability of the test. The students' conceptions also may be created by the study and not brought to light, that is, the students may never have thought about the concept or phenomena before, but had to invent something to answer the researcher or the items in the QADI. Students guessing of answers also will affect validity and reliability of the test, though Tamir (1990) believes that if a test consists of cognitively high level items, students should be advised to attempt all items, making 'educated guesses' where necessary. The limited number of distracters that can be given a question also meant that only the most common alternative conceptions were likely to be diagnosed (Taber, 1999a).

The lack of follow-up interviews

This researcher did not interview, after the test, any student from the four educational level groups involved in the administration of the QADI, so there was no further identification of alternative conceptions related to the content tested by the items in the QADI and no further validation of the findings of the results determined in the study.

The number of textbooks and workbooks analysed

Only two textbooks and workbooks were analysed in this study to determine whether they are consistent with the concepts and propositional knowledge identified in the study. As there are at least two more approved chemistry textbooks for secondary school and many more commercial workbooks on qualitative analysis practical work, the findings in Chapter 4 cannot be generalised for all chemistry textbooks and qualitative analysis workbooks. However, these two textbooks and two workbooks are commonly used by teachers and students in secondary schools, so many students would have referred to the two textbooks for information on qualitative analysis, or have carried out experiments using the two workbooks.

Lack of a control group during the QATP trial

Due to constraints beyond the control of this author, there was no well-defined control group for the trial of the QATP. Thus, this author could not determine with certainty if the QATP had any significant impact on students' understanding of qualitative analysis as measured by the QADI. This researcher, due to time constraints, also could not examine how the S4 group perform on the QADI after a longer period of 'regular' qualitative analysis practical work to determine if the QATP had any long term effect on the S4 students.

SUMMARY

This chapter summarises how the research questions raised in Chapter 1 were answered. Recommendations for the teaching and learning of qualitative analysis, for further research, and the limitations of the study also were discussed.

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APPENDIX A

NOTES FOR USE IN QUALITATIVE ANALYSIS

Test for anions

anion	*test*	*test results*
carbonate (CO_3^{2-})	add dilute acid	effervescence, carbon dioxide produced
chloride (Cl^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	white ppt.
iodide (I^-) [in solution]	acidify with dilute nitric acid, then add aqueous lead(II) nitrate	yellow ppt.
nitrate(NO_3^-) [in solution]	add aqueous sodium hydroxide then aluminium foil; warm carefully	ammonia produced
sulphate(SO_4^{2-}) [in solution]	acidify with dilute nitric acid, then add aqueous barium nitrate	white ppt.

Test for aqueous cations

cation	*effect of aqueous sodium hydroxide*	*effect of aqueous ammonia*
aluminium (Al^{3+})	white ppt., soluble in excess giving a colourless solution	white ppt., insoluble in excess
ammonium (NH_4^+)	ammonia produced on warming	-
calcium (Ca^{2+})	white ppt., insoluble in excess	no ppt. or very slight white ppt
copper(II) (Cu^{2+})	light blue ppt., insoluble in excess	light blue ppt., soluble in excess giving a dark blue solution
iron(II) (Fe^{2+})	green ppt., insoluble in excess	green ppt., insoluble in excess
iron(III) (Fe^{3+})	red-brown ppt., insoluble in excess	red-brown ppt., insoluble in excess
zinc (Zn^{2+})	white ppt., soluble in excess giving a colourless solution	white ppt., soluble in excess giving a colourless solution

Test for gases

gas	*test and test result*
ammonia (NH_3)	turns damp red litmus paper blue
carbon dioxide (CO_2)	turns limewater milky
chlorine (Cl_2)	bleaches damp litmus paper
hydrogen (H_2)	"pops" with a lighted splint
oxygen (O_2)	relights a glowing splint
sulphur dioxide (SO_2)	turns aqueous potassium dichromate(VI) green

APPENDIX B

SECTIONS ON REDOX AND THE IDENTIFICATION OF IONS AND GASES IN THE O-LEVEL PURE CHEMISTRY SYLLABUS FOR 1999

7.3 Redox

d. Describe the use of aqueous potassium iodide, acidified potassium dichromate(VI) and acidified potassium manganate(VII) in testing for oxidising and reducing agents from the colour changes produced.

8.4 Identification of ions and gases

Candidates should be able to describe and explain the use of the following tests to identify:

a. Aqueous cations
Aluminium, ammonium, calcium, copper(II), iron(II), iron(III) and zinc, using aqueous sodium hydroxide and aqueous ammonia, as appropriate. (Formula of complex ions are not required.)

b. Anions
Carbonates (by reactions with dilute acid and then limewater), chloride (by reaction, under acidic conditions, with aqueous silver nitrate), iodide (by reaction, under acidic conditions, with aqueous lead(II) nitrate), nitrate (by reduction with aluminium to ammonia) and sulphate (by reaction, under acidic conditions, with aqueous barium ions).

c. Gases
Ammonia (using damp red litmus paper), carbon dioxide (using limewater), chlorine (using damp litmus paper), hydrogen (using lighted splint), oxygen (using glowing splint) and sulphur dioxide (using acidified potassium dichromate(VI))

APPENDIX C

EXTRACTS OF RELEVANT SECTIONS OF THE O-LEVEL PURE CHEMISTRY SYLLABUS FOR 1999 PERTAINING TO QUALITATIVE ANALYSIS

A. CHEMICAL REACTIONS

Redox

Describe the use of aqueous potassium iodide, acidified potassium dichromate(VI) and acidified potassium manganate(VII) in testing for oxidising and reducing agents from the colour changes produced.

B. ACIDS, BASES AND SALTS

1. The characteristic properties of acids and bases

a. Describe the meanings of the terms acid and alkali in terms of the ions they contain or produce in aqueous solution and their effects on indicator paper.

b. Describe the neutrality and relative acidity and alkalinity in terms of pH (whole numbers only) measured using Universal Indicator paper.

c. Describe the characteristic properties of acids as in reactions with metals, bases, alkalis, carbonates.

d. Describe the characteristic properties of bases with acids and with ammonium salts.

2. Types of oxides

Classify oxides as either acidic, basic or amphoteric related to metallic/non-metallic character.

3. Preparation of salts

a. Describe the preparation, separation and purification of salts by the use of a suitable solvent, filtration and crystallisation. (Methods of preparing salts to illustrate the practical techniques should include the action of acids with metals, insoluble bases and insoluble carbonates.)

b. Suggest a method of preparing a given salt from suitable starting materials, given appropriate information.

4. Identification of ions and gases

Describe and explain the use of the following tests to identify:

a. Aqueous cations
Aluminium, ammonium, calcium, copper(II), iron(II), iron(III) and zinc, using aqueous sodium hydroxide and aqueous ammonia, as appropriate. (Formulae of complex ions are not required.)

b. Anions
Carbonates (by reactions with dilute acid and then limewater), chloride (by reaction, under acidic conditions, with aqueous silver nitrate), iodide (by reaction, under acidic conditions, with aqueous lead(II) nitrate), nitrate (by reduction with aluminium to ammonia) and sulphate (by reaction, under acidic conditions, with aqueous barium ions).

c. Gases
Ammonia (using damp red litmus paper), carbon dioxide (using limewater), chlorine (using damp litmus paper), hydrogen (using lighted splint), oxygen (using glowing splint) and sulphur dioxide (using acidified potassium dichromate(VI)).

C. THE PERIODIC TABLE

1. Group properties

Describe chlorine, bromine and iodine in Group VII (the halogens) as a collection of diatomic non-metals showing a trend in colour, state and their displacement reactions with other halide ions.

2. Transition elements

Describe the transition elements as metals having high densities, high melting points, variable valency and forming coloured compounds; the elements and their compounds often being able to act as catalysts.

D. METALS

1. Properties of metals

Describe the general physical and chemical properties of metals.

2. Reactivity series

a. Place in order of reactivity calcium, copper, (hydrogen), iron, magnesium, potassium, silver, sodium and zinc by reference to:
   i. the reactions, if any, of the metals with water or steam and with dilute hydrochloric acid.
   ii. the reduction, if any, of their oxides with carbon and with hydrogen.

b. Describe the reactivity series as related to the tendency of a metal to form its positive ion, illustrated by its reaction with the aqueous ions of the other listed metals and the oxides of the other listed metals.

c. Describe the action of heat on the carbonates of the listed metals.

E. HYDROGEN

1. Describe the formation of hydrogen as a product of the reaction between reactive metals and water, and metals and acid.
2. Describe a chemical test for water.

F. NITROGEN

Describe the displacement of ammonia from its salts.

G. SULPHUR

Describe the properties of sulphuric acid as a typical acid.

H. ORGANIC CHEMISTRY

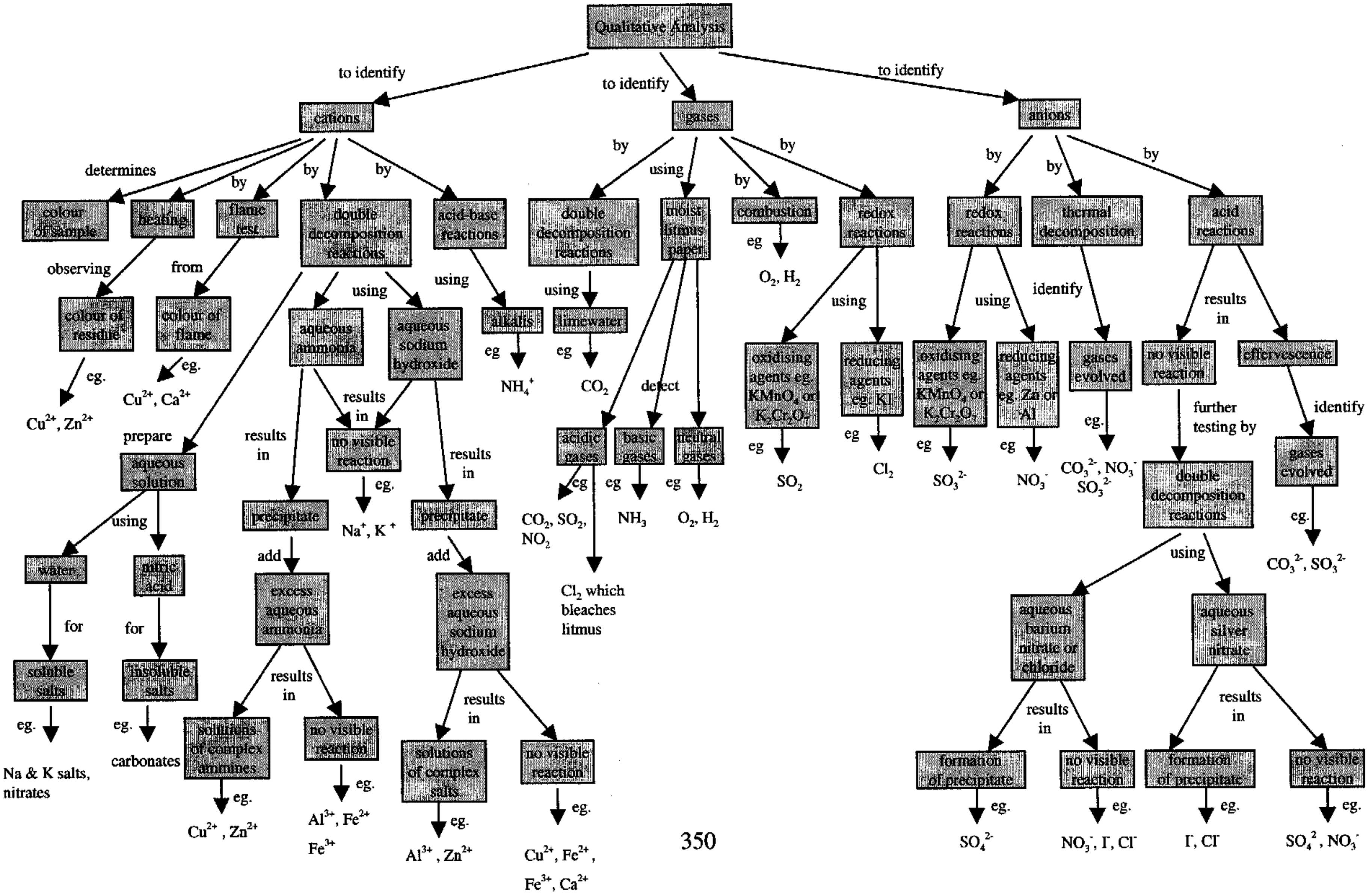
1. Alcohol

Describe the properties of ethanol in terms of burning and of oxidation.

2. Acids

Describe the formation of ethanoic acid by the oxidation of ethanol by the action of atmospheric oxygen and acidified potassium dichromate(VI).

APPENDIX D: FIRST VERSION OF THE CONCEPT MAP ON QUALITATIVE ANALYSIS



APPENDIX E

FIRST VERSION OF THE PROPOSITIONAL KNOWLEDGE STATEMENTS ON QUALITATIVE ANALYSIS

ACIDS, BASES, OXIDES & SALTS

General characteristics

1. Acids ionise in water to form hydrogen ions.
2. Hydrogen ions are responsible for the reactions of acids.
3. The degree of ionisation of an acid in water determines the strength of the acid; the greater the degree of ionisation, the greater the amount of hydrogen ions, the stronger the acid.
4. pH is a measure of how acidic or alkaline an aqueous solution is.
5. Acids turn blue litmus paper red, their $pH < 7$.
6. A base is any metal oxide or hydroxide.
7. Soluble metal hydroxides and aqueous ammonia are alkalis.
8. Alkalis are substances which produce hydroxide ions when dissolved in water.
9. Hydroxide ions are responsible for the reactions of alkalis.
10. The degree of ionisation of an alkali determines its strength. The greater the degree of ionisation, the greater the amount of hydroxide ions, the stronger the alkali.
11. Alkalis turn moist red litmus paper blue, their $pH > 7$
12. Oxides of non-metals are either acidic or neutral.
13. Oxides of metals are either basic or amphoteric.
14. Most acidic oxides dissolve in water to form acids.
15. Neutral oxides have no effect on moist litmus paper.

Reactions

16. An acid will react with a metal above hydrogen in the reactivity series to produce hydrogen and a salt.
17. An acid will react with a carbonate or a hydrogencarbonate to produce a salt, carbon dioxide and water.
18. An acid will react with a sulphate(IV) to produce a salt, sulphur dioxide and water.
19. An acid will react with a base to produce a salt and water only.
20. When an acid reacts with a metal, an insoluble base, carbonate or sulphate(IV) to form an insoluble salt, the reaction will stop after a while due to the formation of the insoluble salt which coats the reactant, preventing further reaction with the acid.
21. An alkali will react with an ammonium salt to produce a salt, ammonia and water

22. An amphoteric oxide is an oxide which will react with an acid or an alkali to produce a salt and water.
23. Aqueous ammonia will react with zinc hydroxide, copper(II) hydroxide and silver chloride to produce soluble complex ions.
24. The solubility of a salt in water determines whether it forms a precipitate during double decomposition reactions.
25. Insoluble salts are prepared by double decomposition reactions (ionic precipitation reactions).

REACTIVITY SERIES

26. The degree of the decomposition of ionic compounds by heat and the products formed depend on the reactivity of the metal present in the compound. The greater the reactivity of the metal, the more stable the compound.
27. Most carbonates decompose on heating to form the oxide and carbon dioxide.
28. Most sulphate(IV) decompose on heating to form the oxide and sulphur dioxide.
29. Most nitrate(V) decompose on heating to form the oxide, oxygen and nitrogen dioxide.
30. Most hydroxides decompose on heating to form the oxide and water.
31. The reactivity of a metal and the strength of the reducing agent determine whether the compound of the metal can be reduced to the metal by the reducing agent.
    a. A metal can be displaced from a solution of its salt if a more reactive metal is introduced to the solution. The less reactive metal and the salt of the more reactive metal are formed.
    b. A metal can be displaced from its oxide if heated with a more reactive metal or reducing agent.

REDOX

32. Oxidation can be defined as
    a. the gain of oxygen
    b. the loss of hydrogen
    c. the loss of electrons
    d. an increase in the oxidation state
33. Reduction can be defined as
    a. the loss of oxygen
    b. the gain of hydrogen
    c. the gain of electrons
    d. a decrease in the oxidation state
34. An oxidising agent (oxidant)
    a. causes the oxidation of another species
    b. accepts electrons from the species being oxidised
    c. is reduced

35. A reducing agent (reductant)
    a. causes the reduction of another species
    b. donates electrons to the species being reduced
    c. is oxidised

QUALITATIVE ANALYSIS

36. The colour of a substance may help in the identification of the substances.
37. The colour changes and evolution of gases, if any, when a substance is heated may help in the identification of the substance.
38. Gases are identified by
    a. their colour and odour
    b. testing with moist litmus paper
    c. precipitation reactions
    d. redox reactions
    e. combustion reactions (using glowing or lighted splint)
39. Aqueous solutions of salts are used to test for cations so that double decomposition reactions can take place.
40. Insoluble salts are treated with dilute nitric(V) acid to produce, if possible, a soluble nitrate(V). Dilute hydrochloric acid and sulphuric(VI) acid should not be used to avoid the formation of any insoluble chloride or sulphate(VI).
41. Cations are identified by their reactions with aqueous sodium hydroxide and aqueous ammonia.
42. If a precipitate is formed due to the formation of an insoluble hydroxide, the colour of the precipitate and whether it is soluble in excess aqueous sodium hydroxide or aqueous ammonia identifies the cation.
    a. Amphoteric hydroxides are soluble in excess aqueous sodium hydroxide to give colourless solutions.
    b. If the precipitate is soluble in excess aqueous ammonia, then it forms a complex salt with the aqueous ammonia.
43. Flame tests are used to identify cations. Different cations give different flame colours.
44. Redox reactions can be used to identify cations.
45. Carbonate and sulphate(IV) anions are identified by their reactions with nitric acids. Identification of carbon dioxide or sulphur dioxide is indicative of the presence of carbonate or sulphate(IV) anions.
46. Aqueous barium nitrate(V) or barium chloride is used to identify sulphate(VI) anions. Insoluble barium sulphate(VI) is formed in a double decomposition reaction.
47. Aqueous silver nitrate(V) or lead(II) nitrate(V) is used to identify chloride and iodide anions. Insoluble silver chloride, silver iodide, lead(II) chloride or lead(II) iodide is formed in a double decomposition reaction.

48. When an acid is to be added to any precipitate formed, the anion of the acid must be the same as the anion of the barium, silver or lead(II) reagent added in the first instance.

49. Nitrate(V) anions are identified by reaction with metals, such as zinc, aluminium or Devada's alloy, and sodium hydroxide. Nitrate(V) ions react with the metals and sodium hydroxide to form ammonia. Identification of ammonia gas is indicative of the presence of nitrate(V) anions.

APPENDIX F

FACTS RELEVANT TO QUALITATIVE ANALYSIS

Oxides

1. Oxides of non-metals are either acidic or neutral.
2. Carbon dioxide, nitrogen dioxide and sulphur dioxide are acidic.
3. Water is a neutral oxide.
4. Oxides of metals are either basic or amphoteric.
5. Examples of basic oxides are oxides of sodium, calcium and iron.
6. Zinc oxide and aluminium oxide are amphoteric oxides.
7. All common oxides (and hydroxides) of metals are insoluble except those of potassium and sodium.

Solubility of salts

8. All sodium, potassium and ammonium salts are soluble.
9. All nitrate(V) salts are soluble.
10. All common chlorides are soluble except those of silver and lead.
11. All common iodides are soluble except those of silver and lead.
12. Lead(II) chloride and lead(II) iodide are soluble in hot water, insoluble in cold water.
13. All common sulphate(VI) salts are soluble except those of barium, calcium and lead.
14. All common carbonates are insoluble except those of sodium, potassium and ammonium.

Indicators

15. pH is a measure of how acidic or alkaline an aqueous solution is.
16. Acidic solutions turn moist blue litmus paper red, their $pH < 7$.
17. Alkaline solutions turn moist red litmus paper blue, their $pH > 7$.
18. Neutral solutions have no effect on litmus, their $pH = 7$.

Reactivity of metals

19. The decreasing order of reactivity of metals is as follows: Potassium, sodium, calcium, magnesium, aluminium, zinc, iron, (hydrogen), copper, silver, gold.
20. Most carbonates, except those of sodium and potassium, decompose on heating to give carbon dioxide and the metal oxide. Carbonates of sodium and potassium are not decomposed by normal heating.
21. Most sulphate(IV) salts, except those of sodium and potassium, decompose on heating to give sulphur dioxide and the metal oxide.

Sulphate(IV) salts of sodium and potassium are not decomposed by normal heating.

22. Nitrate(V) salts of sodium and potassium decompose on heating to form the nitrate(III) salts and oxygen. Nitrate(V) salts of calcium, magnesium, aluminium, zinc, iron and copper decompose on heating to form the metal oxide, oxygen and nitrogen dioxide.

Redox

23. Potassium dichromate(VI) is an oxidising agent.
24. Potassium dichromate(VI) solution is usually acidified with sulphuric(VI) acid for use in redox reactions.
25. When acidified potassium dichromate(VI) is added to a reducing agent, the chromium in the +6 oxidation state, which gives an orange colour to the solution, is reduced to the +3 oxidation state, which gives a green colour to the solution.
26. Potassium manganate(VII) is an oxidising agent.
27. Potassium manganate(VII) solution is usually acidified with sulphuric(VI) acid for use in redox reactions.
28. When acidified potassium manganate(VII) is added to a reducing agent, the manganese in the +7 oxidation state, which gives a purple colour to the solution, is reduced to the +2 oxidation state, which gives a pale pink colour to the solution. If manganese in the +4 oxidation state is produced in a redox reaction under alkaline conditions, a brown precipitate of manganese (IV) oxide would be produced.
29. Sulphuric(VI) acid is used to acidify potassium dichromate(VI) and potassium manganate(VII) because it is not oxidised by them.
30. Iron(III) compounds are oxidising agents.
31. When a solution of an iron(III) salt is added to a reducing agent, the iron in the +3 oxidation state, which gives a yellow colour to the solution, is reduced to the +2 oxidation state, which gives a light green colour to the solution.
32. Iodine is an oxidising agent.
33. When iodine is dissolved in potassium iodide solution, a reddish brown solution is formed. When there is excess iodine present, a black precipitate in a reddish brown solution is obtained.
34. When iodine is dissolved in certain organic solvents such as dichloromethane, a pinkish purple solution is obtained.
35. When aqueous iodine is added to a reducing agent, the iodine is reduced to iodide ion which is colourless.
36. Potassium iodide is a reducing agent.
37. When potassium iodide, which is colourless, is added to an oxidising agent, the iodide ion is oxidised to iodine.
38. Iron(II) compounds are reducing agents.
39. When an acidified solution of an iron(II) salt is added to an oxidising agent, the iron in the +2 oxidation state, which gives a green colour to the solution, is oxidised to the +3 oxidation state, which gives a yellow colour to the solution.

40. Ethanol is a reducing agent.
41. When ethanol is added to an oxidising agent, ethanol is oxidised to form ethanoic acid.

Qualitative analysis

Appearance of substances

42. Most metals are silvery in bulk, and grey in fine powder form; copper is brown.
43. Transition metals usually form coloured compounds.
44. Copper(II) compounds are blue or green.
    a. solid copper(II) oxide is black
    b. solid hydrated copper(II) nitrate and hydrated copper(II) sulphate(VI), and their solutions are blue
    c. solid hydrated copper(II) chloride and its solution is green
    d. solid copper(II) carbonate is green
45. Solid hydrated iron(II) compounds and their solutions are green.
46. Solid hydrated iron(III) compounds are yellow or brown and their solutions are yellow or brown.
47. Compounds of Groups I, II, III, ammonium and zinc in the solid state are usually white, and they form colourless solutions.
48. Carbon is black.
49. Solid iodine is greyish black.

Colour of residues after heating

50. Sodium, potassium, calcium, aluminium and zinc compounds give white residues.
51. Zinc oxide is yellow when hot and white when cooled.
52. Ammonium chloride dissociates when heated and recombine to give a white solid when cooled.
53. Iron(III) oxide is reddish brown.
54. Copper(II) oxide is black.

Test for gases

55. Water vapour
    a. is colourless and odourless.
    b. is neutral to litmus.
    c. turns white anhydrous copper(II) sulphate(VI) to blue hydrated copper(II) sulphate(VI).
    d. turns blue anhydrous cobalt(II) chloride to pink hydrated cobalt(II) chloride.
56. Ammonia gas
    a. is colourless, pungent and very soluble in water.
    b. turns moist red litmus paper blue.

57. Carbon dioxide
   a. is colourless, odourless and soluble in water.
   b. turns moist blue litmus paper slightly red.
   c. gives a white precipitate of calcium carbonate with limewater; the calcium carbonate reacts with excess carbon dioxide and water to form a solution of calcium hydrogencarbonate.
58. Chlorine
   a. is yellowish-green, pungent and soluble in water.
   b. turns moist blue litmus paper red and then bleaches it.
59. Hydrogen
   a. is colourless, odourless and insoluble in water.
   b. is neutral to litmus as it does not produce hydrogen or hydroxide ions.
   c. extinguishes a lighted splinter, placed at the mouth of the test tube of the gas, with a 'pop' sound, as it reacts explosively with oxygen present in the air to produce water.
60. Oxygen
   a. is colourless, odourless and slightly soluble in water.
   b. is neutral to litmus.
   c. relights a glowing splinter, as the increased concentration of oxygen present causes the glowing splinter to burn more vigorously.
61. Sulphur dioxide
   a. is colourless, pungent and soluble in water.
   b. turns moist blue litmus paper red.
   c. turns orange acidified potassium dichromate(VI) green.
   d. turns purple acidified potassium manganate(VII) pale pink.

Test for cations

using sodium hydroxide

62. Calcium ions react with aqueous sodium hydroxide to form slightly soluble calcium hydroxide. The excess calcium hydroxide deposits as a white precipitate which does not react with excess sodium hydroxide.
63. Zinc ions react with aqueous sodium hydroxide to form a white precipitate, zinc hydroxide. The amphoteric zinc hydroxide will then react with excess sodium hydroxide to form soluble sodium zincate, giving a colourless solution.
64. Aluminium ions react with aqueous sodium hydroxide to form a white precipitate, aluminium hydroxide. The amphoteric aluminium hydroxide will then react with excess sodium hydroxide to form soluble sodium aluminate, giving a colourless solution.
65. Sodium hydroxide cannot be used to differentiate between zinc and aluminium ions.
66. Copper(II) ions react with aqueous sodium hydroxide to form a blue precipitate, copper(II) hydroxide.

67. Iron(II) ions react with aqueous sodium hydroxide to form a green precipitate, iron(II) hydroxide. On standing, iron(II) hydroxide is oxidised by oxygen in the air to form reddish brown iron(III) hydroxide.
68. Iron(III) ion reacts with aqueous sodium hydroxide to form a reddish brown precipitate, iron(III) hydroxide.
69. Sodium and potassium ions do not react with aqueous sodium hydroxide.
70. Ammonium ions will give a colourless solution with aqueous sodium hydroxide, which liberates ammonia gas on heating.

using aqueous ammonia

71. Aqueous ammonia is a weak base and hence only small amounts of hydroxide ions are present.
72. Calcium ions react with aqueous ammonia to form small amounts of slightly soluble calcium hydroxide which can remain in solution. If concentrated aqueous ammonia is used, a white precipitate may be obtained.
73. Zinc ions react with aqueous ammonia to form a white precipitate, zinc hydroxide. The zinc hydroxide will then react with excess ammonia to form a complex ammine ion which is soluble in water to form a colourless solution.
74. Aluminium ions react with aqueous ammonia to form a white precipitate, aluminium hydroxide. The aluminium hydroxide will not react with excess aqueous ammonia because it does not form a complex ammine ion, and there is insufficient hydroxide ions to form the aluminate ion.
75. Copper(II) ions react with aqueous ammonia to form a blue precipitate, copper(II) hydroxide. The copper(II) hydroxide reacts with excess ammonia to form a complex ammine ion which is soluble in water to give a deep blue solution.
76. Iron(II) ions react with aqueous ammonia to form a green precipitate, iron(II) hydroxide. On standing, iron(II) hydroxide is oxidised by oxygen in the air to form brown iron(III) hydroxide.
77. Iron(III) ions react with aqueous ammonia to form a reddish brown precipitate, iron(III) hydroxide.
78. Sodium, potassium and ammonium ions do not react with aqueous ammonia.

using potassium iodide

79. The redox reaction between copper(II) ions and potassium iodide is used to identify copper(II) ions. A white precipitate, copper (I) iodide, in a brown solution is obtained.

Test for anions

using dilute acids

80. Carbonate and sulphate(IV) anions are identified using dilute nitric acid.
81. Carbon dioxide or sulphur dioxide liberated when dilute nitric acid is added to the unknown indicates the presence of a carbonate or sulphate(IV) salt.
82. Use of dilute hydrochloric acid or sulphuric(V) acid for the testing of carbonate and sulphate(IV) anions may result in the formation of insoluble chlorides or sulphate(VI) salts.

using aqueous barium chloride or barium nitrate(V)

83. Aqueous carbonates react with aqueous barium chloride or barium nitrate(V) to give a white precipitate, barium carbonate. When dilute hydrochloric acid (if barium chloride is used) or dilute nitric(V) acid (if barium nitrate(V) is used) is added to the white precipitate, the precipitate reacts to give carbon dioxide and soluble barium chloride or barium nitrate(V) respectively.
84. Aqueous sulphates (IV) react with aqueous barium chloride or barium nitrate(V) to give a white precipitate, barium sulphate(IV). When hydrochloric acid (if barium chloride is used) or nitric(V) acid (if barium nitrate(V) is used) is added to the white precipitate, the precipitate reacts to give sulphur dioxide and soluble barium chloride or barium nitrate(V) respectively.
85. Aqueous sulphates (VI) react with aqueous barium chloride or barium nitrate(V) to give a white precipitate, barium sulphate(VI), which does not react with hydrochloric acid or nitric(V) acid.
86. Aqueous nitrate(V) salts do not react with aqueous barium chloride or aqueous barium nitrate(V).
87. There is no need to add hydrochloric acid (if barium chloride is used) or nitric(V) acid (if barium nitrate(V) is used) if no precipitate is formed.
88. Aqueous chlorides and iodides do not react with aqueous barium nitrate(V) or aqueous barium chloride.

using aqueous silver nitrate(V)

89. Aqueous carbonates react with aqueous silver nitrate(V) to give a pale yellow precipitate, silver carbonate. When dilute nitric(V) acid is added to the pale yellow precipitate, the precipitate reacts to give soluble silver nitrate(V) and carbon dioxide.
90. Aqueous sulphates (IV) react with aqueous silver nitrate(V) to give a white precipitate, silver sulphate(IV). When nitric(V) acid is added to the white precipitate, the precipitate reacts to give soluble silver nitrate(V) and sulphur dioxide.

91. When aqueous silver nitrate(V) is added to sulphate(VI) salts, there is no visible reaction. However, if concentrated solutions are used, a white precipitate may be obtained as silver sulphate(VI) is not very soluble in water.
92. There is no need to add dilute nitric(V) acid, if no precipitate is formed.
93. Aqueous nitrates (V) do not react with aqueous silver nitrate(V), so there is no visible reaction.
94. Aqueous chlorides react with aqueous silver nitrate(V) to give a white precipitate, silver chloride, which does not react with nitric acid. When aqueous ammonia is added to the white precipitate of silver chloride, the precipitate disappears due to the formation of a soluble complex ammine ion.
95. Aqueous iodides react with aqueous silver nitrate(V) to give a yellow precipitate, silver iodide, which does not react with nitric acid or aqueous ammonia.

using redox reactions

96. A test for nitrate(V) is to heat it gently with aqueous sodium hydroxide and Devada's alloy or aluminium or zinc powder. There will be a vigorous reaction and ammonia gas is evolved. If the original unknown solution does not contain ammonium ions, then the detection of ammonia gas confirms the presence of nitrate(V).

using aqueous lead(II) nitrate

97. Aqueous chlorides react with aqueous lead(II) nitrate to give a white precipitate, lead(II) chloride. When the mixture is heated, the white precipitate disappears, but reappears on cooling as lead(II) chloride is soluble in hot water but insoluble in cold water.
98. Aqueous iodides react with aqueous lead(II) nitrate to give a yellow precipitate, lead(II) iodide. When the mixture is heated, the yellow precipitate disappears, but reappears on cooling as lead(II) iodide is soluble in hot water but insoluble in cold water.

APPENDIX G

TRANSCRIPT OF THE INTERVIEW
WITH STUDENTS 40 AND 41

Interviewer: My first question is how to do you find QA [qualitative analysis]?

Student 40 : It's very confusing.

Interviewer: Why do you say that?
Student 40 : OK...it's like they tell you like...when you are testing for chloride and you happily do the test and get the results...it's like...it's... because you see...you're...you just have no idea what they might give you...and sometimes...sometimes your...I mean I find it very, very hard to get like...the specific reaction, specific colours and things like that.

Interviewer: What do you mean? Can you further elaborate what you mean (by) specific reaction and colours?

Student 40 : OK...it's like when they ask you to...they just give you some X substance and ask you find out which anion which cation is there. You are half the time...I don't know...I just don't know where to start. So even though like they tell you like first test is for like... say carbonate and then you go on...I'm very like...I don't know I'm very insecure as to...what I do is...when I do a test I just like...I don't know...I'm never thinking on what it might be, I just write down all the...what I see. So in the end when I...will have to make a conclusion...I find it very difficult because...it could just be...it's like...yah like I'm...I put...I put this dilute nitric acid and what lead nitrate. I don't, I never ever think that it could be iodide or whatever. I just...I just do the colour change and then the end when I look at it, it all doesn't make sense to me...and I find it very hard to make a conclusion.

Interviewer: What about you?

Student 41 : Yah I also...I also find it quite difficult because most of the time we have this who series of tests...and we end up with only one conclusion...we only...we usually drive the conclusion from only one test...it's like the other tests seems to confuse us somehow... yah.

Interviewer: I see. What do you mean confuse you somehow?

Student 41 : Because...say sometimes when...you add a certain chemical to it (unknown sample)...then it changes to a colour which you don't find in the QA notes...then you don't know what...what the reaction is...and you just interpret your thoughts when you... you're deriving the conclusion.

Interviewer: I see...now does the procedures make sense to you...in other words, do you understand what's going on?

Student 40 : No, I just follow it.

Interviewer: What about you?

Student 41 : Sometimes I can recall like lead nitrate or silver nitrate or...OK... I can recall what I am doing but sometimes...most of the time I don't really think about it...I just finish everything then I derive the conclusion.

Student 40 : Yah.

Interviewer: OK…any other difficulty that you face?

Student 40 : Well, actually the most…most of the time when we do QA in school at least we do together with titration and everything…and you do it in a fixed timing [have to do one volumetric as well as one qualitative analysis experiment within the time allocated for a practical session]. So we are…I don't know we…I tend to take more time for the titration so when it comes to QA, I'm already panicked…so er you know you tell yourself to be…go slowly and look carefully but then you're thinking about…oh no will I finish it. So I think for me it's the time factor. I'm sure if I do it like slowly and steadily, you give me two hours to do it, I… probably will get the right things…but for me it's the time…I get very panicked.

Interviewer: OK, what about you?

Student 41 : Yah, difficulty in sometimes…when you mix reagent like… certain reagents that they give you…it's not in your syllabus like sodium thiosulphate…things like that…certain cases or…which you might not have learn that in your syllabus…yah and will…you will be very confused yah.

Interviewer: Now when you study for your QA exams, I mean your practical exams, do you refer to your textbooks at all.

Student 40 : No.

Student 41 : No.

Interviewer: No…do you see any chapters or topics that is related to QA?

Student 40 : I read up the list on solubility…yah…I kind of memorise it… that's was the main thing and then I read the…the…reactivity series…yah…and I think those two.

Interviewer: What did you read…what did you read on in reactivity series?

Student 40 : Well I mean er I know like the tentative reaction and certain metals you know when you heat and things like that…yuah and what will you get…the oxides and hydroxides and…

Interviewer: OK.

Student 40 : I just went through that.

Interviewer: OK.

Student 41 : I just look through the QA notes and the list of reducing and oxidising agents…yah…that's it.

Interviewer: OK…all right…let me give you some specific questions. OK… OK can you tell why is sodium hydroxide added? [referring to Interview Questions Set 3]

Student 41 : Is it something to do with the reactivity series…no…metals will it displace it for sodium…something like…

Interviewer: Can you elaborate further what do you mean?

Student 41 : If it's more reactive than sodium, then it should decrease, I mean displace sodium from sodium hydroxide.

Interviewer: OK.

Student 41 : Maybe something like that.

[some discussion between Students 40 and 41]

Interviewer: This is R…OK…and I'm going to add sodium hydroxide to this. What do you think the purpose of adding sodium hydroxide is?

Student 41 : Neutralise acid [laughter].

Interviewer: OK, any other things?

Student 41 : Hydroxide…

Student 40 : Haven't really thought about it.

Interviewer: OK…can you give me examples of situations…where you use sodium hydroxide before…in your QA?

Student 41 : Cations…is that…cations right?

Student 40 : Yes.

Student 41 : That's all. Only for cations…to test for cations.

Student 40 : Yah.

Interviewer: Right. How is it used to test for cations?

Student 40 : Well…[unintelligible]…we…we look at the colour of the precipitate and then eliminate…eliminate and all that until…

Interviewer: OK…now why it the precipitate formed?

Student 40 : Because it is an insoluble…substance.

Student 41 : Insoluble substance yah.

Student 40 : All right.

Interviewer: OK, can you identify what substance it is?

Student 40 : Which one?

Interviewer: OK…assuming this is the substance that I give you and I'm supposed to add sodium hydroxide…all right…OK let me add [adding sodium hydroxide to the unknown sample in a test tube] …I get this. OK can you hold this [the test tube]. Can you make any conclusion?

Student 40 : Iron(II) cation.

Interviewer: OK.

Student 41 : Iron(II).

Student 40 : Iron(II).

Interviewer: OK…you identified iron(II)…but iron(II) what?

Student 40 : Hydrox…ox…

Student 41 : Iron(II) hydroxide.

Student 40 : Hydroxide or [unintelligible].

Interviewer: Why do you say hydroxide or oxide?

Student 40 : Because it reacts with sodium hydroxide and it has to…to react with the substance [laughter]…[unintelligible]…aluminium…iron(II).

Student 41 : Iron(II) oxide.

Student 40 : No…no.

Student 41 : Then…how come you get oxide…now why did you say iron(II) hydroxide and iron(II) oxide?

Interviewer: What sort of reaction do you think took place?
[some discussion]

Student 41 : Precipitation…

Student 40 : I don't know…

Student 41 : I also don't know.

Interviewer: Can you explain or elaborate what do you mean by precipitation?

Student 41 : Formation of insoluble salt.

Interviewer: OK, what happens to give you the insoluble salt?
[some discussion]

Student 41 : Is it…soluble alkali…er no…what am I talking about. Soluble… what's that thing?

Student 40 : This metal…

Student 41 : Metal is…

Student 40 : There's not…
[some discussion]

Student 40 : That iron(II)…got ions react with the hydroxide ions…possibly… [laughter].

Student 41 : [unintelligible]

Interviewer: OK…let me say then…then what happens to the sodium ions and the …anion of the …original iron(II)?

Student 40 : They probably for a soluble…

Student 41 : Form a solution…yah they form a soluble…

Interviewer: OK, OK, now…have you ever done this test using sodium hydroxide solution on a solid sample?

Student 40 : No…except [unintelligible].

Interviewer: Can it be used for a solid sample?

Student 40 : No.

Interviewer: Why not?

Student 40 : Because the ions have to dissociate in aqueous…condition.

Interviewer: Why must it dissociate?

Student 40 : So that they react with the…I mean…

Student 41 : Free ions so that they can…

Student 40 : React…

Student 41 : React with the sodium hydroxide ion.

Interviewer: OK now you think about sodium hydroxide…what does sodium hydroxide contain?

Student 40 : What ions?

Interviewer: What substances are there in it?

Student 40 : Na^+.

Student 41 : Sodium, hydroxide…OH^-.

Student 40 : H^+… OH^-.

Student 41 : H^+… OH^-.

Interviewer: OK…now where does it originate?

Student 40 : The aqueous…that is water.

Interviewer: In water. OK now, sodium hydroxide, OK, contains a lot of water …sodium hydroxide…in it…now do you think the solid can be… can dissolve in the water…can it?

Student 40 : You mean…you mean dissolve in water in sodium hydroxide?

Student 41 : Because…can it dissolve…

Interviewer: When you think of sodium hydroxide, do you ever think that there is water present or is it…or is it [do you] focus solely on sodium hydroxide?

Student 40 : Focus…

Student 41 : I always focus on sodium hydroxide.

Student 40 : Sodium and hydroxide.

Interviewer: The water…you then to…push one side?

Student 40 : Yah…yah.

Interviewer: OK…now sometimes…some precipitate dissolves in excess. OK …can you tell why these precipitate sort of disappears or dissolves in excess?

Student 41 : Maybe when add in excess, it forms another soluble salt, that's why it dissolves. At first when it was added in…maybe two cubic centimetre, it's…a soluble…insoluble salt is formed. Then when more is added, another salt is formed, another soluble salt is formed.

Interviewer: Another soluble salt is formed?

Student 40 : Like limewater turns clear.

Interviewer: OK…OK…all right now…for (b) [referring to the experiment in Part A]…why do you think heat is necessary?
[some discussion]

Student 41 : Dissolve better…

Interviewer: Sorry?

Student 41 : The…[unintelligible].

Student 40 : Never mind.

Student 41 : Any test for sodium…

Interviewer: Here are the results…you have this too [giving students the paper with the results of the experiment in Part A]. Can you make any conclusion from the results?

Student 40 : It's a soluble…

Student 41 : Ammonia.

Student 40 : Ammonia.

Interviewer: OK…how do you test for ammonia?

Student 40 : Moist…litmus paper.

Student 41 : Moist red litmus.

Interviewer: Why must you get…make it, the litmus paper, moist?

Student 41 : So that ammonia…the ions can dissociate when there is water around...when there is moisture around.

Interviewer: You are saying ammonia ions can dissociate?

Student 41 : Ammonia…the…the ions in ammonia gas.

Interviewer: The ions in ammonia gas can dissociate…to be?

Student 40 : Ammonium gas.

Student 41 : Ammonia.

Student 40 : Ammonia…wait, wait, wait…

Interviewer: What will be formed if it dissociates?

Student 41 : When it comes…no…when, when the ammonium ions come into, to water, then it will form ammonium hydroxide which is an alkali…

Student 40 : Forms ammonium hydroxide.

Interviewer: Uh hm.

Student 40 : So the litmus paper turns blue.

Student 41 : Hm…yah, yah it turns blue.

Interviewer: OK…which ion is responsible for turning the litmus blue?

Student 40 : Hydroxide.

Interviewer: Hydroxide…you don't include the ammonium ions?

Student 40 : No.

Interviewer: OK…OK…now so if it is ammonium…ammonia gas… [unintelligible]…why do you…why is it necessary to heat in (b)?

Student 41 : Maybe to test for…
[silence]

Interviewer: OK…OK…it's all right. Maybe I give you another procedure [giving students Part B]. OK now do you know why silver nitrate is added?

Student 41 : So that you will know there's chloride ions present…it will show.

Interviewer: OK…why is the chloride ion pres…how does it show?

Student 41 : Form silver chloride.

Student 40 : Precipitate…

Student 41 : Which is…insoluble
Interviewer: OK…why is the precipitate formed…how is the precipitate formed?
Student 41 : When silver reacts with the chloride ion…form silver chloride…insoluble salt.

Interviewer: OK…OK…now what do you think is the function of (b) [adding aqueous ammonia]?

Student 41 : To test for the cation.

Interviewer: OK…why do you test for the cation?

Student 41 : That's what you say initially...use aqueous ammonia to test for cation.
Interviewer: OK...so could you give the reason why is it used to test for cation... [silence]
Interviewer: Anything you're...acid is used in part (c)
Student 40 : What's the procedure we take?
Student 41 : Nitric...acidify...
Student 40 : Can I check something?
Student 41 : To remove impurities or something like that.
Student 40 : That's...that's the first test...to acidify...
Interviewer: You're saying something?
Student 41 : To remove impurities.
Interviewer: Remove impurities.
Student 40 : To...to see that it might be...
Student 41 : Carbonate.
Student 40 : Carbonate.
Interviewer: OK...let's see what happens...this is...[unintelligible]...used [adding silver nitrate(V) to unknown]...can you draw any conclusions from here
Student 41 : Chloride.
Student 40 : Chloride ion is present.
Interviewer: OK, now I'm adding ammonia [adding aqueous ammonia to silver chloride precipitate]...can you see it...what happens?
Student 41 : Precipitate dissolves.
Student 40 : Dissolves.
Interviewer: OK...why does...why do you think it dissolves?
Student 40 : No but ammonium...silver...ammonium chloride...
Student 41 : Ammonium chloride, is it soluble...yah.
Interviewer: What did you say?
Student 40 : The...precipitate from the first reaction is silver chloride...and which when it reacts with aqueous ammonia...ammonium chloride is formed...which is soluble...yah.
Interviewer: What did you say?
Student 40 : The...precipitate from the first reaction is silver chloride...an which when it reacts with aqueous ammonia...ammonium chloride is formed...which is soluble.
Interviewer: OK...now do you have any idea what...will form if I add acid?
Student 40 : No...remains...
Student 41 : Silver nitrate...nitric acid...
Student 40 : No. Remains white...it remains colourless.
Interviewer: OK...OK...this is the nitric acid...let's see what happens if I add in the acid. Can you see it? What do you think happen?
Student 41 : Silver chloride is formed...again.
Interviewer: Silver chloride...how do you think it's formed?
Student 40 : Just replace the ammonium from the...
Student 41 : [Unintelligible]...maybe when the acid is added, the ammonium chloride...you get ammonia...ammonium nitrate is formed so the chloride ions are...react with silver again.
Interviewer: I see, I see. OK...now...assuming I have another [unintelligible] ...now...what causes the...[unintelligible]...again you were saying?
Student 41 : Silver chloride.
Interviewer: Silver chloride. OK...anything... [silence]

[interviewer keeps Set 3 and shows Set 1 Part B to the students]
Interviewer: OK...why do you think barium chloride is used?
Student 41 : To test for sul...sulphate.
Interviewer: Test for?
Student 41 : Sulphate.
Interviewer: Why is it used to test for sulphate?
Student 41 : Because barium...barium sulphate is insoluble.
Interviewer: OK...so what do you...what do you expect from here?
Student 41 : If it is sulphate, it will...a white precipitate will form.
Interviewer: OK...now have you done this procedure before...after you add in barium chloride you add an...acid?
Student 40 : No.
Interviewer: No? What do you normally do? Do you add an acid?
Student 40 : You have to add the...an acid first.
Interviewer: Is there any difference?
[some discussion]
Interviewer: Why do we add an acid?
Student 40 : I always thought it was just to...yah you see it might be carbonate ...[unintelligible]
Interviewer: OK...now if you...put acid first, what will happen?
Student 41 : If not carbonate not...generally nothing happens.
Interviewer: OK...now...what besides...rather...that means when you put acid, you will be prepared to test for some gases?
Student 40 : Mmm.
Interviewer: What gases would you prepare to test for?
Student 41 : Carbon dioxide.
Interviewer: Why carbon dioxide?
Student 41 : Because if it's carbonate, then you get carbon dioxide.
Interviewer: How?
Student 41 : Acids react with carbonate to give you carbon dioxide.
Student 40 : Yah.
Interviewer: OK...what's...what's the test?
Student 40 : Limewater.
Interviewer: What happens?
Student 40 : A white precipitate which is...[unintelligible].
Student 41 : A white precipitate is formed.
Interviewer: Why is the white precipitate formed?
Student 40 : Calcium...
Student 41 : Calcium hydroxide plus a carbonate [carbon dioxide] form calcium carbonate which is insoluble.
Student 40 : Which is insoluble...
Interviewer: OK...now would you be prepared to test for any other gas...when you use an acid?
Student 40 : Hydrogen...no I don't think so...[laughter]
Interviewer: Why...why do you...you think not hydrogen now...or you think that you should test for hydrogen?
Student 41 : Why do you test for hydrogen? Can you use acid to test for hydrogen?
Student 40 : No. To just clean metal.
Interviewer: OK...you're given the aqueous sample...would you test for hydrogen as well?
Student 40 : Maybe not.

Student 41 : In fact all the time when we do QA, we test for all the gases... [laughter]
Interviewer: You test for all the gases...OK...
Student 41 : Yah.
Student 40 : We start off with the litmus paper and then...
Student 41 : And a glowing splint and a burning splint.
Interviewer: OK...would you test for oxygen then here?
Student 41 : No.
Interviewer: Why not?
Student 41 : Assuming everything changes to carbonate...I mean carbon dioxide, so if it's...shouldn't expect any oxygen given off.
Interviewer: OK...besides possibly like carbon dioxide...possibly hydrogen... anything else that you will test for?
Student 41 : Chlorine...[unintelligible]
Interviewer: Why chlorine?
Student 41 : Because it is hydrochloric acid...[laughter]
Interviewer: OK...what happens to give you chlorine?
[some discussion]
Student 41 : You put acid with another...another halogen ion...
Student 40 : Ha.
Student 41 : I don't know.
Interviewer: OK...never mind. Let me show you...this is the unknown, this is barium chloride...[adding barium chloride to the unknown]... OK...can you make any comment so far...knowing...
Student 40 : The white is sulphate.
Interviewer: The...[unintelligible]...is sulphate...OK now...I put acid...[adding acid to the mixture]...can you tell me what happens?
Student 40 : Barium nitrate is formed.
Interviewer: Why...why is barium nitrate formed?
Student 41 : Nitric acid.
Interviewer: Nitric acid. Anything else...reacts with...
Student 41 : Barium sulphate...no...yah...barium sulphate.
Student 40 : And the water.
Student 41 : Where is the sulphate now?
Student 40 : Its...its gone through thin air...
Student 41 : So how...[laughter]
Interviewer: OK now...before I end, is there anything that you want to tell me about QA...any other...[unintelligible]
Student 40 : It seems worse than before!
Interviewer: Why do you say that?
Student 40 : No...well in the beginning we never really thought about anything ...we just did it...it's like...now we're all like...oh no...why are we doing anything? It just seems we don't know a lot about it!
Interviewer: OK now...why is it difficult to know what you are doing in QA?
Student 41 : We haven't fully understand the theory yet.
Interviewer: What do you mean? What theory?
Student 41 : Maybe we have to know some...some of the special properties of sulphate or...nitrate before you can derive things.
Interviewer: OK...do you have anything (more to say)?
Student 40 : No.

End of interview

APPENDIX H1

INTERVIEW QUESTIONS SET 1

Part A

Test No.	Test	Observations
1a	To a portion of R add aqueous sodium hydroxide until a change is seen.	
b	Add excess of aqueous sodium hydroxide to the mixture from (a)	
c	Add excess of dilute nitric(V) acid to the mixture from (b)	

1. Why do you think sodium hydroxide is used?
To test for cations.

2. What results can you expected from carrying out procedure 1(a)?
A precipitate may be formed or ammonia may be liberated.
Why?
An insoluble hydroxide may be formed or an ammonium salt will react with hydroxide ions to form ammonia gas.

3. Why is excess sodium hydroxide used?
To see if the precipitate reacts further.

4. What result can be expected from carrying out procedure 1(b)?
The precipitate may disappear.

5. Why is dilute nitric acid added?
To neutralise the excess sodium hydroxide, to reverse the previous reaction.

Test No.	Test	Observations
1a	To a portion of R add aqueous sodium hydroxide until a change is seen.	*A white ppt is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a)	*White ppt soluble in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid to the mixture from (b) until no further change is seen.	*White ppt reappears and dissolves on addition of excess acid to give a colourless solution*

6. What is the anion present in the white precipitate?
Hydroxide.

7. Why is the white precipitate obtained?
Formation of insoluble hydroxide in a double decomposition reaction.

8. Why is the white precipitate soluble in excess reagent?
Amphoteric hydroxide reacts with excess alkali to give soluble complex salt.

9. Does the white precipitate really dissolve?
Dissolve is an incorrect term, precipitate reacts with sodium hydroxide give a soluble substance.

10. Can you deduce the identity of the cation?
Zn^{2+} *or* Al^{3+}.

11. Can you give a reason for your answer?
They will initially react with sodium hydroxide to form the amphoteric hydroxides which react with excess alkali to give soluble complex salts.

12. Why did the precipitate reappear?
The acid reacts with excess sodium hydroxide, reversing the earlier reaction, causing the hydroxide to be reformed.

13. Why did the precipitate disappear again?
The acid neutralises the insoluble hydroxide to produce a soluble nitrate(V) and water.

Part B

Test No.	Test	Observations
2a	To a portion of S add an equal volume of aqueous barium chloride.	
b	Add dilute hydrochloric acid to the mixture from (a)	

1. Why is barium chloride added?
To test for anions.

2. What result can be expected from carrying out step 2a?
A precipitate may be formed.

3. Why is hydrochloric acid added?
To test if the anion in S reacts with acids.

4. What must be prepared before the acid is added?
Must prepare damp blue litmus, limewater, acidified potassium manganate(VII)/dichromate(VI).

5. Why must one prepare to test for gases?
The acid may react with a carbonate or sulphate(IV).

6. Why must one use damp blue litmus?
The possible gases, carbon dioxide and sulphur dioxide are acidic.

7. Why is red litmus not required?
Basic gas e.g. ammonia, is not formed in a reaction with acids.

8. Why will hydrogen not be liberated?
Acids react with reactive metals to give hydrogen; since the sample is an aqueous solution, no metal is present.

9. Why is limewater used to test for carbon dioxide?
Formation of insoluble calcium carbonate.

10. Why is acidified potassium manganate(VII)/dichromate(VI) used to test for sulphur dioxide?
Redox reaction with sulphur dioxide, causes changes in oxidation state of manganese/chromium resulting in colour changes.

Test No.	Test	Observations
2a	To a portion of S add an equal volume of aqueous barium chloride.	*A white ppt is obtained.*
b	Add dilute hydrochloric acid to the mixture from (a)	*White ppt soluble in hydrochloric acid to give a colourless solution.*

11. Why is a white precipitate formed?
The anion in S reacts with barium ions to form an insoluble barium salt.

12. Does the precipitate really dissolve in acid?
No, the precipitate reacts with the acid to form a soluble salt.

13. Can you deduce the identity of the precipitate?
Carbonate or sulphate(IV).

14. Is there any else that the student should write down in his/her observation?
Effervescence.
Can you explain your answer?
Carbonates react with nitric acid to produce carbon dioxide gas while sulphate(IV) reacts with nitric acid to produce sulphur dioxide gas.

15. Instead of hydrochloric acid, can sulphuric(VI) acid or nitric(V) acid be used?
No.
Can you explain your answer?
Introducing foreign ions, which may complicate matters, e.g. barium ions will react with sulphate(VI) ions from sulphuric(VI) acid to form barium sulphate(VI) which is insoluble, giving a precipitate.

APPENDIX H2

INTERVIEW QUESTIONS SET 2

Part A

Test No.	Test	Observations
1	Note the appearance of sample S. Heat a small amount of S in a dry test tube until there is no further change.	

1. Why is it important to note the appearance of the sample?
Colour of sample can give clues to the identity of the ions in S.

2. How can the colour of the sample give clues to the identity of the cation in S
White solid – Groups I, II & III metals, zinc; Blue – copper(II); Green – copper(II), iron(II); Yellow or brown – iron(III).

3. What must be prepared before one starts heating?
Bunsen burner lighted, and at hand, wooden splint, moist litmus papers limewater, acidified potassium manganate(VII)/dichromate(VI).

4. Why must one prepare to test for gases?
Heating may cause the decomposition of an ammonium salt, a carbonate, sulphate(IV) or nitrate(V) if present.

5. Why must one use damp litmus papers?
The possible gases, carbon dioxide, sulphur dioxide or nitrogen dioxide are acidic; ammonia is basic; oxygen is neutral.

6. Why will hydrogen not be liberated?
Heating a sample will not cause the formation of hydrogen gas.

7. Why is limewater used to test for carbon dioxide?
Formation of insoluble calcium carbonate.

8. Why is acidified potassium manganate(VII)/dichromate(VI) used to test for sulphur dioxide?
Redox reaction with sulphur dioxide, causes changes in oxidation state of manganese/chromium resulting in colour changes.

9. Why is a glowing splint used to test for oxgyen?
Increase in oxygen content in test tube will cause glowing splint to burn more vigorously, hence relighting it.

10. Why else must one look out for when heating?
Changes in colour of sample e.g. colour of sample when hot and when allowed to cool.

11. What can colour changes tell us?
Give clues to identity of cation eg, colour of residue can give clues; blue sample turns black – copper(II) oxide formed; white sample turns yellow when hot and white when cooled – zinc oxide formed.

Test No.	Test	Observations
1	Note the appearance of sample S. Heat a small amount of S in a dry test tube until there is no further change.	*S is a blue solid.* *When heated, S turns black. A brown pungent gas is evolved which turns blue litmus red. On cooling S remains black.*

12. Can you deduce what cation is present?
Probably copper(II).
Why?
Blue sample – copper(II) salts; turns black when heated – formation of copper(II) oxide.

13. Can you deduce what the brown gas is?
Nitrogen dioxide.
Why?
Many nitrate(V) salts decompose when heated giving nitrogen dioxide, a brown acidic gas.

14. Is there anything else that the student could have done?
Test for oxygen as decomposition of nitrate(V) salts will liberate oxygen as well.

Part B

Test No.	Test	Observations
2a	To a portion of T, add an equal volume of aqueous sodium hydroxide and allow the mixture to stand for a few minutes.	
b.	Filter the mixture from (a). To the filtrate, add a piece of aluminium foil and warm gently.	

1. Why do you think sodium hydroxide is used?
To test for cations.

2. What results can you expected from carrying out procedure 2(a)?
A precipitate may be formed, ammonia may be liberated.

3. Can anything else be inferred from procedure 2a?
Allowing mixture to stand most likely for precipitate formed to settle, therefore zinc and aluminium ions most likely not present.

4. Why add aluminium foil?
Since sodium hydroxide already added, this is to test for a nitrate(V).

5. What must one prepare before carrying out 2(b)?
Damp red litmus at hand to test for ammonia.
Why?
Nitrate(V) salts will react with aluminium and sodium hydroxide to form ammonia gas.

Test No.	Test	Observations
2a	To a portion of T, add an equal volume of aqueous sodium hydroxide and allow the mixture to stand for a few minutes.	*A green precipitate is formed and settles at the bottom of the test tube.*
b.	Filter the mixture from (a). To the filtrate, add a piece of aluminium foil and warm gently.	*A vigorous reaction occurs and a gas is formed which turns red litmus blue.*

6. What is the anion present in the green precipitate?
Hydroxide.

7. Why is the green precipitate obtained?
Formation of insoluble hydroxide in a double decomposition reaction.

8. Can you deduce the identity of the green precipitate?
Iron(II) hydroxide.

9. What sort of reaction do you think occur in 2(b)?
Redox.
Why?
Nitrate(V) is reduced to ammonia.

10. Is there any precaution that you must take to decide if nitrate(V) is present?
Ammonium ion must not be present, otherwise cannot be certain of source of ammonia.

APPENDIX H3

INTERVIEW QUESTIONS SET 3

Part A

Test No.	Test	Observations
1a	To a portion of R add aqueous sodium hydroxide until in excess.	
b	Heat the mixture from (a) gently	

1. Why do you think sodium hydroxide is used?
   To test for cations.

2. What results can you expected from carrying out procedure 1(a)?
   A precipitate may form or ammonia may be liberated.
   Why?
   An insoluble hydroxide may be formed or an ammonium salt will react with hydroxide ions to form ammonia gas.

3. Why is excess sodium hydroxide used?
   To see if the precipitate reacts further.

4. What is the purpose of heating the mixture?
   To liberate ammonia if it is produced.

5. Why is it possible for ammonia to be produced?
   Alkalis react with ammonium salts to give ammonia, a salt and water.

6. What must be prepared before heating the mixture?
   Damp red litmus.

7. Why is damp red litmus used?
   Only gas that can be produced is ammonia and it is basic.

8. What other evidence will indicate that ammonia is liberated?
   Its pungent smell.

Test No.	Test	Observations
1a	To a portion of R add aqueous sodium hydroxide until in excess.	*No visible reaction.*
b	Heat the mixture from (a) gently	*A pungent gas is liberated.*

9. What can you infer from step 1(a)?
Sodium, potassium or ammonium ions may be present.

10. Can you deduce the identity of the cation?
NH_4^+ *may be present.*

11. What other test is required to identify the gas?
Litmus test.

12. Can you give a reason for your answer?
Ammonia gas is basic.

13. Can aqueous ammonia be used instead of aqueous sodium hydroxide in this situation?
No.
Why?
Source of ammonia gas cannot be determined as ammonia gas is also produced by aqueous ammonia.

Part B

Test No.	Test	Observations
2a	To a portion of S add an equal volume of aqueous silver nitrate(V).	
b	Add aqueous ammonia to the mixture from (a).	
c	To a portion of the mixture from (b), add dilute nitric(V) acid until a change is seen.	

1. Why is silver nitrate(V) added?
To test for anions.

2. What result can be expected from carrying out step 2(a)?
A precipitate may be formed in a double decomposition reaction.

3. Why is aqueous ammonia added?
To confirm if a chloride is present.

4. What result would you expect in step 2(b)
The precipitate disappears if chloride is present, otherwise, no visible reaction.

5. Why is dilute nitric(V) acid added?
T*o neutralise the aqueous ammonia and to test if anion reacts with acids.*

6. What must be prepared before the acid is added?
Must prepare damp blue litmus, limewater, acidified potassium manganate(VII)/dichromate(VI).

7. Why must one prepare to test for gases?
The acid may react with a carbonate or sulphate(IV).

8. Why must one use damp blue litmus?
The possible gases, carbon dioxide and sulphur dioxide are acidic.

9. Why is red litmus not required?
Basic gas e.g. ammonia, is not formed in a reaction with acids.

10. Why will hydrogen not be liberated?
Acids react with reactive metals to give hydrogen; since the sample is an aqueous solution, no metal is present.

11. Why is limewater used to test for carbon dioxide?
Formation of insoluble calcium carbonate.

12. Why is acidified potassium manganate(VII)/dichromate(VI) used to test for sulphur dioxide?
Redox reaction with sulphur dioxide, causes changes in oxidation state of manganese/chromium resulting in colour changes.

Test No.	Test	Observations
2a	To a portion of S add an equal volume of aqueous silver nitrate(V).	*A white ppt is obtained.*
b	Add aqueous ammonia to the mixture from (a).	*ppt partially soluble in aqueous ammonia.*
c	To a portion of the mixture from (b), add dilute nitric acid until a change is seen	*More white ppt reappears.* *Test tube feels warm.*

13. What inferences can you make from the observation of part 2(b)?
A chloride may be present as some precipitate disappears when aqueous ammonia is added.

14. Why is the precipitate formed?
An insoluble salt is formed in a double decomposition reaction.

15. Can you name the precipitate?
Silver chloride.

16. Why does some of the precipitate disappear when aqueous ammonia is added?
The silver chloride present reacts with the aqueous ammonia to produce a soluble complex salt.

17. Why is dilute nitric(V) acid added?
To neutralise the excess aqueous ammonia and reverse its reaction with the precipitate.

18. Can you name the precipitate and explain how it is formed?
Silver chloride is reformed when nitric acid neutralises the excess aqueous ammonia and reverses the previous reaction forming silver chloride.

19. Instead of nitric acid, can hydrochloric acid be used?
No.

. Can you explain your answer?
Hydrochloric acid contains a foreign anion, chloride, which produces unwanted reactions i.e. it complicates matters by reacting with silver ions present – one cannot be certain whether silver ions reacts with S.

APPENDIX H4

INTERVIEW QUESTIONS SET 4

Part A

Test No.	Test	Observations
1	To a portion of R add an equal volume of aqueous sodium carbonate.	

1. Why do you think sodium carbonate is used?
To test for cations.

2. What results can you expected from carrying out procedure 1?
A precipitate may form, or carbon dioxide may be liberated.
Why?
An insoluble carbonate may be formed, or the carbonate ion will react with any hydrogen ions present in R to form carbon dioxide.

3. What must be prepared before the sodium carbonate is added?
Must prepare damp blue litmus and limewater.

4. Why must one prepare to test for gases?
The carbonate may react with any hydrogen ion present.

5. Why must one use damp blue litmus?
The possible gas, carbon dioxide is acidic.

6. Why is limewater used to test for carbon dioxide?
Formation of insoluble calcium carbonate.

Test No.	Test	Observations
1	To a portion of R add an equal volume of aqueous sodium carbonate.	*A colourless gas is evolved which turns blue litmus red.*

7. What can you infer from test 1?
Hydrogen ions are present.

8. Can you give a reason for your answer?
Hydrogen ions in R react with the carbonate to give carbon dioxide.

9. What additional test is required to confirm the identity of the gas?
Limewater as the only possible gas is carbon dioxide.

Part B

Test No.	Test	Observations
1a	To a portion of S add an equal volume of aqueous ammonia solution.	
b	Add dilute nitric(V) acid to the mixture from (a) until a change is seen.	

1. Why do you think aqueous ammonia is used?
To test for cations.

2. What results can you expected from carrying out procedure 1(a)?
A precipitate may be formed.
Why?
An insoluble hydroxide may be formed.

3. What result can be expected from carrying out procedure 1(b)?
Precipitate may disappear, or a gas may be evolved.
Why?
Acid will neutralise the excess aqueous ammonia and react with the precipitate in an acid-base reaction, or acid-carbonate or acid-sulphate(IV) reactions may occur.

4. What must be prepared before the acid is added?
Must prepare damp blue litmus, limewater, acidified potassium manganate(VII)/dichromate(VI).

5. Why must one prepare to test for gases?
The acid may react with a carbonate or sulphate(IV).

6. Why must one use damp blue litmus?
The possible gases, carbon dioxide and sulphur dioxide are acidic.

7. Why is red litmus not required?
Basic gas e.g. ammonia, is not formed in a reaction with acids.

8. Why will hydrogen not be liberated?
Acids react with reactive metals to give hydrogen; since the sample is an aqueous solution, no metal is present.

9. Why is limewater used to test for carbon dioxide?
Formation of insoluble calcium carbonate.

10. Why is acidified potassium manganate(VII)/dichromate(VI) used to test for sulphur dioxide?
Redox reaction with sulphur dioxide, causes changes in oxidation state of manganese/chromium resulting in colour changes.

Test No.	Test	Observations
1a	To a portion of S add an equal volume of aqueous ammonia solution.	*A green ppt is formed. A pungent gas which turns red litmus blue is detected.*
b	Add dilute nitric(V) acid to the mixture from (a) until a change is seen.	*The green precipitate dissolves in the acid to give a light green solution.*

11. What is the anion present in the green precipitate?
Hydroxide.

12. Why is the green precipitate obtained?
Formation of insoluble hydroxide in a double decomposition reaction.

13. Why is the green precipitate soluble in dilute nitric acid?
The acid reacts with the insoluble hydroxide to give a soluble nitrate(V) and water.

14. Does the green precipitate really dissolve?
Dissolve is an incorrect term as the precipitate reacts with nitric(V) acid to give a soluble substance.

15. Can you deduce the identity of the cation?
Fe^{2+}.

16. Can you give a reason for your answer?
It gives a green precipitate with aqueous ammonia.

17. Why do we ignore the presence of ammonia?
The aqueous ammonia used liberates ammonia.

APPENDIX I

PILOT STUDY: FIRST VERSION OF FREE RESPONSE TEST

INTRODUCTION

With the data obtained from observations of practical sessions and interviews with the Grade 10 students, the first version of a free response test was developed. This free response test consisted of 22 questions in two separate but approximately equivalent papers, Parts 1 (Appendix I1) and 2 (Appendix I2) because it was tedious and tiring for a student to answer all 22 questions. Tables I.1 and I.2 specify the source of the questions, the propositional statements involved and the possible alternative conceptions and non-conceptions. The two papers were reviewed by Dr. Chung.

The first part of 20 questions required students to select an answer from several options while the second part of the questions required students to supply reasons for their choice of answers. The remaining two questions required students to write down the identity of the products of the respective double decomposition reactions before explaining their answers. Experiment A sets the scene for Questions 1 to 5 in Part 1, Experiments B and C for Questions 1 to 4 and 6 to 8 in Part 2, respectively. All these experiments were from past years' October/November O-level pure chemistry practical examinations, so students should be familiar with the experiments. The observations given in each experiment were based on the results students normally obtain after carrying out the procedures. All other questions except Questions 8, 10 and 11 in Part 1, and 5 in Part 2 also were based either on past years' O-level pure chemistry practical or theory papers. The four questions mentioned above were based on student difficulties determined in the interviews and observations of practical sessions.

Test No.	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white precipitate is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a)	*White precipitate disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid to the mixture from (b) until no further change is seen.	*White precipitate reappears. When excess acid is added, the precipitate disappears giving a colourless solution*

Figure I.1: Experiment A in Part 1

Table I.1: Specifications of Part 1 of the first version of the free response test on qualitative analysis

Item	Source of question	Propositional statements	Possible alternative conceptions and non-conceptions
1	Practical Papers 97, 95, 93, 91, 90	9,10,14,15	- Displacement by sodium/zinc ions
2	Practical Papers 97, 95, 93, 91, 90 Theory Papers 96, 92	9,10,14,15	- No idea what products are formed or what a double decomposition reaction is.
3	Practical Papers 97, 95, 93, 91, 90	9,10,12	- Displacement by sodium ions. - Precipitate dissolves in excess solvent. - Sodium hydroxide is reactive enough to dissolve precipitate.
4	Practical Papers 97, 95, 93, 91, 90	1,2,6,9,10,12	- Displacement by hydrogen ions. - Redox reaction with acid. - Insoluble salt is a product of the neutralisation reaction.
5	Practical Papers 97, 95, 93, 91, 90	1,2,12	- Displacement by hydrogen ions. - Redox reaction with acid. - Precipitate dissolves because addition solvent is added.
6	Practical Papers 97, 93, 92	1,2,4,14,15	- Silver nitrate(V) is to test for halides only. - Carbon dioxide formed only when acid is added directly to carbonates, (and not after barium nitrate(V)).
7	Practical Papers 97, 93, 92	1,2,4,5,14,15	- No idea about the function of acid.
8	Interviews and observations.	1,2,5,7	- No idea why selection of acid is important. - Any acid can be used.
9	95	18,19	- Carbon dioxide formed only when acid reacts with carbonates. - Carbon dioxide only formed when things burn in air and ionic compounds do not burn. - Hydrogen can be liberated when an ionic compound is heated.
10	Interviews and observations.	22,23,24,25,26	- No idea what acid should be used to acidify the oxidising agent and the reasons why.
11	Interviews and observations	14,29,30	- No idea why reagents cannot be added to solid sample.

Table I.2: Specifications of Part 2 of the first version of the free response test on qualitative analysis

Item	Source of question	Propositional statements	Possible alternative conceptions and non-conceptions
1	Practical Papers 97, 93, 92	1,2,4,5	- Acid removes impurities. - Redox reactions with acid. - No ideas why acid is added.
2	Practical Papers 97, 93, 92	7,8	- No idea about which acid to add after adding silver nitrate(V).
3	Practical Papers 97, 93, 92	13	- Ammonium chloride is produced. - Displacement by ammonia. - Precipitate dissolves in ammonia. - Aqueous ammonia is reactive enough to dissolve precipitate.
4	Practical Papers 97, 93, 92	1,2,6,9,10,13	- Displacement by hydrogen ions. - Redox reaction with acid. - Acid (hydrogen ions or the nitrate(V) ions) reacts with ammonium ions. - Acid decomposes ammonium chloride.
5	Interviews and observations.	1,2,5	- No idea about reaction of sulphate(IV) with acid. - Redox reaction with acid.
6	Practical Papers 97, 94, 90	9,10,14,15	- Displacement by ammonium ions. - Redox reaction occurs.
7	Practical Papers 97, 94, 90 Theory Papers 96, 92	9,10,14,15	- No idea what products are formed or what a double decomposition reaction is.
8	Practical Papers 97, 94, 90	13	- Displacement by ammonium ions. - Precipitate dissolving in excess solvent. - Aqueous ammonia reactive enough to dissolve precipitate.
9	Practical Papers 96, 92, 91 Theory Papers 96, 92	14,15	- Barium nitrate(V) is to test for sulphate(VI) only - No idea what products are formed or what a double decomposition reaction is. - No idea that barium carbonate is insoluble or that barium chloride is soluble.
10	Practical Papers 96, 92, 91	14,15	- No idea about double decomposition. - Displacement by barium ions
11	Practical Papers 96, 92, 91	1,2,4,14,15	- Carbon dioxide formed only when acid is added directly to carbonates, (and not after barium nitrate) - No idea about the function of adding acid after barium nitrate(V).

Parts 1 and 2 were administered at the end of February 1999 and early March 1999 to 34 graduate trainee-teachers who volunteered to take the test and 19 final-year (4th year) chemistry undergraduates. Each person only took one paper assigned to him/her randomly. In total, 18 trainee-teachers and nine undergraduates took Part 1, and 16 trainee-teachers and 10 undergraduates took Part 2. Most respondents chose an answer from the options given but only a few wrote reasons supporting their choice. The results from the administration of Parts 1 and 2 are discussed in the following sections.

Part 1

Questions 1 to 5 tested the subjects' knowledge of double decomposition, complex ion formation and neutralisation.

1. What type of reaction occurs when aqueous sodium hydroxide reacts with aqueous zinc chloride to form a white precipitate?
A Displacement
B. Double decomposition
C. Redox
D. ______________________

Option	PDGE98	BSc498	Total	Percentage
A	9	4	13	48.1
B*	6	0	6	22.2
C	0	2	2	7.4
D	3	3	6	22.2
Total	18	9	27	100

In Question 1, six subjects chose the correct option, B, but another six wrote 'precipitation' as option D, which was equally acceptable based on the arguments in Chapter 3. This author replaced 'double decomposition' with 'precipitation' in the second version of the free response test as he believed that many secondary students and even some tertiary students and graduates were unfamiliar with the term 'double decomposition'. It seemed that several trainee-teachers had the 'reactive ion displaces less reactive ion' alternative conception as they gave explanations such as 'sodium was more reactive than zinc so it could displace zinc from zinc chloride' and 'zinc was more electropositive compared to sodium and thus displaced it to form zinc hydroxide'. One trainee-teacher who chose the double decomposition option wrote that there should not be a white precipitate in the first place as all hydroxides were soluble, and if there was any precipitate, it would be sodium chloride which was formed because the solution was too concentrated. Two undergraduates chose the redox option but did not explain why.

2. The products formed when aqueous sodium hydroxide reacts with aqueous zinc chloride are _____.

______________________________________(write your answer)

In Question 2, many trainee-teachers and undergraduates were either able to write the formulas or the names of the two compounds formed although five gave only one product; one wrote down sodium chloride only, while four others gave zinc hydroxide only. One trainee-teacher wrote that the sodium zincate was formed while another stated that zinc hydroxide was in the aqueous state.

3. In step (b), a colourless solution is obtained because the precipitate _____ the excess sodium hydroxide.
   A dissolves in
   B reacts with
   C. ______________________________

Option	PDGE98	BSc498	Total	Percentage
A	3	2	5	18.5
B*	9	7	16	59.3
C	5	0	5	18.5
O	1	0	1	3.7
Total	18	9	27	100

The formation of the zincate ion in Question 3 caused some problems. Five subjects believed that the precipitate dissolved in the excess aqueous sodium hydroxide with one stating that the sodium and hydroxide ions help dissolve the solid; it was uncertain why the subject meant by the statement. One other subject wrote that the precipitate dissolved because more solvent was added. One subject who circled option C wrote that the precipitate was sodium chloride which simply dissolved; this was the same student who, in Question 1, wrote that all hydroxides were soluble and that the precipitate was sodium chloride. Three other subjects who chose option C indicated that a soluble compound or complex was formed. One subject did not answer the question (option O).

4. A student concludes that the white precipitate obtained in step (c) is the same as the white precipitate obtained in step (a). Do you agree with the student's conclusion?

   A Yes B No

Option	PDGE98	BSc498	Total	Percentage
A*	10	8	18	66.7
B	7	1	8	29.6
O	1	0	1	3.7
Total	18	9	27	100

The reappearance of the precipitate in Question 4 was described by two subjects, who chose option B, as the formation of zinc nitrate(V); they did not realise that zinc nitrate(V) was soluble.

5. A student concludes that, in step (c), the white precipitate dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Option	PDGE98	BSc498	Total	Percentage
A	4	1	5	18.5
B*	13	8	21	77.8
O	1	0	1	3.7
Total	18	9	27	100

The reaction of the precipitate with acid in Question 5 was described by five subjects as the precipitate dissolving in the additional solvent, and by one other person as nitrate(V) ions reacting with zinc hydroxide to form soluble zinc nitrate(V).

Questions 6 and 7 required the subjects to know that the procedures given could test for carbonate ions and the purpose of adding the acid.

6. A student is given a solution which may contain a carbonate ion. She decides to add aqueous silver nitrate(V) to the solution first and followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A Yes B No

Option	PDGE98	BSc498	Total	Percentage
A*	10	5	15	55.6
B	7	2	9	33.3
O	1	2	3	11.1
Total	18	9	27	100

Nine subjects believed that the presence of carbonate could not be determined this way. This might be because they simply recalled that silver nitrate(V) was used to test for halides without understanding the reactions involved and why acid had to be added. One subject wrote that since silver nitrate(V) was used to test for chlorides, this was a bad way to test for carbonates as the acid must be added directly to the carbonate. A trainee-teacher wrote that the common ion effect of nitrate(V) might prevent the dissociation of nitric(V) acid as the system behaved like a 'crude buffer'. This trainee-teacher did not realise that nitric(V) acid dissociates to a large extent in water, hence it could not be used in buffer solutions. Another subject wrote that he had never heard of silver carbonate.

7. When the student adds silver nitrate(V) solution to the unknown solution from Question 20, there is no visible reaction. She decides that it is unnecessary to add the dilute nitric(V) acid. Do you agree with her?

I. Yes. II. No.

Option	PDGE98	BSc498	Total	Percentage
A*	9	1	10	37.0
B	7	8	15	55.6
O	2	0	2	7.4
Total	18	9	27	100

In Question 7, the reasons given for choosing option B included 'the test required an acidic medium', 'the products of the reaction might be soluble so no visible reaction was observed' and 'the test for carbonate lies in the addition of the acid and not the silver nitrate(V)'.

8. A student is given a solid sample of a calcium compound. He suspects that the compound is calcium sulphate(IV). Which dilute acid can he use to determine whether the compound contains sulphate(IV) ions?

I Nitric(V) acid
II Sulphuric(VI) acid
III Hydrochloric acid

A I only　B II only　C III only
D I and II only　E I and III only
F II and III only　G I, II and III　H None

Option	PDGE98	BSc498	Total	Percentage
A	2	0	2	7.4
B	1	0	1	3.7
C	1	0	1	3.7
D	0	2	2	7.4
E*	4	1	5	18.5
F	0	1	1	3.7
G	1	1	2	7.4
H	5	3	8	29.6
O	4	1	5	18.5
Total	18	9	27	100

Using sulphuric(VI) acid in Question 8 results in the formation of an insoluble layer of calcium sulphate(VI) which causes the reaction to cease. There was a wide spread of answers and only five subjects chose the correct option. Many subjects mistook calcium sulphate(VI) for calcium sulphate(IV) shown in the chemical formula that they wrote down. Thus they did not work out the formation of sulphur dioxide from the reaction between the sulphate(IV) salt and acid. If this item is used, the formula of calcium sulphate(IV) must be given. Many subjects also stated wrongly that calcium chloride was insoluble.

9. Which of following gas(es) can be obtained when an ionic compound is heated?

I Carbon dioxide.
II Hydrogen.
III Sulphur dioxide.

A	I only	B	II only	C	III only
D	I and II only	E	I and III only		
F	II and III only	G	I, II and III	H	None

Option	PDGE98	BSc498	Total	Percentage
A	1	0	1	3.7
B	0	1	1	3.7
D	1	0	1	3.7
E*	10	3	13	48.1
G	1	0	1	3.7
H	3	4	7	25.9
O	2	1	3	11.1
Total	18	9	27	100

Only half the subjects chose the correct answer for Question 9 and a wide spread of answers was again obtained. One subject who chose option H remarked that only water would be evolved, another wrote that 'all gases listed above do not contain elements that are contained in ionic compounds', while a third subject wrote that ionic compounds did not decompose to liberate a gas. This author proposed that the second subject was thinking of the combustion of carbon and sulphur, and that ionic compounds did not contain carbon and sulphur in the elemental state.

10. A student wishes to acidify potassium dichromate(VI). Which of the following acid(s) can she use?

I Nitric(V) acid.
II Sulphuric(VI) acid.
III Hydrochloric acid.

A	I only	B	II only	C	III only
D	I and II only	E	I and III only		
F	II and III only	G	I, II and III	H	None

Option	PDGE98	BSc498	Total	Percentage
A	0	1	1	3.7
B*	3	0	3	11.1
C	1	1	2	7.4
D	1	0	1	3.7
F	2	3	5	18.5
G	4	4	8	29.6
H	1	0	1	3.7
O	6	0	6	22.2
Total	18	9	27	100

A wide spread of answers was obtained with only three subjects selecting the correct answer. One subject who chose option C believed that nitrogen dioxide and sulphur dioxide would be released when nitric(V) acid and sulphuric(VI) acid were used respectively. One subject who chose option G remarked that as long as the acid did not interfere with the test, any strong acid that ionised almost completely should do the job. Two subjects who also chose option G wrote that all the three acids could provide the hydrogen ions needed for reaction. Six subjects could not give any answer. Thus it could be seen many did not realise that side reactions could result from the use of nitric(V) acid and hydrochloric acid.

11. A student is given a powder and asked to determine the cation present in the powder. He adds aqueous sodium hydroxide directly to the powder. Do you think that it is experimentally correct to add aqueous sodium hydroxide directly to the powder?

A Yes. B No.

Option	PDGE98	BSc498	Total	Percentage
B*	16	9	25	92.6
O	2	0	2	7.4
Total	18	9	27	100

Question 11 posed few problems to the subjects.

Part 2

Questions 1 to 4 involved reactions such as double decomposition, complex ion formation and neutralisation.

1. In Experiment B step (b), what is the purpose of adding the dilute nitric(V) acid?

A To remove impurities.
B To oxidise the precipitate.
C ______________________

Option	PDGE98	BSc498	Total	Percentage
A	1	1	2	7.7
B	2	3	5	19.2
C*	9	5	14	53.8
O	4	1	5	19.2
Total	16	10	26	100

In Question 1, many did not know the purpose of the acid. Two subjects believed that the acid was used to remove impurities but did not specify what the impurities were. Of the five who chose option B, one wrote that nitric(V) acid was a strong oxidising agent, but in this instance, the acid was not acting as an oxidising agent. Only two of the 14 subjects who wrote in the space given for option C stated that the acid was to test for the presence of carbonates. Seven people stated that it was to see whether the precipitate dissolved in the acid, two wrote that it was to acidify the medium, and one believed it was to shift the equilibrium. Two persons wrote that nitric(V) acid was not an oxidising agent, while another two stated that if the precipitate dissolved in the acid, then it was a base, otherwise it was an acid. Five people did not answer the question.

2. In step (b), can dilute sulphuric(VI) acid or dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A Dilute sulphuric(VI) acid only.
B Dilute hydrochloric acid only.
C Both acids can be used.
D Both acids cannot be used.

Option	PDGE98	BSc498	Total	Percentage
A	2	1	3	11.5
B	2	0	2	7.7
C	1	4	5	19.2
D*	9	5	14	53.8
O	2	0	2	7.7
Total	16	10	26	100

Question 2 posed some problems. One subject who chose option A wrote that sulphuric(VI) acid was an oxidising agent while hydrochloric acid was not. In theory, sulphuric(VI) acid also could be added as silver sulphate(VI) was a moderately soluble salt but its use would introduce a foreign anion, sulphate(VI), into the mixture. This would cause problems if other reagents were subsequently added to the mixture and they react with sulphate(VI). One subject gave the reason that all the acids were of similar strength for choosing option C, while another noted that all the acids reacted with carbonate. A subject who chose option D wrote that the two acids were not oxidising agents, while another stated that nitric(V) acid could dissolve more compounds. Thus many trainee-teachers and undergraduates did not seem to understand that nitric(V) acid had to be used to avoid introducing any foreign anion into the mixture.

3. In step (c (i)), it can be concluded that a reaction occurs resulting in the formation of ammonium chloride.

A True B False

Option	PDGE98	BSc498	Total	Percentage
A	8	4	12	46.2
B*	7	6	13	50.0
O	1	0	1	3.8
Total	16	10	26	100

In Question 3, 50% of the subjects did not know that a silver ammine complex was formed. Four believed that aqueous ammonia reacted with silver chloride to form ammonium chloride and silver hydroxide; they also did not realise that silver hydroxide was insoluble. One trainee-teacher wrote that the ammonium ion displaces the silver ion. Two subjects who chose option B remarked that no conclusion could be made as the white precipitate was not necessarily a chloride; the results clearly showed that it was a chloride.

4. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the precipitate.

A True B False

Option	PDGE98	BSc498	Total	Percentage
A	3	5	8	30.8
B*	10	5	15	57.7
O	3	0	3	11.5
Total	16	10	26	100

About 40% of the subjects did not know what happened when acid was added to the silver ammine complex and excess aqueous ammonia in Question 4, with eight of them believing that the silver ions were oxidised by the nitric(V) acid to silver. One trainee-teacher wrote 'hydrogen ions displace ammonium ions in ammonium chloride to free the chloride ion which then reacts with silver ions to reform silver chloride', while another stated that silver chloride was insoluble in nitric(V) acid, so it 'reprecipitated out'.

5. When dilute hydrochloric acid reacts with calcium sulphate(IV) (calcium sulphite), sulphur dioxide is produced. It can be concluded that the acid oxidises the calcium sulphate(IV).

A True. B False

Option	PDGE98	BSc498	Total	Percentage
A	2	0	2	7.7
B*	13	9	22	84.6
O	1	1	2	7.7
Total	16	10	26	100

Question 5 is more straightforward compared to Question 8 in Part 1 so more subjects chose the correct option. Two trainee-teachers who chose option A wrote the following equations:

(1) $4HCl + Ca_2SO_4 \rightarrow 2CaCl_2 + SO_2 + 2H_2O$
(2) $CaSO_4 + HCl \rightarrow SO_2 + Ca + H_2O$

It could be seen from equations (1) and (2) that the students mistook sulphate(VI) for sulphate(IV). In equation (1), the valency of calcium as well as the reaction was incorrect. No such reaction as described by equation (2) existed. In addition, the calcium was reduced in equation (2) not oxidised, so the trainee-teacher who wrote equation (2) might be confused over what constituted oxidation and reduction.

Questions 6 to 8, like Questions 1 to 3 in Part 1, tested the subjects' knowledge of double decomposition and complex ion formation.

6. What type of reaction occurred in step (a)?

A Displacement
B Double decomposition
C Redox
D ________________________________

Option	PDGE98	BSc498	Total	Percentage
A	4	5	9	34.6
B*	2	0	2	7.7
C	2	2	4	15.4
D	5	2	7	26.9
O	3	1	4	15.4
Total	16	10	26	100

Out of the four who chose option A in Question 6, two wrote that water was displaced by ammonia in the copper(II) – water complex, one believed that the copper ion was displaced and the fourth stated that copper ions displaced hydrogen ions from water. The two subjects who wrote about the displacement of water by ammonia might have been thinking about the formation of the copper(II) ammine complex with excess aqueous ammonia. One trainee-teacher who chose option C believed that copper(II) was reduced to copper (I). Out of the seven subjects who chose to write their answers in option D, four stated that formation of a complex occurred, one thought the reaction was neutralisation, while the remaining two stated that a precipitation reaction occurred.

7. What is the identity of the light blue precipitate obtained in step (a)?

________________________________(write your answer)

In Question 7, six subjects give a total of three different versions of the copper(II) ammine complex which they thought was produced in this step; however, no copper(II) ammine complex was formed. 11 subjects gave the correct answer, copper(II) hydroxide. One undergraduate thought that copper(II) sulphate(VI) was produced and one trainee-teacher thought that a copper (I) compound was formed.

8. In step (b), it can be concluded that the light blue precipitate dissolves in the excess aqueous ammonia to give a concentrated solution.

A True B False

Option	PDGE98	BSc498	Total	Percentage
A	2	1	3	11.5
B*	14	9	23	88.5
Total	16	10	26	100

In Question 8, eight trainee-teachers and four undergraduates either wrote that a complex ion was formed or gave the correct formula of the copper(II) ammine complex ion. Four other trainee-teachers stated that the copper complex formed was of a different oxidation state from the light blue precipitate.

9. Aqueous barium nitrate(V) is added to a colourless solution T, and a white precipitate is formed. Which of the following could be the possible identity/identities of the precipitate?

I Barium sulphate(VI)
II Barium carbonate
III Barium chloride

A I only B II only C III only
D I and II only E I and III only
F II and III only G I, II and III H None

Option	PDGE98	BSc498	Total	Percentage
A	1	0	1	3.8
B	3	0	3	11.5
C	1	0	1	3.8
D*	6	1	7	26.9
E	0	2	2	7.7
F	0	1	1	3.8
G	3	6	9	34.6
O	2	0	2	7.7
Total	16	10	26	100

Question 9 tested the subjects' knowledge of double decomposition and the solubility of salts. Many subjects would know that barium sulphate(VI) is insoluble but a few might forget that barium chloride is soluble and barium carbonate is insoluble. This was reflected in the results; only 27% of the subjects had the answer correct. Thus this author felt that this question should be modified or discarded as it was mainly a recall question.

10. In Question 9, what type of reaction has occurred to give the precipitate?

A Displacement
B Double decomposition
C Redox
D ______________________________

Option	PDGE98	BSc498	Total	Percentage
A	8	9	17	65.4
B*	4	0	4	15.4
D	1	1	2	7.7
O	3	0	3	11.5
Total	16	10	26	100

Question 10 was similar to Question 6 in Part 2, and like Question 6, few subjects selected the correct option. Again many trainee-teachers (8) and undergraduates (9) believed that a displacement reaction had occurred instead of a double decomposition reaction. Three trainee-teachers wrote that the nitrate(V) ion in barium nitrate(V) was displaced by another to give the precipitate; it was uncertain whether the trainee-teachers meant 'displace' or 'replace'. One undergraduate who chose option D wrote that neutralisation occurred while a trainee-teacher stated that a precipitation reaction occurred.

11. If dilute nitric(V) acid is added to the mixture from Question 9, can a reaction take place resulting in the formation of a gas such as carbon dioxide?

A Yes

Option	PDGE98	BSc498	Total	Percentage
A*	12	8	20	76.9
B	2	2	4	15.4
O	2	0	2	7.7
Total	16	10	26	100

Question 11 was similar to Question 6 in Part 1, but posed less problems to the subjects. Many trainee-teachers and undergraduates knew that there could be a reaction between the acid and barium carbonate (if present). One student who chose option B stated that nitric acid was an oxidising agent, so no carbon dioxide could be formed.

The alternative conceptions and non-conceptions determined through the administration of the free response tests Parts 1 and 2 are summarised in Table I.3. It seemed that a number of trainee-teachers and undergraduates had difficulty understanding qualitative analysis. They need to read, reflect and clarify their conceptions; otherwise, they might transfer their alternative conceptions to their students. In a study involving science graduates in a high school science teacher pre-service programme, Gunstone (1994) also found out that the science graduates have considerable propositional knowledge but little understanding of it. He describes a graduates as having "grossly inadequate conceptual structures" (p.131). This also seemed to be an apt description for several trainee-teachers and undergraduates who participated in this study.

SUMMARY

This appendix highlights the findings of an initial pen-and-paper probe into Fourth Year undergraduates' and graduate trainee-teachers' understanding of qualitative analysis. The data collected in this pilot study provided insights into the development of the qualitative analysis instrument as well as into the alternative conceptions and non-conceptions of the undergraduates and trainee-teachers in the sample.

Table I.3: Results from the administration of the first version of the free response test

Alternative conceptions

1. Double decomposition.
   - a. Chloride ions in zinc chloride are displaced by hydrogen ions.
   - b. Sodium is more reactive than zinc, so displaces zinc from zinc chloride.
   - c. Zinc is more reactive than sodium, so displaces sodium from sodium hydroxide.
   - d. Sodium chloride is the precipitate formed due to the solution being too concentrated.
   - e. A redox reaction occurs.
   - f. Ammonia displaces water in copper(II)-water complex.
   - g. Ammonium displaces copper ions.
   - h. Copper ions displace hydrogen ions from water.
   - i. A complex ion is formed.
   - j. Neutralisation occurs.
2. Formation of complex ion
   - a. Precipitate dissolves in the additional solvent (excess alkali) added.
   - b. Ammonium chloride is formed.
   - c. Ammonium ion displaces silver in silver chloride.
   - d. Copper in the complex ion formed is of a different oxidation state.
3. Addition of acid
   - a. Precipitate dissolves in the additional solvent (excess acid) added.
   - b. Anion of the acid reacts with the precipitate to form a soluble salt.
   - c. Acids must be added directly to the unknown sample to test for carbonates and not after the addition of aqueous silver or barium salts.
   - d. An acid is added to remove impurities.
   - e. The acid added oxidises the precipitate.
   - f. Hydrogen ion displaces ammonium ions in ammonium chloride.
4. When ionic compounds are heated
   - a. Only water will be liberated when ionic compounds are heated.
   - b. Ionic compounds do not decompose when heated to liberate gases.

Non-conceptions

1. No idea what happens in a double decomposition reaction/No idea what are the products formed in a double decomposition reaction.
2. No idea what a complex ion is/how a complex ion is formed.
3. No idea what happens when acid is added to a solution containing a complex ion and excess alkali.
4. Why an acid is introduced after the addition of aqueous silver or barium salts to an unknown solution.
5. No idea which salts are soluble and which are insoluble.
6. Do not know the properties and reactions of nitric(V) acid, sulphuric(VI) acid and hydrochloric acid.
7. What possible reactions can occur when substances are heated.
8. Which acid to use, and the reasons why, to acidify potassium dichromate(VI).
9. Why it is important that the anion of an acid must be the same as the anion of the silver salt for both to be added to an unknown solution.

APPENDIX I1

PART 1 OF THE FIRST VERSION OF THE FREE RESPONSE TEST ON QUALITATIVE ANALYSIS

Instructions:

- Choose the most suitable option in each question by circling it. Give your reason for choosing the option.
- If you feel that all the options given are inappropriate, you may write down what you think the correct answer should be, and give your reason.

For Questions 1 to 5, refer to Experiment A.

Experiment A

Test No.	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white precipitate is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a)	*White precipitate disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid to the mixture from (b) until no further change is seen.	*White precipitate reappears. When excess acid is added, the precipitate disappears giving a colourless solution*

1. What type of reaction occurs when aqueous sodium hydroxide reacts with aqueous zinc chloride to form a white precipitate?

   A Displacement
   B. Double decomposition
   C. Redox
   D. ____________________

*Reason/Justification*____________________________________

2. The products formed when aqueous sodium hydroxide reacts with aqueous zinc chloride are _____.

   ______________________________(write your answer)

*Reason/Justification*____________________________________

3. In step (b), a colourless solution is obtained because the precipitate _____ the excess sodium hydroxide.

A dissolves in
B reacts with
C. ______________________________

*Reason/Justification*______________________________________

4. A student concludes that the white precipitate obtained in step (c) is the same as the white precipitate obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

*Reason/Justification*______________________________________

5. A student concludes that, in step (c), the white precipitate dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

*Reason/Justification*______________________________________

6. A student is given a solution which may contain a carbonate ion. She decides to add aqueous silver nitrate(V) to the solution first and followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A Yes B No

*Reason/Justification*______________________________________

7. When the student adds silver nitrate(V) solution to the unknown solution from Question 20, there is no visible reaction. She decides that it is unnecessary to add the dilute nitric(V) acid. Do you agree with her?

A Yes. B No.

*Reason/Justification*______________________________________

8. A student is given a solid sample of a calcium compound. He suspects that the compound is calcium sulphate(IV). Which dilute acid can he use to determine whether the compound contains sulphate(IV) ions?

I Nitric(V) acid
II Sulphuric(VI) acid
III Hydrochloric acid

A I only B II only C III only
D I and II only E I and III only
F II and III only G I, II and III H None

Reason/Justification ____

9. Which of following gas(es) can be obtained when an ionic compound is heated?

I Carbon dioxide.
II Hydrogen.
III Sulphur dioxide.

A I only B II only C III only
D I and II only E I and III only
F II and III only G I, II and III H None

Reason/Justification ____

10. A student wishes to acidify potassium dichromate(VI). Which of the following acid(s) can she use?

I Nitric(V) acid.
II Sulphuric(VI) acid.
III Hydrochloric acid.

A I only B II only C III only
D I and II only E I and III only
F II and III only G I, II and III H None

Reason/Justification ____

11. A student is given a powder and asked to determine the cation present in the powder. He adds aqueous sodium hydroxide directly to the powder. Do you think that it is experimentally correct to add aqueous sodium hydroxide directly to the powder?

A Yes. B No.

Reason/Justification ____

APPENDIX I2

PART 2 OF THE FIRST VERSION OF THE FREE RESPONSE TEST ON QUALITATIVE ANALYSIS

Instructions:

- Choose the most suitable option in each question by circling it. Give your reason for choosing the option.
- If you feel that all the options given are inappropriate, you may write down what you think the correct answer should be, and give your reason.

For Questions 1 to 4, refer to Experiment B.

Test No.	Test	Observations
a	To a portion of S, add an equal volume of aqueous silver nitrate(V). Divide the mixture into 2 portions.	*A white precipitate is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction.*
c(i)	To the second portion, add aqueous ammonia.	*Precipitate disappears and a slightly cloudy solution is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White precipitate appears.*

1. In Experiment B step (b), what is the purpose of adding the dilute nitric(V) acid?

   A To remove impurities.
   B To oxidise the precipitate.
   C ______________________________

*Reason/Justification*____

2. In step (b), can dilute sulphuric(VI) acid or dilute hydrochloric acid be added instead of dilute nitric(V) acid?
   A Dilute sulphuric(VI) acid only.
   B Dilute hydrochloric acid only.
   C Both acids can be used.
   D Both acids cannot be used.

*Reason/Justification*____

3. In step (c (i)), it can be concluded that a reaction occurs resulting in the formation of ammonium chloride.

A True B False

*Reason/Justification*____

4. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the precipitate.

A True B False

*Reason/Justification*____

5. When dilute hydrochloric acid reacts with calcium sulphate(IV) (calcium sulphite), sulphur dioxide is produced. It can be concluded that the acid oxidises the calcium sulphate(IV).

A True. B False

*Reason/Justification*____

For Questions 6 to 8, refer to Experiment C.

Experiment C

Test No.	Test	Observations
a	To a solution containing copper(II) ions, add two drops of aqueous ammonia.	*A light blue precipitate is obtained.*
b	To the mixture from (a), add excess aqueous ammonia.	*A dark blue solution is formed.*

6. What type of reaction occurred in step (a)?

A Displacement
B Double decomposition
C Redox
D ____________________________

*Reason/Justification*____

7. What is the identity of the light blue precipitate obtained in step (a)?

______________________________(write your answer)

*Reason/Justification*______________________________

8. In step (b), it can be concluded that the light blue precipitate dissolves in the excess aqueous ammonia to give a concentrated solution.

A True B False

*Reason/Justification*______________________________

9. Aqueous barium nitrate(V) is added to a colourless solution T, and a white precipitate is formed. Which of the following could be the possible identity/identities of the precipitate?

I Barium sulphate(VI)
II Barium carbonate
III Barium chloride

A I only B II only C III only
D I and II only E I and III only
F II and III only G I, II and III H None

*Reason/Justification*______________________________

10. In Question 9, what type of reaction has occurred to give the precipitate?

A Displacement
B Double decomposition
C Redox
D ______________________________

*Reason/Justification*______________________________

11. If dilute nitric(V) acid is added to the mixture from Question 9, can a reaction take place resulting in the formation of a gas such as carbon dioxide?

A Yes B No

*Reason/Justification*______________________________

APPENDIX J

SECOND VERSION OF THE FREE RESPONSE TEST ON QUALITATIVE ANALYSIS

Instructions:

- Choose the most suitable option in each question by circling it. Give your reason for choosing the option.
- If you feel that all the options given are inappropriate, you may write down what you think the correct answer should be, and give your reason.

For Questions 1 to 4, refer to Experiment A:

Experiment A

Test No.	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white solid is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	*White solid disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid (HNO_3) to the mixture from (b) until no further change is seen.	*White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.*

1. What type of reaction occurs when aqueous sodium hydroxide reacts with aqueous zinc chloride to form a white solid?

A Displacement
B Neutralisation
C Precipitation
D Redox
E ____________________

Reason/Justification

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

A dissolves in
B reacts with
C. ________________________________

Reason/Justification

3. A student concludes that the white solid obtained in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

4. The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

For Questions 5 to 9, refer to Experiment B:

Experiment B

Test No.	Test	Observations
a	To a portion of S, add an equal volume of aqueous silver nitrate(V) ($AgNO_3$). Divide the mixture into 2 portions.	*A white solid is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction.*
c(i)	To the second portion, add aqueous ammonia.	*White solid disappears and a slightly cloudy liquid is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White solid appears.*

5. Write down the formula of the white solid formed in step (a).

____

Reason/Justification

6. In step (b), what is the purpose of adding the dilute nitric(V) acid?

A To remove impurities.
B To oxidise the white solid.
C ______________________________

Reason/Justification

7. In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A Yes B No

Reason/Justification

8. In step (c (i)), it can be concluded that a reaction, resulting in the formation of ammonium chloride, has occurred.

A True B False

Reason/Justification

9. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid.

A True B False

Reason/Justification

10. Which of the following gas(es) can be obtained when an ionic compound is heated?

I Carbon dioxide.
II Hydrogen.

A	I only	B	II only
C	I and II	D	None of the above

Reason/Justification

11. A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first and followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A	Yes	B	No

Reason/Justification

12. Instead of adding dilute nitric(V) acid in Question 11, can the student add sulphuric(VI) acid (H_2SO_4)?

A	Yes	B	No

Reason/Justification

13. When do you test for oxygen gas? When you

I. heat an unknown sample.
II. add acid to an unknown sample.

A	I only	B	II only
C	I and II	D	None of the above

Reason/Justification

APPENDIX K

FIRST VERSION OF THE TWO-TIER MULTIPLE CHOICE DIAGNOSTIC INSTRUMENT

For Questions 1 to 4, refer to Experiment A:

Experiment A

Test No.	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white solid is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	*White solid disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid (HNO_3) to the mixture from (b) until no further change is seen.	*White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.*

1. What type of reaction occurs when aqueous sodium hydroxide reacts with aqueous zinc chloride to form a white solid?

A Displacement
B Precipitation
C Redox

Reason/Justification

(1) Hydroxide ion is more reactive than chloride ion.
(2) Sodium chloride precipitates out because the solution is too concentrated.
(3) Sodium hydroxide loses oxygen but gains chlorine in forming sodium chloride and zinc chloride loses chlorine but gains oxygen in forming zinc hydroxide.
(4) Sodium ion is more reactive than zinc ion.
(5) Zinc ions combine with the hydroxide ions.

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

A dissolves in B reacts with

Reason/Justification

(1) More solvent is added so there is more space for the white solid to dissolve.
(2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(3) Sodium ion displaces the cation from the white solid.
(4) Sodium is a very reactive metal, hence sodium hydroxide is a strong solvent.
(5) The white solid forms a soluble compound with the excess sodium hydroxide.

3. A student concludes that the white solid obtained in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the excess sodium hydroxide to form sodium nitrate(V) which appears as the white solid.
(3) The acid reacts with the zinc compound to form zinc nitrate(V) which appears as the white solid.
(4) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(5) The acid removes the solvent for the precipitate so the precipitate reappears.

4. The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Adding more acid dilutes the solution.
(2) Hydrogen is more reactive than the cation in the white solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the white solid.
(5) The acid reacts with the white solid to form a soluble compound.

For Questions 5 to 9, refer to Experiment B:

Experiment B

Test No.	Test	Observations
	Q is a compound which contains a cation and an anion which could possibly be chloride.	
a	To a portion of Q, add an equal volume of aqueous silver nitrate(V) ($AgNO_3$). Divide the mixture into 2 portions.	*A white solid is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction. The white solid remains.*
c(i)	To the second portion, add aqueous ammonia.	*White solid disappears and a colourless liquid is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White solid appears.*

5. What is the white solid obtained in step (a)?

A	Ag	B	AgCl
C	$ZnCl_2$	D	$Zn(NO_3)_2$

Reason/Justification

(1) The silver ions are displaced by the more reactive cations from Q.
(2) The silver ions combine with the chloride ions.
(3) The white solid disappears when aqueous ammonia is added in step c(i).
(4) The nitrate(V) ions are displaced by the more reactive chloride ions.

6. In step (b), what is the purpose of adding the dilute nitric(V) acid?

A To acidify the mixture.
B To determine if the sample contains carbonate ions.
C To dissolve the white solid.
D To oxidise the white solid.
E To remove impurities to ensure a fair test.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Carbonate ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.
(3) Nitric(V) acid is a strong oxidising agent.
(4) Nitric(V) acid is a good solvent.
(5) So that Q can react properly with silver nitrate(V).

7. In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A	Yes	B	No

Reason/Justification

(1) Both nitrate(V) and chloride ions are present in the mixture.
(2) Chloride ions from hydrochloric acid will interfere with the test.
(3) Hydrochloric acid can be used as it has similar properties and reactions.
(4) Hydrochloric acid will not react with the white solid.
(5) Hydrochloric acid will react with the white solid.

8. In step (c (i)), it can be concluded that a reaction, resulting in the formation of ammonium chloride, has occurred.

A True B False

Reason/Justification

(1) Ammonium chloride is a soluble salt.
(2) Chloride ions still present in solution react with the aqueous ammonia.
(3) The ammonium ion is more reactive than the silver ion, so it displaces the silver ion.
(4) The aqueous ammonia reacts with the white solid to produce a soluble compound which is not ammonium chloride.

9. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid.

A True B False

Reason/Justification

(1) The acid decomposes the ammonium chloride to liberate chloride ions which react with the silver ions present in solution.
(2) The acid reacts with the aqueous ammonia to produce a new insoluble salt.
(3) The acid reacts with the aqueous ammonia and the soluble compound in step (c (i)) to produce the same white solid as in step (a).
(4) The acid removes the ammonium ions so that silver ions can react with hydroxide ions.
(5) The white solid is the element silver.

10. A student believes that she has to test for hydrogen and carbon dioxide every time she heats an ionic compound. Do you agree?

A Yes B No

Reason/Justification

(1) Ionic compounds have strong bonds and do not decompose on heating.
(2) Ionic compounds which contain carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen on heating.
(3) Some carbonates decompose on heating to give carbon dioxide but hydrogen is never liberated when ionic compounds are heated.
(4) The ionic compounds would react with oxygen on heating to give water and/or carbon dioxide.
(5) Gases are only evolved when covalent compounds are heated.

11. A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A Yes B No

Reason/Justification

(1) An insoluble carbonate would be formed leaving no free carbonate ions in solution to react with the acid.
(2) Nitric(V) acid will react with both a soluble and an insoluble carbonate.
(3) The above procedure is strictly to test for the presence of sulphate(VI) only.
(4) The acid must be added directly to the solution to test for the presence of a carbonate.
(5) The unknown compound will only react with the nitric(V) acid and not with the barium nitrate(V).

12. Instead of adding dilute nitric(V) acid in Question 11, can the student add dilute sulphuric(VI) acid (H_2SO_4)?

A Yes B No
C There is no difference

Reason/Justification

(1) Any acid can be used as they have similar properties and reactions.
(2) Sulphuric(VI) acid is much stronger than nitric(V) acid.
(3) Sulphate(VI) ions from sulphuric(VI) acid will interfere with the test.
(4) Sulphuric(VI) acid will react with the nitrate(V) ions.
(5) The addition of barium nitrate(V) invalidates the test.

13. Will you test for oxygen gas when you heat an unknown solid?

A Yes B No

Reason/Justification

(1) All gases must be tested when a substance is heated.
(2) Oxygen gas is produced only when acids react with compounds containing oxygen.
(3) Oxygen gas will not be liberated during heating, instead it would be used up.
(4) Some compounds decompose on heating to give oxygen gas.

APPENDIX L

SECOND VERSION OF THE TWO-TIER MULTIPLE CHOICE DIAGNOSTIC INSTRUMENT

Instructions
Choose the most suitable option and the reason for your choice in each question by filling the appropriate circles in the answer sheet. If you feel that all options given are inappropriate, indicate the question number and write down what you think the correct answer should be behind the answer sheet.

For Questions 1 to 4, refer to Experiment A:

Experiment A

Step	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white solid is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	*White solid disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid (HNO_3) to the mixture from (b) until no further change is seen.	*White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.*

1. What happens when aqueous sodium hydroxide is added to aqueous zinc chloride resulting in the white solid?

A Displacement
B Precipitation
C Redox

Reason/Justification

(1) The solution is too concentrated with sodium chloride so the sodium chloride comes out of the solution as a solid.
(2) Sodium hydroxide loses oxygen in forming sodium chloride and zinc chloride gains oxygen in forming zinc hydroxide.
(3) Sodium ion is more reactive than zinc ion.
(4) Zinc ions combine with the hydroxide ions.

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

A dissolves in B reacts with

Reason/Justification

(1) More solvent is added so there is more space for the white solid to dissolve.
(2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(3) Sodium ion displaces the cation from the white solid.
(4) The white solid forms a new soluble compound with the excess sodium hydroxide.

3. A student concludes that the white solid obtained in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the excess sodium hydroxide to form sodium nitrate(V) which appears as the white solid.
(3) The acid reacts with the zinc compound to form zinc nitrate(V) which appears as the white solid.
(4) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(5) The acid removes the solvent which dissolves the white solid in step (b), so the white solid reappears.

4. The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Adding more acid dilutes the solution.
(2) Hydrogen is more reactive than the cation in the white solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the white solid.
(5) The acid reacts with the white solid to form a new soluble compound.

For Questions 5 to 9, refer to Experiment B:

Experiment B

Step	Test	Observations
	Q is an aqueous solution of a compound which containing a cation and an anion which could possibly be chloride.	
a	To a portion of Q, add an equal volume of aqueous silver nitrate(V) ($AgNO_3$). Divide the mixture into 2 portions.	*A white solid is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction. The white solid remains.*
c(i)	To the second portion, add aqueous ammonia.	*White solid disappears and a colourless liquid is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White solid appears.*

5. What is the white solid obtained in step (a)?

A $AgCl$
B $ZnCl_2$
C $Zn(NO_3)_2$

Reason/Justification

(1) The silver ions are displaced by the more reactive cations from Q.
(2) The silver ions combine with the chloride ions.
(3) The white solid disappears when aqueous ammonia is added in step c(i).
(4) The nitrate(V) ions are displaced by the more reactive chloride ions.

6. In step (b), the purpose of adding the dilute nitric(V) acid is to:

A acidify the mixture.
B determine if the sample contains carbonate ions.
C dissolve the white solid.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Carbonate ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.
(3) Dilute nitric(V) acid is a strong oxidising agent.
(4) Dilute nitric(V) acid is a good solvent.
(5) So that Q can react properly with silver nitrate(V).

7. In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A Yes B No

Reason/Justification

(1) Both nitrate(V) and chloride ions are already present in the mixture.
(2) Chloride ions from dilute hydrochloric acid will interfere with the test.
(3) Dilute hydrochloric acid can be used as it has similar properties and reactions as dilute nitric(V) acid.
(4) Dilute hydrochloric acid will not react with the white solid.
(5) Dilute hydrochloric acid will react with the white solid.

8. In step (c (i)), it can be concluded that a reaction, resulting in the formation of ammonium chloride, has occurred.

A True B False

Reason/Justification

(1) Ammonium chloride is a soluble salt.
(2) Chloride ions still present in solution react with the aqueous ammonia.
(3) The ammonium ion is more reactive than the silver ion, so it displaces the silver ion.
(4) The aqueous ammonia reacts with the white solid to produce a soluble compound which is not ammonium chloride.

9. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid.

A True B False

Reason/Justification

(1) The acid decomposes the ammonium chloride to liberate chloride ions which react with the silver ions present in solution.
(2) The acid reacts with the aqueous ammonia to produce a new insoluble salt.
(3) The acid reacts with the aqueous ammonia and the soluble compound in step (c (i)) to produce the same white solid as in step (a).
(4) The acid removes the ammonium ions so that silver ions can react with hydroxide ions.
(5) The white solid is the element, silver.

10. Will you test for oxygen gas when you heat an unknown solid?

A Yes B No

Reason/Justification

(1) All gases must be tested when a substance is heated.
(2) Oxygen gas is produced only when acids react with compounds containing oxygen.
(3) Oxygen gas will not be liberated during heating, instead it would be used up.
(4) Some compounds decompose on heating to give oxygen gas.

11. A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A Yes B No

Reason/Justification

(1) An insoluble carbonate would be formed leaving no free carbonate ions in solution to react with the acid.
(2) Dilute nitric(V) acid will react with both a soluble and an insoluble carbonate.
(3) The above procedure is strictly to test for the presence of sulphate(VI) only.
(4) The acid must be added directly to the solution to test for the presence of a carbonate.
(5) The unknown compound will only react with the dilute nitric(V) acid and not with the barium nitrate(V).

12. Instead of dilute nitric(V) acid, can the student add dilute sulphuric(VI) acid (H_2SO_4) after the addition of barium nitrate(V) in Question 11?

A Yes B No

Reason/Justification

(1) Any acid can be used as they have similar properties and reactions.
(2) Sulphate(VI) ions from dilute sulphuric(VI) acid will interfere with the test.
(3) Dilute sulphuric(VI) acid will react with the nitrate(V) ions.
(4) The addition of barium nitrate(V) has already invalidated (spoilt) the test for carbonates.

For Questions 13 to 16, refer to Experiment C:

Experiment C

Step	Test	Observations
a	To a sample of aqueous copper(II) sulphate(VI), add aqueous ammonia until a change is seen.	*A light blue solid is obtained.*
b	Add excess of aqueous ammonia to the mixture from (a).	*Light blue solid disappears in excess aqueous ammonia to give a deep blue solution.*
c	Add dilute sulphuric(VI) acid to the mixture from (b) until no further change is seen.	*A light blue solid appears. When excess acid is added, the solid disappears giving a blue solution.*

13. What happens when aqueous ammonia is added to aqueous copper(II) sulphate(VI) in step (a)?

A Displacement
B Precipitation
C Redox

Reason/Justification

(1) Aqueous ammonia gains oxygen in forming ammonium sulphate(VI) but copper(II) sulphate(VI) loses oxygen in forming copper(II) hydroxide.
(2) Copper(II) ions combine with the hydroxide ions.
(3) Copper(II) ion is more reactive than ammonium ion.
(4) Copper(II) ion is less reactive than the ammonium ion.

14. In step (b), why does the light blue solid disappear?

A It dissolves in aqueous ammonia.
B It reacts with aqueous ammonia.

Reason/Justification

(1) Ammonium ion displaces the cation from the light blue solid.
(2) More solvent is added so there is more volume for the light blue solid to dissolve in.
(3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added.
(4) There is a chemical reaction between the light blue solid and excess ammonia forming product(s) which is/are soluble.

15. The light blue solid obtained in step (a) and in step (c) is the same.

A True B False

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the copper(II) compound to form copper(II) suphate (VI) which appears as the light blue solid.
(3) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(4) The acid removes the solvent which dissolves the light blue solid in step (b), so the light blue solid reappears.

16. Excess dilute sulphuric(VI) acid acts as a solvent for the light blue solid in step (c).

A True B False

Reason/Justification

(1) Adding more acid dilutes the mixture.
(2) Hydrogen is more reactive than the cation in the light blue solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the light blue solid.
(5) The acid reacts with the light blue solid to form a new soluble compound.

For Questions 17 to 18, refer to Experiment D:

Experiment D

Step	Test	Observations
	R is a colourless aqueous solution of a compound containing a cation and an anion which could possibly be iodide.	
a	To a portion of R, add an equal volume of dilute nitric(V) acid.	*No visible reaction, a colourless solution remains.*
b	To the mixture from (a), add a small volume of aqueous lead(II) nitrate(V) ($Pb(NO_3)_2$).	*Yellow solid is obtained.*

17. The purpose of adding the dilute nitric(V) acid in step (a) is to

A acidify the mixture.
B determine if R reacts with the acid.
C remove impurities.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Dilute nitric(V) acid is a strong oxidising agent.
(3) Dilute nitric(V) acid is a good solvent.
(4) So that R can react properly with lead(II) nitrate(V).
(5) The acid will react with any carbonate or sulphate(IV) (SO_3^{2-}) ion if they are present in R.

18. How is the yellow solid formed?

A Displacement
B Precipitation

Reason/Justification

(1) The lead(II) ion is more reactive than the cation from R.
(2) The lead(II) ion is less reactive than the cation from R.
(3) The lead(II) ions combine with iodide ions.
(4) The iodide ions are more reactive than the nitrate(V) ions.
(5) The iodide ions are less reactive than the nitrate(V) ions.

19. A student believes that she has to test for hydrogen and carbon dioxide when she heats an unknown ionic compound (in powder form). Do you agree?

A Yes B No

Reason/Justification

(1) Ionic compounds have strong bonds and do not decompose on heating.
(2) Gases are only evolved when covalent compounds are heated.
(3) Some carbonates decompose on heating to give carbon dioxide but hydrogen is never liberated when any ionic compound is heated.
(4) The ionic compound would react with oxygen on heating to give water and/or carbon dioxide.
(5) Those ionic compounds containing carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen on heating.

APPENDIX M

QUALITATIVE ANALYSIS DIAGNOSTIC INSTRUMENT

Instructions
Choose the most suitable option and the reason for your choice in each question by filling the appropriate circles in the answer sheet. If you feel that all options given are inappropriate, indicate the question number and write down what you think the correct answer should be behind the answer sheet.

For Questions 1 to 4, refer to Experiment A:

Experiment A

Step	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white solid is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	*White solid disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid (HNO_3) to the mixture from (b) until no further change is seen.	*White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.*

1. What happens when aqueous sodium hydroxide is added to aqueous zinc chloride resulting in the white solid?

A Displacement
B Precipitation
C Redox

Reason/Justification

(1) The solution is too concentrated with sodium chloride so the sodium chloride comes out of the solution as a solid.
(2) Sodium hydroxide loses oxygen in forming sodium chloride and zinc chloride gains oxygen in forming zinc hydroxide.
(3) Sodium ion is more reactive than zinc ion.
(4) Zinc ions combine with the hydroxide ions.

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

A dissolves in B reacts with

Reason/Justification

(1) More solvent is added so there is more space for the white solid to dissolve.
(2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(3) Sodium ion displaces the cation from the white solid.
(4) The white solid forms a new soluble compound with the excess sodium hydroxide.

3. A student concludes that the white solid observed in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the excess sodium hydroxide to form sodium nitrate(V) which appears as the white solid.
(3) The acid reacts with the zinc compound to form zinc nitrate(V) which appears as the white solid.
(4) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(5) The acid removes the solvent which dissolves the white solid in step (b), so the white solid reappears.

4. The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Adding more acid dilutes the solution.
(2) Hydrogen is more reactive than the cation in the white solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the white solid.
(5) The acid reacts with the white solid to form a new soluble compound.

For Questions 5 to 9, refer to Experiment B:

Experiment B

Step	Test	Observations
	Q is an aqueous solution of a compound which containing a cation and an anion which could possibly be chloride.	
a	To a portion of Q, add an equal volume of aqueous silver nitrate(V) ($AgNO_3$). Divide the mixture into 2 portions.	*A white solid is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction. The white solid remains.*
c(i)	To the second portion, add aqueous ammonia.	*White solid disappears and a colourless liquid is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White solid appears.*

5. What is the white solid obtained in step (a)?

A $AgCl$
B $ZnCl_2$
C $Zn(NO_3)_2$

Reason/Justification

(1) The silver ions are displaced by the more reactive cations from Q.
(2) The silver ions combine with the chloride ions.
(3) The white solid disappears when aqueous ammonia is added in step c(i).
(4) The nitrate(V) ions are displaced by the more reactive chloride ions.

6. In step (b), the purpose of adding the dilute nitric(V) acid is to:

A acidify the mixture.
B determine if the sample contains carbonate ions.
C dissolve the white solid.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Carbonate ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.
(3) Dilute nitric(V) acid is a strong oxidising agent.
(4) Dilute nitric(V) acid is a good solvent.
(5) So that Q can react properly with silver nitrate(V).

7. In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A Yes B No

Reason/Justification

(1) Both nitrate(V) and chloride ions are already present in the mixture.
(2) Chloride ions from dilute hydrochloric acid will interfere with the test.
(3) Dilute hydrochloric acid can be used as it has similar properties and reactions as dilute nitric(V) acid.
(4) Dilute hydrochloric acid will not react with the white solid.
(5) Dilute hydrochloric acid will react with the white solid.

8. In step (c (i)), it can be concluded that the white solid disappeared because it reacted with the aqueous ammonia to form ammonium chloride.

A True B False

Reason/Justification

(1) Ammonium chloride is a soluble salt.
(2) Chloride ions still present in solution react with the aqueous ammonia.
(3) The ammonium ion is more reactive than the silver ion, so it displaces the silver ion.
(4) The aqueous ammonia reacts with the white solid to produce a soluble compound which is not ammonium chloride.

9. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid.

A True B False

Reason/Justification

(1) The acid decomposes the ammonium chloride to liberate chloride ions which react with the silver ions present in solution.
(2) The acid reacts with the aqueous ammonia to produce a new insoluble salt.
(3) The acid reacts with the aqueous ammonia and the soluble compound in step (c (i)) to produce the same white solid as in step (a).
(4) The acid removes the ammonium ions so that silver ions can react with hydroxide ions.
(5) The white solid is the element, silver.

10. Will you test for oxygen gas when you heat an unknown solid?

A Yes B No

Reason/Justification

(1) All gases must be tested when a substance is heated.
(2) Oxygen gas is produced only when acids react with compounds containing oxygen.
(3) Oxygen gas will not be liberated during heating, instead it would be used up.
(4) Some compounds decompose on heating to give oxygen gas.

11. A student is given a solution which may contain a carbonate ion. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether a carbonate ion is present when she carries out the above procedure?

A Yes B No

Reason/Justification

(1) An insoluble carbonate would be formed leaving no free carbonate ions in solution to react with the acid.
(2) Dilute nitric(V) acid will react with both a soluble and an insoluble carbonate.
(3) The above procedure is strictly to test for the presence of sulphate(VI) only.
(4) The acid must be added directly to the solution to test for the presence of a carbonate.
(5) The unknown compound will only react with the dilute nitric(V) acid and not with the barium nitrate(V).

12. Instead of dilute nitric(V) acid, can the student add dilute sulphuric(VI) acid (H_2SO_4) after the addition of barium nitrate(V) in Question 11?

A Yes
B No

Reason/Justification

(1) Any acid can be used as they have similar properties and reactions.
(2) Sulphate(VI) ions from dilute sulphuric(VI) acid will interfere with the test.
(3) Dilute sulphuric(VI) acid will react with the nitrate(V) ions.
(4) The addition of barium nitrate(V) has already invalidated (spoilt) the test for carbonates.

For Questions 13 to 16, refer to Experiment C:

Experiment C

Step	Test	Observations
a	To a sample of aqueous copper(II) sulphate(VI), add aqueous ammonia until a change is seen.	*A light blue solid is obtained.*
b	Add excess of aqueous ammonia to the mixture from (a).	*Light blue solid disappears in excess aqueous ammonia to give a deep blue solution.*
c	Add dilute sulphuric(VI) acid to the mixture from (b) until no further change is seen.	*A light blue solid appears. When excess acid is added, the solid disappears giving a light blue solution.*

13. What happens when aqueous ammonia is added to aqueous copper(II) sulphate(VI) in step (a)?

A Displacement
B Precipitation
C Redox

Reason/Justification

(1) Aqueous ammonia gains oxygen in forming ammonium sulphate(VI) but copper(II) sulphate(VI) loses oxygen in forming copper(II) hydroxide.
(2) Copper(II) ions combine with the hydroxide ions.
(3) Copper(II) ion is more reactive than the ammonium ion.
(4) Copper(II) ion is less reactive than the ammonium ion.

14. In step (b), why does the light blue solid disappear?

A It dissolves in aqueous ammonia.
B It reacts with aqueous ammonia.

Reason/Justification

(1) Ammonium ion displaces the cation from the light blue solid.
(2) More solvent is added so there is more volume for the light blue solid to dissolve in.
(3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added.
(4) There is a chemical reaction between the light blue solid and excess ammonia forming product(s) which is/are soluble.

15. The light blue solid obtained in step (a) and in step (c) is the same.

A True B False

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the copper(II) compound to form copper(II) suphate (VI) which appears as the light blue solid.
(3) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(4) The acid removes the solvent which dissolves the light blue solid in step (b), so the light blue solid reappears.

16. Excess dilute sulphuric(VI) acid acts as a solvent for the light blue solid in step (c).

A True B False

Reason/Justification

(1) Adding more acid dilutes the mixture.
(2) Hydrogen is more reactive than the cation in the light blue solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the light blue solid.
(5) The acid reacts with the light blue solid to form a new soluble compound.

For Questions 17 to 18, refer to Experiment D:

Experiment D

Step	Test	Observations
	R is a colourless aqueous solution of a compound containing a cation and an anion which could possibly be iodide.	
a	To a portion of R, add an equal volume of dilute nitric(V) acid.	*No visible reaction, a colourless solution remains.*
b	To the mixture from (a), add a small volume of aqueous lead(II) nitrate(V) ($Pb(NO_3)_2$).	*Yellow solid is obtained.*

17. The purpose of adding the dilute nitric(V) acid in step (a) is to

A acidify the mixture.
B determine if R reacts with the acid.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Dilute nitric(V) acid is a strong oxidising agent.
(3) Dilute nitric(V) acid is a good solvent.
(4) So that R can react properly with lead(II) nitrate(V).
(5) The acid will react with any carbonate or sulphate(IV) (SO_3^{2-}) ion if they are present in R.

18. How is the yellow solid formed?

A Displacement
B Precipitation

Reason/Justification

(1) The lead(II) ion is more reactive than the cation from R.
(2) The lead(II) ion is less reactive than the cation from R.
(3) The lead(II) ions combine with iodide ions.
(4) The iodide ions are more reactive than the nitrate(V) ions.
(5) The iodide ions are less reactive than the nitrate(V) ions.

19. A student believes that she has to test for hydrogen and carbon dioxide when she heats an unknown ionic compound (in powder form). Do you agree?

A Yes B No

Reason/Justification

(1) Ionic compounds have strong bonds and do not decompose on heating.
(2) Gases are only evolved when covalent compounds are heated.
(3) Some carbonates decompose on heating to give carbon dioxide but hydrogen is never liberated when any ionic compound is heated.
(4) The ionic compound would react with oxygen on heating to give water and/or carbon dioxide.
(5) Those ionic compounds containing carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen on heating.

APPENDIX N1

TEACHER'S GUIDE TO THE QUALITATIVE ANALYSIS TEACHING PACKAGE

INTRODUCTION

A. WHY QUALITATIVE ANALYSIS (QA) IS DIFFICULT

Research has found that students find qualitative analysis difficult. The reasons are:

1. Students do not know that they are required to make links between theory and practical work, or how to make these links.

2. Students do not know the purpose of the experiments and procedures, hence their action degenerates to simply following instructions with little or no cognitive involvement and their aim becomes one of 'getting the right answer'.

3. The content of qualitative analysis is extensive, abstract and complex. It involves the application of knowledge from different topics, much of which is remote from everyday life experiences. It also involves process skills such as manipulative and inferential skills, as well as metacognitive strategies.

4. Students' working memory may be overloaded when they carry out qualitative analysis experiments. They need to read instructions, carry them out, prepare additional tests for gases, observe, record and interpret their results, as well as be mindful of the time left to complete their experiments and reports. The resulting overload leaves little space for thought and learning.

5. Students lack mastery of the skills required in QA. Many do not know how to carry out the procedures in the correct manner, and unfortunately, teachers do not spend time helping students develop such procedural skills. Students also may not know what to observe and what valid inferences to make because they do not understand the reactions behind the procedures, that is, they lack the appropriate knowledge framework for qualitative analysis.

6. Students do not need to understand what they are doing in the experiments in order to do well in the practical examinations. Teachers also stress on 'drill and practice' rather than understanding for the same reason. Thus there is little incentive to expend the effort on thinking deeply into the topic.

B. THEORETICAL BASIS OF THE QA WORKBOOK

1. Experience
    a. To allow students to have tacit knowledge of the phenomena, reagents and apparatus.
    b. To allow students to discuss and explain the phenomena before the teacher introduces the relevant concepts.
    c. To guide them to construct explanations which are intelligible, plausible and fruitful.
        i. Students to learn reactions at 3 levels, macroscopic, microscopic and symbolic.
        ii. Use of analogies and computer simulations to explain/give a picture of reactions at the micro-level.

2. Exercise

    To allow students to be proficient in manipulative, observational and inferential skills to increase their self-confidence and increase their expertise in QA.

3. Application

    To allow students to apply what they have learnt to plan, execute and evaluate experiments to identify unknown samples.

4. Metacognitive skills
    a. To allow students to see how an expert analyses QA worksheets and carry out experiments.
    b. To allow students to model the expert.

CATIONS

EXPERIENCE 1

A. Precipitation and reaction of a few precipitates with excess reagents

1. **Sodium chloride + sodium hydroxide**
   Experience no visible reaction.

2. **Iron(III) solution + sodium hydroxide**
   a. Experience precipitation and compare with (1).
   b. See that the precipitate is insoluble in excess water or aqueous sodium hydroxide.
   c. Learn the reason for the formation of insoluble salt – double decomposition and precipitation.
   d. Use computer animation provided to explain precipitate formation, dissolution and insolubility.
   e. Students to make a precipitate of their choice – consult list of insoluble salts, and decide which solutions to use in order to get the precipitate.

3. **Zinc solution + sodium hydroxide**
   a. Experience a precipitate which is insoluble in water added but disappears when excess sodium hydroxide added.
   b. Discuss complex ion formation.
   c. Make another precipitate which dissolves in excess sodium hydroxide.

4. **Copper(II) solution + sodium hydroxide & copper(II) solution + aqueous ammonia**
   a. Compare and discuss the above reactions.

5. **Solid zinc carbonate + acid + sodium hydroxide**
   a. Make a solution of zinc ions from zinc carbonate and discuss the reaction.
   b. Discuss whether reagents should be added to solid samples to determine if a precipitate forms – cannot determine whether solid present is a precipitate or undissolved/ insoluble original material.

B. Identifying cations

Discuss how the results from the addition of aqueous sodium hydroxide and aqueous ammonia to unknown solutions help in the identification of cations.

1. Formation of precipitate.
2. Colour of precipitate.
3. Further reaction of precipitate with excess alkali (complex ion formation).

EXERCISE 1

1. **Adding reagents**
   - a. how much unknown to use
   - b. how to add a small amount of reagent
   - c. how to add reagent to excess
   - d. how to shake/stir after adding reagent

2. **Making solutions with soluble salts**
   - a. how to prepare a saturated solution
   - b. how to fold a filter paper
   - c. how to filter

3. **Making solutions with insoluble salts**
   - a. how to prepare a saturated solution using acid-salt reactions

4. **Determining the colour of a precipitate in coloured liquid**
   eg. the precipitate formed in the reaction between aqueous barium nitrate(V) and aqueous copper(II) sulphate(VI)
   - a. how to decant the coloured liquid leaving the precipitate behind
   - b. how to filter off the precipitate

5. **Add sodium hydroxide and aqueous ammonia to solutions containing**
   - a. zinc ions
   - b. aluminium ions
   - c. calcium ions
   - d. copper(II) ions
   - e. iron(II) ions
   - f. iron(III) ions
   - g. sodium ions

   Focus is on what to observe and record as students should have already mastered manipulative skills.

EXPERIENCE 2

1. **Odour of ammonia and its reaction with litmus.**
   - a. Experience odour of ammonia.
   - b. Learn why litmus paper needs to be moist, and precautions to take when using litmus paper.

2. **Reaction of ammonium ions and sodium hydroxide with gentle heating**
   - a. Experience and discuss the reaction – take note of the odour of the gas and the use of litmus.
   - b. Learn why aqueous ammonia cannot be used to test for ammonium ions.

EXERCISE 2

Heating mixture containing ammonium ions

1. how to heat
2. how to use litmus to test for ammonia
3. what to observe and how to write down the observation

APPLICATION

1. Plan an experiment to identify the cations in three unknown solid samples.
2. Rehearse mentally what to do before starting.

GASES

EXPERIENCE

A. Colour and odours of gases.

1. Experience the colour and odour of some gases. Students should be warned not to breathe the gases in deeply as they are POISONOUS. Students are to do these experiments in groups of 4 to minimise the amount of gases produced.
    a. Sulphur dioxide - acid + sulphate(IV)
    b. Chlorine - solid manganese (IV) oxide + concentrated hydrochloric acid
    c. Nitrogen dioxide - copper + concentrated nitric(V) acid

B. Introduce the reactions in which gases are produced. The gases evolved indicate the ions/element present.

Gas	Ion/element present	Reactions
Hydrogen	Hydrogen ions, metals	Acid + reactive metals
Oxygen	Nitrate(V) Oxides	Thermal decomposition of nitrate(V) Thermal decomposition of some oxides
Carbon dioxide	Hydrogen ions, carbonates, hydrogencarbonates	Thermal decomposition of carbonate Acid + carbonate/hydrogencarbonate
Sulphur dioxide	Hydrogen ions, sulphate(VI)	Thermal decomposition of sulphate(IV) Acid + sulphate(IV)
Chlorine	Chloride	Chloride + oxidising agents
Nitrogen dioxide	Nitrate(V)	Thermal decomposition of nitrate(V) Reduction of nitrate(V)
Ammonia	Ammonium ions	Ammonium salts + alkalis + heat

C. Redox reactions

1. Redox reactions are involved in the identification of gases.

2. Sulphur dioxide + acidified potassium manganate(VII) and acidified potassium dichromate(VI).
    a. Discuss why only sulphuric(VI) acid is used to acidify the oxidising agents and not hydrochloric or nitric(V) acid.
    b. Discuss the reasons for the colour changes – manganese and chromium in various oxidation states, properties of transition metals – coloured compounds and variable oxidation state.

3. Zinc + copper(II) sulphate solution
    a. Learn that displacement reaction is also a redox reaction.
    b. Learn what happens at the micro-level.

4. Changing iron(II) to iron(III) and vice versa
   a. Introduce students to oxidising and reducing agents in the lab:
      i. acidified aqueous potassium manganate(VII).
      ii. acidified aqueous potassium dichromate(VI).
      iii. hydrogen peroxide.
      iv. potassium iodide.
      v. metals.
      vi. hydrogen.

   b. Allow students to convert iron(II) to iron(III) and vice-versa:
      i. Application of knowledge of redox.
      ii. Application of knowledge of cations to detect the conversion of iron(II) to iron(III) and vice versa.

D. Salt-acid reactions

1. Aqueous sodium carbonate + acid
   a. Be ready to test for gases (which?) when acid is added.
   b. Is choice of acid to be used important?
      (i) formation of insoluble salt
      (ii) introduction of a foreign anion

2. Aqueous sodium carbonate + aqueous barium nitrate(V) + acid
   a. Addition of barium nitrate(V) does not affect acid-carbonate reaction.
   b. Why precipitate disappears? – reaction with acid and not dissolves in acid
   c. Which acid to add? – complications with sulphuric(VI) acid

EXERCISE

A. Use of litmus to test gases

Review how to use litmus paper

B. Specific tests for gases.

Gas	Test
Hydrogen	Litmus + lighted splint (why?)
Oxygen	Litmus + glowing splint (why?)
Carbon dioxide	Litmus + limewater (why?)
Sulphur dioxide	Litmus + acidified potassium manganate(VII) or potassium dichromate(VI) (why?)
Nitrogen dioxide	Litmus + colour (why?)
Chlorine	Litmus + KI/starch (why?)
Ammonia (done already)	Litmus (why?)

Students should know what to look out for and how to record observations.

METACOGNITIVE STRATEGIES

How an expert will go about testing unknown gases

1. Looking at the reactants to determine what gases to expect

Reagent to be added	Likely gases	Sequence of tests
Dilute acid	Carbon dioxide Sulphur dioxide	1. litmus 2. limewater 3. acidified $KMnO_4$ or $K_2Cr_2O_7$
Dilute acid + shiny, metallic particles	Hydrogen	1. litmus 2. lighted splint
Sodium hydroxide + gentle heating	Ammonia	1. litmus
Heating	Carbon dioxide Sulphur dioxide	1. litmus a. if gas evolved is acidic and colourless (i) limewater (ii) acidified $KMnO_4$ or $K_2Cr_2O_7$
	Oxygen Nitrogen dioxide	b. if gas evolved is colourless and neutral or if gas evolved is brown and acidic (i) glowing splint
Oxidising agents + heat or concentrated hydrochloric acid + heat	Chlorine	1. litmus 2. colour of gas

2. Test for gases

a. Getting reagents, apparatus ready.
b. Colour and or odour of the gases evolved.
c. Litmus test.
d. Specific gas test.

APPLICATION

Test unknown gases liberated.

ANION

EXPERIENCE

A. Heating of substance

1. Substances to be heated:
   a. zinc nitrate(V).
   b. potassium/sodium nitrate(V).
   c. ammonium chloride.
   d. mixture of carbon and copper(II) oxide

2. Students to take note of the following while heating the samples:
   a. colour changes of the sample.
   b. changes in state of the sample.
   c. evolution of gases.

3. Theory behind changes
   a. Decomposition – evolution of gases, colour changes in residue, degree of decomposition depends on stability of compound, and reactivity of the metal present in sample influences stability of compound
   b. Thermal dissociation – 'sublimation' of ammonium chloride
   c. Dehydration – removal of water of crystallisation
   d. Redox – reduction of copper(II) oxide by carbon

B. Precipitation reaction

1. **Aqueous sodium chloride + aqueous silver nitrate + dilute nitric(V) acid/aqueous ammonia.**
   Discuss the formation of silver chloride and why it 'dissolves' in aqueous ammonia – formation of soluble ammine.

2. **Aqueous sodium sulphate(VI) + aqueous barium chloride + dilute hydrochloric acid**
   Discuss the formation of barium sulphate(VI) and that it does not react with with hydrochloric acid.

3. **Aqueous sodium carbonate + aqueous barium chloride + dilute hydrochloric acid.**
   Discuss the formation of barium carbonate and why it 'dissolves' in dilute hydrochloric acid – acid + carbonate reaction.

4. **Aqueous potassium iodide + aqueous lead(II) nitrate(V) + gentle heating + dilute nitric(V) acid**
   Discuss the formation of lead(II) iodide, its solubility in hot water and that it does not react with nitric(V) acid.

5. **Aqueous sodium sulphate(IV) + aqueous barium chloride + dilute hydrochloric acid**
   Discuss formation of barium sulphate(IV) and its reaction with hydrochloric acid.

Students are to note that anions can be determined by

- a. double decomposition/precipitation reaction
- b. further reaction with dilute acid / aqueous ammonia
- c. testing for gases liberated (if any)

Discuss effect of adding acid before the addition of barium, silver or lead(II) reagents – acid reactions first (if any) followed by reaction with barium, silver or lead(II) (if any).

If it is necessary and if time permits, allow students to repeat procedures 1 to 5 but reversing the order of addition of acid and the barium, silver or lead(II) reagents.

C. Inappropriate use of acids

1. Examples
    - a. Aqueous sodium chloride + aqueous barium chloride + dilute sulphuric(VI) acid
    - b. Aqueous potassium nitrate(V) + aqueous silver nitrate(V) + dilute hydrochloric acid

2. Theory

    Introduction of foreign anions may lead to unwanted double decomposition and precipitation reactions.

D. Redox

1. Aqueous copper(II) sulphate + aqueous potassium iodide
    - a. Redox
        - i. Discuss the formation of copper (I) iodide and iodine.
        - ii. Decide colour of the precipitate.
    - b. Testing substances
        - i. If copper(II) sulphate is added to unknown and a buff precipitate in a brown liquid is observed, then positive test for iodide.
        - ii. If potassium iodide is added to unknown and same result obtained, then positive test for copper(II) ion.

2. Test for nitrate(V) – Devadas alloy/zinc powder/aluminium powder

    Reaction between Al/Zn, water, nitrate(V) and hydroxide ions produces the aluminate/zincate, ammonia and hydrogen.

EXERCISE

A. Heading

1. How much reagent to add
    a. If given a solid sample, add the solid under it covers the hemisphere at the bottom of the test tube.
    b. If given a liquid, add until it reaches a height of 2 cm in a test tube.

2. How to heat
    a. Wear goggles for eye protection.
    b. Use a non-luminous flame for a hotter flame and to prevent blackening of apparatus.
    c. For a solid sample,
        i. heat gently for 2 min, by putting the test tube away from the tip of the blue cone, the hottest part of the flame.
        ii. observe for any colour change or liquid forming in the test tube.
        iii. heat strongly for 3 min by putting the test tube at the tip of the blue cone.
        iv. observe for any colour change, change of state, evolution of gases (test for the gases) and formation of liquid/solids at the upper region of the test tube.
    d. For a liquid sample,
        i. heat near the surface of the liquid and shake frequently.
        ii. do not heat at the bottom of the test tube as the liquid may splash out.

3. Practice heating
    a. copper(II) sulphate – water of crystallisation, formation of copper(II) oxide and sulphur trioxide.
    b. aqueous ammonium chloride + aqueous sodium hydroxide

B. Devadas alloy test

Note:

1. Use of test tube holder as reaction is very vigorous once it starts.
2. Test for ammonia.

SOME STRATEGIES

A. Heating samples

1. Observe the colour of sample.

2. Get ready to test for gases
    a. litmus
    b. limewater and delivery tube
    c. acidified potassium manganate(VII) / potassium dichromate(VI)
    d. wooden splint

3. Gentle heating
    a. Start using litmus.
    b. Look out for appearance of a colourless liquid (water), use cobalt chloride paper.

4. Strong heating
    a. Observe changes in colour of the sample.
    b. Observe changes in state
        i. melting
        ii. 'sublimation' – ammonium salts
    c. Evolution of gases – note the result of litmus test before proceeding
        i. neutral gas – test for oxygen
        ii. acidic gas – test for nitrogen dioxide (brown), sulphur dioxide, carbon dioxide

5. Recording observations
    a. Colour changes of sample during heating and cooling.
    b. Changes of state of sample during heating and cooling.
    c. Appearance of substances at upper region of test tube.
    d. Testing of gases.

B. Testing anions using aqueous barium nitrate(V)/chloride, aqueous silver nitrate(V) and aqueous lead(II) nitrate(V)

1. Presence/absence of precipitate – indicate types of anions

Precipitate	Barium nitrate / chloride (aq)	Silver nitrate(V) (aq)	Lead(II) nitrate(V) (aq)
None	Nitrate(V) Chloride Iodide	Nitrate(V) Sulphate(VI) (white ppt if concentrated solution is used)	Nitrate(V)
White	Sulphate(IV) Sulphate(VI) Carbonate	Sulphate(IV) Carbonate Chloride	Sulphate(IV) Sulphate(VI) Carbonate Chloride
Yellow	-	Iodide	Iodide

    a. Reaction of precipitate with acid and ready to test for gases
        i. carbonate – carbon dioxide
        ii. sulphate(IV) – sulphur dioxide

    b. Reaction of precipitate with aqueous ammonia
    Silver chloride being soluble in aqueous ammonia due to the formation of complex ammine.

2. Recording observations
    a. Colour of precipitate.
    b. Reaction with acid, and colour of resulting solution formed
    c. Tests for gases.

C. Redox reactions

1. Carry out test for nitrate(V) if negative reaction for both aqueous barium nitrate(V)/chloride and aqueous silver nitrate(V), and if nitrogen dioxide and/or oxygen evolved during heating.

2. Use of copper(II) sulphate(VI) to test for iodide ions and vice versa

Application

Students to identify anions in 6 solid samples using heat as well as precipitation reactions.

1. zinc carbonate
2. potassium nitrate(V)
3. sodium sulphate(IV)
4. ammonium chloride
5. zinc nitrate(V)
6. iron(II) sulphate(VI)

METACOGNITIVE STRATEGY

Experience

Teacher to show how he/she will approach a QA problem

1. Look at procedures to determine
    a. what the procedures are for, eg. determining cations or anions and if possible which cation or anion.
    b. what to expect, eg. evolution of gases.
    c. what to prepare for, eg. testing of gases.

2. Demonstrate one procedure, and think aloud
    a. what the procedures are for, eg. determining cations or anions and if possible which cation or anion
    b. what to expect eg. evolution of gases
    c. what to prepare for, eg. testing of gases
    d. experimental techniques eg.
        i. how much reagents to add
        ii. what apparatus to use
        iii. how to heat
        iv. how to test for gases
        v. how to determine colour of precipitate
    e. what possible observations can be obtained and why

Exercise

Students to practise analysing QA worksheets in pairs

1. what the procedures are for, eg. determining cations or anions and if possible which cation or anion, and why
2. what to expect eg. evolution of gases
3. what to prepare for, eg. testing of gases
4. experimental techniques eg.
    a. how much reagents to add
    b. what apparatus to use
    c. how to heat
    d. how to test for gases
    e. how to determine colour of precipitate
5. what possible observations can be obtained and why

APPLICATION

Students to analyse a few past years examination questions.

Worksheet 1&2 Cations

Reagents required

1. aqueous sodium chloride (labelled D as well)
2. solid sodium chloride (labelled A as well)
3. aqueous sodium sulphate(VI)
4. aqueous sodium hydroxide
5. aqueous sodium carbonate

6. aqueous potassium iodide

7. aqueous copper(II) sulphate(VI)
8. solid copper(II) carbonate

9. aqueous iron(II) chloride
10. solid iron(II) carbonate (labelled G)

11. aqueous iron(III) chloride

12. aqueous calcium chloride
13. marble chips (solid calcium carbonate) (labelled F)

14. aqueous aluminium nitrate(V)
15. solid aluminium nitrate(V) or any soluble aluminium compound (labelled E)

16. aqueous zinc chloride
17. solid zinc carbonate (labelled H and X)

18. aqueous ammonia
19. aqueous ammonium chloride (labelled C as well)
20. solid ammonium chloride (labelled B as well)

21. aqueous lead(II) nitrate(V)

22. aqueous barium chloride

Apparatus required for all sessions

1. test tubes, holders and rack
2. filter paper and funnel
3. 50ml beakers
4. wooden splint
5. bunsen burner
6. delivery tube
7. blue and red litmus papers
8. strips of filter paper

Worksheet 3&4 Gases

Reagents required

1. solid sodium sulphate(IV) (also labelled as J)
2. aqueous sodium carbonate

3. aqueous potassium manganate(VII)
4. aqueous potassium dichromate(VI)
5. aqueous potassium iodide

6. aqueous iron(II) chloride
7. aqueous iron(III) chloride
8. iron filings

9. copper turnings
10. aqueous copper(II) sulphate(VI)

11. aqueous barium chloride
12. aqueous barium nitrate(V)

13. potassium iodide-starch papers or potassium iodide-starch solution

14. solid ammonium chloride (labelled as K)

15. manganese (IV) oxide

16. zinc pieces
17. solid zinc nitrate(V) (labelled as L)

18. magnesium pieces (2 cm)

19. limewater

20. dilute hydrochloric acid
21. concentrated hydrochloric acid

22. dilute nitric(V) acid
23. concentrated nitric(V) acid

24. dilute sulphuric(VI) acid

25. hydrogen peroxide (10-strength)

Worksheet 5&6 Anions

Reagents required

1. solid zinc nitrate(V)
2. solid zinc carbonate (labelled as M)

3. aqueous potassium iodide

4. solid sodium nitrate(V) (also labelled as N)
5. solid sodium sulphate(IV) (labelled as O)
6. aqueous sodium nitrate(V)
7. aqueous sodium chloride
8. aqueous sodium sulphate(IV)
9. aqueous sodium sulphate(VI)
10. aqueous sodium carbonate
11. aqueous sodium hydroxide

12. solid ammonium chloride (also labelled as P)
13. aqueous ammonium chloride
14. aqueous ammonia

15. mixture of carbon powder + copper(II) oxide

16. Devada's alloy or zinc or aluminium powder

17. aqueous copper(II) sulphate(VI)
18. solid copper(II) sulphate(VI)

19. solid zinc nitrate(V) (labelled as Q)

20. solid iron(II) sulphate(VI) (labelled as R)

21. aqueous silver nitrate(V)

22. aqueous barium chloride
23. aqueous barium nitrate(V)

24. aqueous lead(II) nitrate(V)

25. dilute nitric(V) acid

26. dilute hydrochloric acid

27. dilute sulphuric(VI) acid

APPENDIX N2

THE QUALITATIVE ANALYSIS WORKBOOK

Worksheet 1 Cations

I. Precipitate Experience

A. Sodium chloride, iron(III) chloride and sodium hydroxide

Procedure	What you see
1. Add aqueous sodium chloride into a test tube until it reaches a height of 1 cm. Add two drops of aqueous sodium hydroxide and shake the mixture. 2. Add aqueous iron(III) chloride into a test tube until it reaches a height of 1 cm. Add two drops of aqueous sodium hydroxide and shake the mixture.	

1. Explain the differences in what happened above.

2. Compare your answer with your partner or another pair/group and try to reconcile differences (if any). Write down the agreed explanations if it is different from (1).

3. After listening to the explanation given by your teacher, in your own words, explain what is meant by: (you may discuss with your classmates)

   a. double decomposition reaction.

b. precipitation reaction.

c. sodium chloride (common salt) is soluble in water.

d. iron(III) hydroxide is insoluble.

4. Now make your own precipitate

a. Name an insoluble salt that you wish to make.

b. Name two solutions that you would use to make the insoluble salt

c. Was your attempt successful? Explain why you managed to obtain the insoluble salt.

d. Can a solid and a solution be used to prepare an insoluble salt instead of two solutions? Explain.

B. Zinc chloride and sodium hydroxide

Procedure	What you see	Can you explain what happened?
Add aqueous zinc chloride into a test tube until it reaches a height of 2 cm		
a. Add two drops of aqueous sodium hydroxide.		
b. Divide the mixture obtained in step (a) into two portions.		
(i) To one portion, add water, 1cm height portions at a time until it reaches 1 cm from the top of the test tube. Shake the mixture after each addition.		
(ii) To the other portion, add aqueous sodium hydroxide, 1cm height portions at a time until it reaches 2 cm from the top of the test tube. Shake the mixture after each addition. Save the mixture.		
(iii) Add 1 cm height of the mixture from (II) into a test tube. Add dilute hydrochloric acid drop by drop until the test tube is half full.		

1. Can you explain the differences in (i) and (ii), and what happened in (iii)?

2. Compare your answer with your partner or another group and record the agreed answer if it is different from (1).

3. After listening to your teacher's explanation, in your own words explain
   a. what happens when water is added in step (i).
   b. what happens when aqueous sodium hydroxide is added in step (ii).
   c. what happens when dilute hydrochloric acid is added in step (iii)
   d. the term "amphoteric".
   e. the term "complex ion".

4. Make a substance which you think will behave the same way as zinc hydroxide.
   a. Name the substance.
   b. Name the two solutions that you would use to make the substance.

c. Add (i) water to a portion of the substance and (ii) sodium hydroxide to another portion of the substance. Did it behave the same way as zinc hydroxide? If not, why?

C. Copper(II) sulphate with sodium hydroxide and aqueous ammonia

Procedure	What you see	Can you explain what happened?
a. Add aqueous copper(II) sulphate(VI) into a test tube Until it reaches a height of 1 cm. (i) Add 2 drops of aqueous sodium hydroxide and shake the mixture. (ii) Continue adding aqueous sodium hydroxide, 1cm height portions at a time until it reaches 2 cm from the top of the test tube. Shake the mixture after each addition. b. Add copper(II) sulphate(VI) solution into a test tube Until it reaches a height of 1 cm. (i) Add 2 drops of aqueous ammonia and shake the mixture. (ii) Continue adding aqueous ammonia, 1cm height portions at a time until it reaches 2 cm from the top of the test tube. Shake the mixture after each addition.		

1. Is there any difference in your teacher's and your explanations for the reactions which occurred? If so, record the differences down and your comments on them.

   a. steps a(i) and b(i)

   b. steps a(ii) and b(ii)

D. Solid sample

1. The solid sample X may contain zinc ions. Describe how you would test for the presence of zinc ions in the sample and carry out your test.

Procedure	What you see

2. Does sample X contain zinc ions?

3. Describe the precautions that you need to take to determine the ions present in a solid sample.

E. Test for cations.

Aqueous sodium hydroxide and aqueous ammonia are used to test for cations. The following gives important clues to the identity of the cations present:

1. whether a precipitate is formed
2. the colour of the precipitate
3. whether the precipitate dissolves in excess reagent

Can you explain why?

Worksheet 2. Cations (continued)

II. Exercise

A. Adding reagents

1. Aims:

You will learn to:

a. Put the appropriate amount of the zinc solution to be tested into a test tube.
b. Add a small amount of aqueous sodium hydroxide to the zinc solution.
c. Add aqueous sodium hydroxide until it is in excess.
d. Shake the mixture after each addition of aqueous sodium hydroxide.

2. Skills to be practised

a. Solution to be tested

When you add the zinc solution into a test tube, you should add till it reaches a height of about 1 cm. Why?

b. A small amount of reagent

When you add a small amount of aqueous sodium hydroxide, you should add about two drops and shake the mixture thoroughly (by shaking the test tube or using a glass rod to stir). Why?

c. Excess reagent

When you add aqueous sodium hydroxide to, you should add 1 cm height portions at a time, shaking the mixture thoroughly each time until the mixture reaches about 2 cm from the top of the test tube. If there is a need to, pour away ¾ of the content of the test tube and continue adding as described.

3. Practice and checklist.

Practise adding aqueous sodium hydroxide to aqueous zinc chloride until you can do it well.

Items	I am able to:	My partner is able to:
Add the solution to be tested into a test tube		
Add a small amount of reagent into the test tube		
Add reagent until excess		
Shake the mixture thoroughly each time a reagent is added.		

B. Making solutions.

1. List the steps needed to make a saturated solution.

2. Make 20 ml saturated solutions of
   a. sodium chloride.
   b. copper(II) sulphate(VI) with copper(II) carbonate as a starting material.

   NB. Keep the solution (b) for later use.

3. Checklist

Item	I am able to:	My partner is able to:
Prepare a saturated solution		
Fold a filter paper		
Filter the saturated solution and collect the filtrate		

C. Test for cations (1)

What to observe and how to record your observation.

a. Whether a precipitate is formed when a small amount of reagent is added.

b. If a precipitate is obtained, record its colour
E.g. *A white precipitate is obtained*

c. If there seems to be no reaction, then write
No visible reaction.

d. If you are instructed to add a reagent until in excess or add a reagent until there is no more change occurs (which means the same thing), take note what happens to the precipitate.

  i. If the precipitate disappears, record it and the colour of the solution formed.

  E.g. *The white precipitate disappears and a colourless solution is obtained.*

  The blue precipitate disappears and a deep blue solution is obtained.

  ii. If there seems to be no reaction, then write
  There is no visible reaction, the white precipitate remains.

e. To determine the colour of a precipitate in a coloured liquid, you have to allow the precipitate to settle and pour away the liquid. Another alternative would be to filter off the precipitate.

What is the colour of the precipitate formed in the reaction between aqueous copper(II) sulphate(VI) and aqueous barium (II) chloride?

D. The experiments

You are going to observe what happens to some cations when sodium hydroxide or aqueous ammonia is added to them. These reagents are used to identify unknown cations in QA experiments.

1. Mental preparation

In your mind, rehearse how you would

a. add the solution to be tested into the test tube.
b. add a little reagent.
c. add the reagent till excess.
d. write your observations.

2. Instructions for the experiments:

a. Add aqueous sodium hydroxide to a sample of the given zinc solution until there is no further change. Let the mixture stand for a few minutes. Record your observations in the table below.

E.g. *A white precipitate is formed which dissolves in excess alkali to give a colourless solution. On standing, the colourless solution turns yellow.*

b. Add aqueous ammonia to a new sample of the zinc solution until there is no further change. Let the mixture stand for a few minutes. Record your observations.

c. Repeat steps (a) and (b) with aqueous solutions containing
    i. aluminium ions.
    ii. calcium ions
    iii. copper(II) ions (which you prepared earlier).
    iv. iron(II) ions.
    v. iron(III) ions.
    vi. sodium ions.

3. Reactions of cations with aqueous sodium hydroxide and aqueous ammonia

Solution containing	Addition of aqueous sodium hydroxide	Addition of aqueous ammonia
Zinc ions		
Aluminium ions		
Calcium ions		
Copper(II) ions (use the solution that you prepared)		
Iron(II) ions		
Iron(III) ions		
Sodium ions (use the solution that you prepared)		

Which cation(s) give different results with different reagents? Why do these ions give different results with different reagents?

III. Ammonium experience

A. Odour of ammonia

1. Pour 1 cm height of aqueous ammonia into a test tube. **Gently** fan the vapour towards you and smell the vapour **cautiously**.

2. Ammonia gas has a characteristic odour. You need to remember it. Describe the odour.

B. Use of litmus paper

1. Wet a red and blue litmus paper with deionised or distilled water. Put both moist litmus papers at the mouth of the test tube containing aqueous ammonia and observe. The litmus papers must not touch the wall of the test tube. Why?

Moist red litmus	Moist blue litmus

2. Why must the litmus papers be moist?

B. Reaction of ammonium chloride with aqueous sodium hydroxide

1. Add solid ammonium chloride into a test tube until it fills the bottom hemisphere. Add aqueous sodium hydroxide to a height of 2 cm. Is there any visible change? Cautiously smell the mixture.

2. Using a non-luminous flame with the gas tap half opened, hold the test tube using a test tube holder about 4 mm away from the tip of the blue cone. Direct the flame at the liquid near the top of the test tube and shake the test tube frequently. Why is it not advisable to heat the bottom of the test tube?

3. Place moist red litmus paper at the mouth of the test tube and observe. Can you smell any gas evolved?

4. What is the reaction involved?

5. Why is it unnecessary to use blue litmus paper in this case?

6. Why can't we aqueous ammonia instead of aqueous sodium hydroxide?

IV Exercise - test for ammonium ions.

1. Determine whether solids A and B, and solutions C and D contain ammonium ions.

Sample	Yes / No
A	
B	
C	
D	

2. Checklist

Item	I am able to:	My partner is able to:
Gently heat a solution		
Use litmus paper		
Conduct test for ammonia gas		

IV. Application

Determine the cations present in the three solids given.

Procedure	Observation	Conclusion
Sample F		
Sample G		
Sample H		

Worksheet 3 Gases

I. Gas Experience

A. Observe the colour and odour of the given gases.

Follow the instructions carefully so that only a small amount of gas is produced. The gases are **POISONOUS. DO NOT** BREATHE IN DEEPLY.

Procedure	Colour	Odour
Sulphur dioxide Add solid sodium sulphate(IV) to a test tube until it just fills the hemisphere at the bottom of the test tube. Use a test tube holder to hold the test tube. Add dilute hydrochloric acid till it reaches a height of 2 cm. Shake the mixture. Gently fan the gases above the opening of the test tube towards your nose.		
Chlorine Add solid manganese (IV) oxide to a test tube until it just fills the hemisphere at the bottom of the test tube. Use a test tube holder to hold the test tube. Add a few drops of concentrated hydrochloric acid. Shake the mixture. Gently fan the gases above the opening of the test tube towards your nose.		
Nitrogen dioxide Add copper turnings to a test tube until it just fills the hemisphere at the bottom of the test tube. Use a test tube holder to hold the test tube. Add a few drops of concentrated nitric(V) acid. Shake the mixture. Gently fan the gases above the opening of the test tube towards your nose.		

B. Reactions which result in the evolution of gases.

In QA, gases are often produced in reactions. These gases indicate the ions present in the unknown sample.

Gases	Ions/substances indicated	Reactions which produce the gas
Hydrogen	hydrogen ion, metals	Acids + metals → salt + hydrogen
Oxygen	nitrate(V)	Thermal decomposition of nitrate(V)
Carbon dioxide	hydrogen ion, carbonate, hydrogencarbonate	Acid + carbonate / hydrogencarbonate → salt + water + carbon dioxide Thermal decomposition of carbonate/hydrogencarbonate
Sulphur dioxide	hydrogen ion, sulphate(IV)	Acid + sulphate(VI)→ salt + water + sulphur dioxide Thermal decomposition of sulphate(IV)
Chlorine	chloride, oxidising agent	Oxidation of chlorides
Nitrogen dioxide	Nitrate(V), reducing agent	Thermal decomposition of nitrates Reduction of nitrates
Ammonia	ammonium ion, alkali	Ammonium salts + alkalis → Salt + water + ammonia

II. Redox Experience

A. Sulphur dioxide + acidified aqueous potassium manganate(VII)/ aqueous potassium dichromate(VI).

1. Procedure

a. Pour about 5 ml of aqueous potassium manganate(VII) in a beaker.
b. Add an equal volume of sulphuric acid to the aqueous potassium manganate(VII). You now have acidified aqueous potassium manganate(VII).
c. Dip a strip of filter paper into the mixture.
d. Add solid sodium sulphate(IV) to a test tube until it just fills the hemisphere at the bottom of the test tube. Add dilute hydrochloric acid till it reaches a height of 2 cm.

e. Place the strip of paper dipped in acidified aqueous potassium manganate(VII) at the opening of the test tube and observe any changes.
f. Record your observations in the table below.

2. Repeat steps 1(a) to (f) using aqueous potassium dichromate(VI) instead of aqueous potassium manganate(VII).

Using acidified aqueous potassium manganate(VII)	Using acidified aqueous potassium dichromate(VI)

3. What is responsible for the colours in aqueous potassium manganate(VII) and in aqueous potassium dichromate(VI)?

4. Explain what happens when sulphur dioxide reacts with aqueous potassium manganate(VII) and with aqueous potassium dichromate(VI)

5. Why is aqueous potassium manganate(VII) and aqueous potassium dichromate(VI) acidified with dilute sulphuric(VI) acid and not dilute nitric(V) or hydrochloric acid?

B. Zinc + aqueous copper(II) sulphate

Procedure	Observation
Add aqueous copper(II) sulphate(VI) to a height of 3 cm in test tube. Add 3 pieces of zinc. Shake regularly for 2 minutes. Observe.	

What happens when the aqueous solution of copper(II) sulphate (VI) react with zinc. Why?

C. Iron(II) and iron(III) compounds.

1. List of oxidising and reducing agents.

Oxidising agents	Reducing agents
acidified aqueous potassium manganate(VII) acidified aqueous potassium dichromate(VI) hydrogen peroxide	potassium iodide metals hydrogen

2. You are to change a given solution containing iron(II) ions to iron(III) ions.

   a. Describe what you would do to change iron(II) to iron(III).

   b. Describe how you would confirm that the iron(III) is produced.

   c. Carry out your plan. How do you know whether your plan has worked?

3. You are now going to change a given solution containing iron(III) ions to iron(II) ions.

   a. Describe what you would do to change iron(III) to iron(II).

   b. Describe how you would confirm that the iron(II) is produced.

   c. Carry out your plans. How do you know whether your plans has worked?

III. Salt-Acid Reaction Experience

A. Aqueous sodium carbonate + acid.

Procedure	Observations
Add aqueous sodium carbonate to 1 cm height in a test tube. Add twice amount of any dilute acid to the aqueous sodium carbonate. Observe.	

1. Did you expect to observe any reaction? Why?

2. Is the choice of acid to be added important in the above reaction? Why?

B. Aqueous sodium carbonate + aqueous barium nitrate(V) + dilute nitric acid

Procedure	Observations
Add aqueous sodium carbonate to 1 cm height in a test tube. Add an equal amount of aqueous barium nitrate(V) to the aqueous sodium carbonate. Observe. Divide the above mixture into 3 parts. a. To one part, add dilute nitric(V) acid until there is no further change. Observe. b. To the second part, add dilute sulphuric(VI) acid until there is no further change. Observe c. To the third part, add dilute hydrochloric acid until there is no further change. Observe	

1. Explain what happened when aqueous barium nitrate(V) was added.

2. Explain what happened when dilute nitric(V) acid was added.

3. Does it matter if dilute sulphuric(VI) acid or dilute hydrochloric acid is used in place of dilute nitric(V) acid? Why?

4. Can aqueous barium chloride and dilute hydrochloric acid be used instead of aqueous barium nitrate(V) and dilute nitric(V) acid? Why?

IV. Exercise on Testing of Gases

A. Introduction.

1. You must be able to test for gases in QA. The exercises below will help you master the techniques required. You must also be able to record positive tests for gases.

2. Before you use litmus papers, remember to wet them. Hold the litmus papers at the opening of the test tube without touching the walls of the test tube.

B. The tests

1. Hydrogen

a. Things to prepare:

Light a bunsen burner. Have a few wooden splint on hand.

b. To produce hydrogen:

Put a 2 cm strip of magnesium ribbon into a test tube. Add dilute hydrochloric acid (why?) to a height of 2 cm in a test tube. Close the opening of the test tube with your thumb (why?).

c. To test for hydrogen

Procedure	Observation
1. Test the gas with moist litmus papers. 2. Set the end of a wooden splint burning and place it about 1 cm into the opening of the test tube.	*The colourless gas evolved is neutral to litmus and it extinguished the lighted splint with a 'pop' sound.*

d. Explain the reaction between the lighted splint and hydrogen.

2. Oxygen

a. Things to get ready

Light a bunsen burner. Have a few wooden splint on hand.

b. To produce oxygen

Add solid manganese (IV) oxide to a test tube until it just fills the hemisphere at the bottom of the test tube. Add hydrogen peroxide to a height of 2 cm to the manganese (IV) oxide (what is its function?). Heat the mixture gently if necessary (why?).

c. To test for oxygen

Procedure	Observation
1. Test the gas with moist litmus papers 2. Introduce a glowing splint halfway into the test tube.	*The colourless gas evolved is neutral to litmus and it relighted the glowing splint.*

d. Explain the reaction between the glowing splint and oxygen.

3. Test for carbon dioxide

a. Things to prepare

Put limewater to about 1 cm depth in a test tube. Put the long end of a delivery tube into the test tube, making sure that the end is long enough to be immersed into the limewater (why?).

b. To produce carbon dioxide

Add solid copper(II) carbonate to a test tube until it just fills the hemisphere at the bottom of the test tube. Add dilute sulphuric(VI) acid (why?) to a height of 2 cm to the copper(II) carbonate. Fix the delivery tube onto the test tube (why?).

c. To test for carbon dioxide

Procedure	Observation
1. Test the gas with moist litmus papers 2. Bubble the gas into the limewater.	The colourless gas evolved turned moist blue litmus paper red and gives a white precipitate with limewater.

d. Explain the reaction between carbon dioxide and limewater. On prolonged bubbling, the precipitate will disappear and a colourless solution is obtained. Why?

4. Sulphur dioxide

a. Things to prepare

Place about 5 ml of acidified aqueous potassium manganate(VII) or acidified aqueous potassium dichromate(VI) into beaker. Dip a strip of filter paper into the reagent.

b. To produce sulphur dioxide

Add solid sodium sulphate(IV) to a test tube until it just fills the hemisphere at the bottom of the test tube. Add dilute sulphuric acid (why?) to a height of 2 cm to the sodium sulphate(IV). Close the opening of the test tube with your thumb.

c. The test for sulphur dioxide

Procedure	Observation
1. Test the gas with moist litmus papers 2. Hold the filter paper dipped in acidified aqueous potassium manganate(VII) or acidified aqueous potassium dichromate(VI) at the opening of the test tube without touching the walls of the test tube.	*A colourless gas was evolved which turned moist blue litmus paper red and decolourised acidified aqueous potassium manganate(VII) or turned orange acidifed aqueous potassium dichromate(VI) green.*

d. Explain the reaction between sulphur dioxide and acidified aqueous potassium manganate(VII)/dichromate(VI)

5. Nitrogen dioxide

a. To produce nitrogen dioxide

Add copper turnings to a test tube until it just fills the hemisphere at the bottom of the test tube. Using a test tube holder to hold the test tube, add a few drops of concentrated nitric(V) acid (why).

b. To test for nitrogen dioxide

Procedure	Observation
1. Note the colour of the gas. 2. Test the gas with moist litmus papers	*A brown gas is evolved which turns moist blue litmus paper red.*

6. Chlorine

a. Things to prepare

A strip of filter paper soaked in potassium iodide and starch mixture.

b. To produce chlorine

Add solid manganese (IV) oxide to a test tube until it just fills the hemisphere at the bottom of the test tube. Using a test tube holder to hold the test tube, add a few drops of concentrated hydrochloric acid (why?). Heat the mixture gently

c. To test for chlorine

Procedure	Observation
1. Note the colour of the gas. 2. Test the gas with moist litmus papers	*A yellowish green gas was evolved which turned moist blue litmus paper red and finally bleached it.*
3. Test the gas with the strip of filter paper soaked in aqueous potassium iodide and starch.	*The gas turned the potassium iodide-starch paper dark blue.*

d. Explain the reaction between litmus and chlorine.

e. Explain the reaction between potassium iodide-starch and chlorine.

C. Checklist

Test for	I can do it	My partner can do it
Hydrogen		
Oxygen		
Carbon dioxide		
Sulphur dioxide		
Nitrogen dioxide		
Chlorine		

Worksheet 5 Gases (continued)

V. STRATEGIES FOR TESTING GASES

A. Introduction.

1. Gases are frequently produced during reactions in QA.
2. Identifying the gases evolved gives clues to the identity of the substances present in an unknown sample.
3. Testing of gases should be done in a logical, systematic and well-prepared manner.
   a. You need to be able to determine whether a certain procedure will result in the formation of gases.
   b. You need to prepare the necessary apparatus and reagents before you carry out the procedure (why?).

   c. You need to be aware of other clues such as colour and odour of the gases.

B. Questions to ask yourself

1. Addition of dilute acid to an unknown sample
   a. What gases may be evolved?

   b. How do I prepare to test for these gases?

2. Addition of an oxidising agent

   a. What gases may be evolved?

   b. How do I prepare to test for these gases?

3. Addition of aqueous sodium hydroxide (especially if the procedure also states gentle heating)

   a. What gases may be evolved?

   b. How do I prepare to test for these gases?

4. Heating of samples

   a. What gases can be evolved?

   b. How do I prepare to test for these gases?

VI. APPLICATION

Testing for unknown gases

Procedure	Observations	Inferences
Add dilute hydrochloric acid sample J.		
Add solid K to a test tube. Add aqueous sodium hydroxide to K and heat gently.		
Add solid L to a test tube until it just fills the hemisphere at the bottom of the test tube. Heat strongly.		

Worksheet 6 Anions

I. Heating experience

A. Heating zinc nitrate(V)

Procedure	Observations
Add solid zinc nitrate(V) until it just fills the hemisphere at the bottom of a test tube. Heat for 5 min. using a non-luminous flame. Record any colour changes or evolution of gas	

Explain why there may be colour changes and evolution of gases when substances are heated.

B. Heating potassium/sodium nitrate(V)

Procedure	Observations
Add solid potassium/sodium nitrate(V) until it just fills the hemisphere at the bottom of a test tube. Heat for 5 min. using a non-luminous flame. Record any colour changes or evolution of gas	

Compare the results obtained with the heating of zinc nitrate(V). Explain the similarities and/or differences between the two.

C. Ammonium chloride

Procedure	Observations
Add solid ammonium chloride until it just fills the hemisphere at the bottom of a test tube. Heat using a non-luminous flame. Record any colour changes or evolution of gas	

Compare the results obtained with the heating of zinc nitrate(V). Explain the similarities and/or differences between the two.

D. Carbon + copper(II) oxide

Procedure	Observations
Add the mixture of carbon and copper(II) oxide until it just fills the hemisphere at the bottom of a test tube. Heat using a non-luminous flame. Record any colour changes or evolution of gas	

Explain what happened when the mixture was heated.

II. Precipitation experience

Anions can be identified by the formation of insoluble barium, silver or lead(II) salts when barium chloride/nitrate(V), silver nitrate(V) or lead(II) nitrate(V) solutions are added. They are further distinguished by the addition of acid.

A. **Aqueous sodium chloride + aqueous silver nitrate(V) + dilute nitric(V) acid / aqueous ammonia**

Procedure	Observation
To aqueous sodium chloride, add an equal amount of aqueous silver nitrate(V). Divide the resulting mixture into two portions. To one portion, add dilute nitric(V) acid until there is no further change. To the other portion, add aqueous ammonia until there is no further change.	

Explain your observations.

B. **Aqueous sodium sulphate(VI) + aqueous barium chloride + dilute hydrochloric acid**

Procedure	Observation
To aqueous sodium sulphate(VI), add an equal amount of aqueous barium chloride. Add dilute hydrochloric acid until there is no further change.	

Explain your observations.

C. **Sodium carbonate + barium chloride + hydrochloric acid**

Procedure	Observation
To aqueous sodium carbonate, add an equal amount of aqueous barium chloride. Add dilute hydrochloric acid until there is no further change.	

Explain your observations.

D. **Aqueous potassium iodide + aqueous lead(II) nitrate(V) + dilute nitric(V) acid**

Procedure	Observation
To aqueous potassium iodide, add an equal amount of aqueous lead(II) nitrate(V). Heat gently. Add dilute nitric(V) acid until there is no further change.	

Explain your observations.

E. **Aqueous sodium sulphate(IV) + aqueous barium chloride + dilute hydrochloric acid**

Procedure	Observation
To aqueous sodium sulphate(IV), add an equal amount of aqueous barium chloride. Add dilute hydrochloric acid until there is no further change.	

Explain your observations.

F. Some theory

1. Aqueous barium nitrate(V)/chloride, silver nitrate(V) and lead(II) nitrate(V) are used to test for anions in an unknown aqueous sample.

2. If a precipitate is formed, it is due to double decomposition reactions resulting in the formation of an insoluble salt.

3. Whether the precipitate further reacts with dilute acids or ammonia gives clues to the identity of the anion.

4. Does the order of addition of the barium/silver/lead(II) reagents and dilute acids matter?

5. It is important that the correct acid is added.

   a. If aqueous barium nitrate(V) is added, it will be followed by dilute nitric(V) acid
   b. If aqueous barium chloride is added, it will be followed by dilute hydrochloric acid
   c. If aqueous silver nitrate(V) is added, it will be followed by dilute nitric(V) acid.
   d. If aqueous lead(II) nitrate(V) is added, it will be followed by dilute nitric(V) acid.

6. Do you see a trend in the acid used above?

7. The following experiments will illustrate point (4)

Procedure	Observation	Explanation
To aqueous sodium chloride, add an equal amount of aqueous barium nitrate(V). Add dilute sulphuric(VI) acid until there is no further change.		
To aqueous sodium nitrate(V), add an equal amount of aqueous silver nitrate(V). Add dilute hydrochloric acid until there is no further change.		

III. Redox Experience

A. Aqueous copper(II) sulphate(VI) + aqueous potassium iodide

Procedure	Observation
To aqueous copper(II) sulphate(VI), add an equal amount of aqueous potassium iodide. Shake the mixture and allow it to stand for a few minutes (why?)	

1. Explain your observations.

Copper(II) sulphate is used to test for iodide ions. However, if you had added potassium iodide to an unknown sample and the same result is obtained, then this indicates the presence of copper(II) ions.

B. Testing for nitrate(V)

1. Use of aqueous barium nitrate/chloride and silver nitrate will give negative results for nitrate(V).

2. Negative results cannot confirm the presence of the nitrate(V) ion.

3. One method of determining the presence of the nitrate(V) ion is heating the solid sample (and not the solution – why?)

4. Another method is to heat the nitrate(V) with Devada's alloy / zinc / aluminium and sodium hydroxide. The nitrate(V) will be reduced to ammonia during the reaction.

Procedure	Observation
If solid nitrate(V) is used Dissolve the solid in aqueous sodium hydroxide. *If aqueous solution of nitrate(V) is used.* Add an equal amount of aqueous sodium hydroxide. Add a small spatula full of Devada's alloy / zinc powder / aluminium powder to the solution and heat gently. Test for ammonia and hydrogen.	

5. The presence of nitrate(V) can only be confirmed in the above procedure if ammonium ions are not present in the first instance. Why?

IV. Exercise on heating

A. Heating

1. Adding reagent

   a. If given a solid sample, add the solid under it fills the hemisphere at the bottom of the test tube.
   b. If given a liquid, add the liquid until it reaches a height of 2 cm in a test tube.

2. Heating

   a. Wear eye protection at all times when heating is involved (why?).

   b. Use a non-luminous flame (why?).

   c. For a solid sample:
      i. Heat gently for 2 min, by putting the test tube 5mm away from the tip of the blue cone, the hottest part of the flame.
      ii. Observe for any colour change or liquid forming in the test tube.
      iii. Heat strongly for 3 min by putting the test tube at the tip of the blue cone.
      iv. Observe for any colour change, change of state, evolution of gases, formation of liquid/solids at the upper region of the test tube

   d. For a liquid sample:
      i. Heat near the surface of the liquid and shake frequently (why?)
      ii. Do not heat at the bottom of the test tube as the liquid may splash out (why?)

2. Heating of copper(II) sulphate(VI)

Procedure	Observation
Heat a sample of solid copper(II) sulphate(VI). Record any changes that occur.	

Explain your observations

4. Heating of aqueous sodium hydroxide and aqueous ammonium chloride

Procedure	Observation
To aqueous ammonium chloride add an equal amount of aqueous sodium hydroxide. Heat.	

Explain your observations

5. Devadas' alloy/aluminium/zinc test

Procedure	Observation
Add an equal amount of aqueous sodium hydroxide to aqueous sodium nitrate(V). Add a small spatula full of Devada's alloy / zinc powder / aluminium powder to the solution and heat gently. Test for the gases evolved	

Explain your observations.

B. Checklist

Procedure	I am able to	My partner is able to
Heat a solid sample a. Gently b. strongly		
Heat a liquid sample a. gently b. strongly		

Worksheet 7 Anions (continued)

I. Metacognition

A. What to do when one is required to heat

1. Note the colour of sample as this will give clues to the identity of the cation present.

2. Get ready to test for gases.
   - a. litmus
   - b. limewater and delivery tube
   - c. acidified aqueous potassium manganate(VII) / aqueous potassium dichromate(VI)
   - d. wooden splint

3. Heat gently
   - a. Use litmus.
   - b. Look out for water of crystallisation – cobalt chloride paper.

4. Heat strongly

   - a. Note changes in colour of the residue which can give clues to the identity of the cation present.

   - b. Note changes in state.
     - i. melting
     - ii. "sublimation" – ammonium salts

   - c. Note the result of litmus test before proceeding further.
     - i. No visible change – test for oxygen
     - ii. Acidic gas – test for sulphur dioxide and carbon dioxide. Note that if a brown acidic gas (nitrogen dioxide) is evolved, test for oxygen as well (why?).

5. Recording observations

   - a. Colour changes of sample during heating and cooling.
   - b. Changes of state in sample during heating and cooling.
   - c. Appearance of substances in the upper region of the test tube.
   - d. Results of tests for gases.

B. Using aqueous barium nitrate/chloride, aqueous silver nitrate(V) and aqeuous lead(II) nitrate(V)

1. Strategies

a. Get ready to test for gases i.e. carbon dioxide and sulphur dioxide (why?)

b. Note

   i. colour of precipitate
   ii. reaction with acid
   iii. tests for gases

c. The table below may help you to identify the anions.

Precipitate	Aqueous barium nitrate(V) / chloride	Aqueous silver nitrate(V)	Aqueous lead(II) nitrate(V)
None	Nitrate(V) Chloride Iodide	Nitrate(V) Sulphate(VI) (white ppt if concentrated solution used)	Nitrate(V)
White	Sulphate(IV) Sulphate(VI) Carbonate	Sulphate(IV) Carbonate Chloride	Sulphate(IV) Sulphate(VI) Carbonate Chloride
Yellow		Iodide	Iodide

d. In identifying anions, is possible to add dilute acid first before adding aqueous barium chloride, silver nitrate(V) or lead(II) nitrate(V)? Is the order of addition of the reagents important?

C. Use of aqueous copper(II) sulphate(VI) / aqueous potassium iodide.

Aqueous copper(II) sulphate(VI) is sometimes used to identify iodide ions. Similarly, aqueous potassium iodide is used to identify copper(II) ions.

II. APPLICATION

Identify the anions in the 6 solid samples using two tests, one of which is heating.

	Procedure	Observations	Inferences
M			
N			
O			

	Procedure	Observations	Inferences
P			
Q			
R			

Worksheet 8 Metacognitive Strategies

I. Expert Experience

Teacher to show how s/he will approach a QA problem

1. The procedures given in the question.
    a. what the procedures are for, eg. determining cations or anions and if possible which cation or anion
    b. what to expect eg. evolution of gases
    c. what to prepare for, eg. testing of gases

2. Observe your teacher carry out the experiment and listen to her/his explanations on what she/he is doing
    a. what are the procedures for, eg. determining cations or anions and if possible which cation or anion
    b. what to expect eg. evolution of gases
    c. what to prepare for, eg. testing of gases
    d. experimental techniques eg.
        i. how much reagents to add
        ii. what apparatus to use
        iii. how to heat
        iv. how to test for gases
        v. how to determine colour of precipitate
    e. what possible observations can be obtained and why

II. Analysis Exercise

You are to practise analysing the worksheets given to you.

Take note of:

1. what are the procedures for, eg. determining cations or anions and if possible which cation or anion, and why
2. what to expect eg. evolution of gases
3. what to prepare for, eg. testing of gases
4. experimental techniques eg.
    a. how much reagents to add
    b. what apparatus to use
    c. how to heat
    d. how to test for gases
    e. how to determine colour of precipitate

5. what possible observations can be obtained and why

III. APPLICATION

Analyse the past years' examination questions for 5 min before starting on the experiments.

APPENDIX N3

ANSWERS TO THE ACTIVITIES AND QUESTIONS IN THE QUALITATIVE ANALYSIS WORKBOOK

Worksheet 1 Cations

I. Precipitate Experience

A. Sodium chloride, iron(III) chloride and sodium hydroxide

Procedure	What you see
1. Add aqueous sodium chloride into a test tube until it reaches a height of 1 cm. Add two drops of aqueous sodium hydroxide and shake the mixture.	*No visible reaction.*
2. Add aqueous iron(III) chloride into a test tube until it reaches a height of 1 cm. Add two drops of aqueous sodium hydroxide and shake the mixture.	*Reddish brown precipitate obtained.*

1. Explain the differences in what happened above.

   No reaction between sodium chloride and sodium hydroxide but there is a reaction between iron(III) chloride and sodium hydroxide to give a precipitate.

2. Compare your answer with your partner or another pair/group and try to reconcile differences (if any). Write down the agreed explanations if it is different from (1).

3. After listening to the explanation given by your teacher, in your own words, explain what is meant by: (you may discuss with your classmates)

   a. double decomposition reaction.

      A chemical reaction which involves the exchange of ions.

b. precipitation reaction.

A reaction in which an insoluble substance is produced,

c. sodium chloride (common salt) is soluble in water.

The attraction between the water molecules and sodium and chloride ions releases energy to break the bonds between sodium and chloride ions. Thus the solid sodium chloride breaks down to form sodium and chloride ions.

d. iron(III) hydroxide is insoluble.

The attraction between the water molecules and iron(III) and hydroxide ions is unable to release enough energy to break the bonds between iron(III) and hydroxide ions. Thus the solid iron(III) chloride does not dissolve in water.

4. Now make your own precipitate

a. Name an insoluble salt that you wish to make.

Depends on student.

b. Name two solutions that you would use to make the insoluble salt

Depends on student.

c. Was your attempt successful? Explain why you managed to obtain the insoluble salt.

Depends on student.

d. Can a solid and a solution be used to prepare an insoluble salt instead of two solutions? Explain.

No because we cannot be certain if any solid present is the undissolved/insoluble original solid or a precipitate is formed

B. Zinc chloride and sodium hydroxide

Procedure	What you see	Can you explain what happened?
Add aqueous zinc chloride into a test tube until it reaches a height of 2 cm		
a. Add two drops of aqueous sodium hydroxide.	*White precipitate is formed*	*Insoluble zinc hydroxide is formed.*
b. Divide the mixture obtained in step (a) into two portions.		
(i) To one portion, add water, 1cm height portions at a time until it reaches 1 cm from the top of the test tube. Shake the mixture after each addition.	*White precipitate remains*	*Zinc hydroxide is insoluble in water.*
(ii) To the other portion, add aqueous sodium hydroxide, 1cm height portions at a time until it reaches 2 cm from the top of the test tube. Shake the mixture after each addition. Save the mixture.	*White precipitate disappears/"dissolves" to form a colourless solution.*	*Zinc hydroxide reacts with excess sodium hydroxide to form soluble sodium zincate which gives a colourless solution.*
(iii) Add 1 cm height of the mixture from (II) into a test tube. Add dilute hydrochloric acid drop by drop until the test tube is half full.	*White precipitate reappears and then disappears when more acid is added to form a colourless solution.*	*The acid reacts with the sodium zincate and excess sodium hydroxide to reform zinc hydroxide, the white precipitate. Zinc hydroxide reacts with the acid to form soluble zinc chloride which gives a colourless solution.*

1. Can you explain the differences in (i) and (ii), and what happened in (iii)?

   Depends on student.

2. Compare your answer with your partner or another group and record the agreed answer if it is different from (1).

   Depends on student.

3. After listening to your teacher's explanation, in your own words explain

   a. what happens when water is added in step (i).

      Nothing happens because zinc hydroxide does not dissolve or react with water.

   b. what happens when aqueous sodium hydroxide is added in step (ii).
      Zinc hydroxide reacts with excess sodium hydroxide to form soluble sodium zincate which gives a colourless solution.

   c. what happens when dilute hydrochloric acid is added in step (iii).

      The acid reacts with the sodium zincate and excess sodium hydroxide to reform zinc hydroxide, the white precipitate. Zinc hydroxide reacts with the acid to form soluble zinc chloride which gives a colourless solution.

   d. the term "amphoteric".

      Describes a metal oxide or hydroxide which will react with both acids and alkalis to give a salt and water only.

   e. the term "complex ion".

      Describes an ion formed when anions or molecules are attracted to a cation (usually a transition metal ion).

4. Make a substance which you think will behave the same way as zinc hydroxide.

   a. Name the substance.

      Aluminium or lead(II) hydroxide.

   b. Name the two solutions that you would use to make the substance.

      Depends on student.

c. Add (i) water to a portion of the substance and (ii) sodium hydroxide to another portion of the substance. Did it behave the same way as zinc hydroxide? If not, why?

Depends on student.

C. Copper(II) sulphate with sodium hydroxide and aqueous ammonia

Procedure	What you see	Can you explain what happened?
a. Add aqueous copper(II) sulphate(VI) into a test tube Until it reaches a height of 1 cm.	*Blue solution.*	
(i) Add 2 drops of aqueous sodium hydroxide and shake the mixture.	*Light blue precipitate isobtained.*	*Insoluble copper(II) hydroxide is formed.*
(ii) Continue adding aqueous sodium hydroxide, 1cm height portions at a time until it reaches 2 cm from the top of the test tube. Shake the mixture after each addition.	*No visible reaction, the light blue precipitate remains in the mixture.*	*Copper(II) hydroxide does not react with sodium hydroxide.*
b. Add copper(II) sulphate(VI) solution into another test tube Until it reaches a height of 1 cm.		
(i) Add 2 drops of aqueous ammonia and shake the mixture.	*Light blue precipitate obtained.*	*Insoluble copper(II) hydroxide is formed.*
(ii) Continue adding aqueous ammonia, 1cm height portions at a time until it reaches 2 cm from the top of the test tube. Shake the mixture after each addition.	*Light blue precipitate "dissolves" in excess ammonia to give a dark blue solution.*	*Copper(II) hydroxide reacts with excess aqueous ammonia to give a soluble complex ammine.*

1. Is there any difference in your teacher's and your explanations for the reactions which occurred? If so, record the differences down and your comments on them.

   a. steps a(i) and b(i)
   Depends on student.

   b. steps a(ii) and b(ii)
   Depends on student.

D. Solid sample

1. The solid sample X may contain zinc ions. Describe how you would test for the presence of zinc ions in the sample and carry out your test.

Procedure	What you see
Add acid to X to form a solution.	*There is effervescence and a colourless solution is formed.*
Add aqueous sodium hydroxide to the solution until the mixture is alkaline.	*A white precipitate is obtained.*
Add excess aqueous sodium hydroxide to the mixture.	*White precipitate "dissolves" in excess aqueous sodium hydroxide to give a colourless solution.*

2. Does sample X contain zinc ions?

   There is a chance.

3. Describe the precautions that you need to take to determine the ions present in a solid sample.

   Need to make a solution of the sample.

E. Test for cations.

Aqueous sodium hydroxide and aqueous ammonia are used to test for cations. The following gives important clues to the identity of the cations present:

1. whether a precipitate is formed
2. the colour of the precipitate
3. whether the precipitate dissolves in excess reagent

Can you explain why?

1. *If a precipitate is formed, then you know that the metal forms an insoluble hydroxide.*
2. *The colour of the precipitate can help in the identification of the hydroxide. E.g. copper(II) hydroxide is blue, iron(II) hydroxide is green.*
3. *If the precipitate "dissolves" in excess reagent, then it forms a complex ion and this helps in the identification of the cation.*

Worksheet 2. Cations (continued)

II. Exercise

A. Adding reagents

1. Aims:

You will learn to:

- a. Put the appropriate amount of the zinc solution to be tested into a test tube.
- b. Add a small amount of aqueous sodium hydroxide to the zinc solution.
- c. Add aqueous sodium hydroxide until it is in excess.
- d. Shake the mixture after each addition of aqueous sodium hydroxide.

2. Skills to be practised

a. Solution to be tested

When you add the zinc solution into a test tube, you should add till it reaches a height of about 1 cm. Why?

Too much solution results in wastage and makes it difficult to add reagents to excess.

b. A small amount of reagent

When you add a small amount of aqueous sodium hydroxide, you should add about two drops and shake the mixture thoroughly (by shaking the test tube or using a glass rod to stir). Why?

To ensure that we do not accidentally add excess reagent at the start.

c. Excess reagent

When you add aqueous sodium hydroxide to, you should add 1 cm height portions at a time, shaking the mixture thoroughly each time until the mixture reaches about 2 cm from the top of the test tube. If there is a need to, pour away ¾ of the content of the test tube and continue adding as described.

3. Practice and checklist.

Practise adding aqueous sodium hydroxide to aqueous zinc chloride until you can do it well.

Items	I am able to:	My partner is able to:
Add the solution to be tested into a test tube		
Add a small amount of reagent into the test tube		
Add reagent until excess		
Shake the mixture thoroughly each time a reagent is added.		

B. Making solutions.

1. List the steps needed to make a saturated solution.

   a. *Heat a volume of water (optional).*
   b. *Add the solid to a volume of water and stir.*
   c. *Allow to cool.*
   d. *Filter off the excess solid.*

2. Make 20 ml saturated solutions of
   a. sodium chloride.
   b. copper(II) sulphate(VI) with copper(II) carbonate as a starting material.

   NB. Keep the solution (b) for later use

3. Checklist

Item	I am able to:	My partner is able to:
Prepare a saturated solution		
Fold a filter paper		
Filter the saturated solution and collect the filtrate		

C. Test for cations (1)

What to observe and how to record your observation.

a. Whether a precipitate is formed when a small amount of reagent is added.

b. If a precipitate is obtained, record its colour
E.g. *A white precipitate is obtained*

c. If there seems to be no reaction, then write
No visible reaction.

d. If you are instructed to add a reagent until in excess or add a reagent until there is no more change occurs (which means the same thing), take note what happens to the precipitate.

   i. If the precipitate disappears, record it and the colour of the solution formed.

   E.g. *The white precipitate disappears and a colourless solution is obtained.*

   The blue precipitate disappears and a deep blue solution is obtained.

   ii. If there seems to be no reaction, then write
   There is no visible reaction, the white precipitate remains.

e. To determine the colour of a precipitate in a coloured liquid, you have to allow the precipitate to settle and pour away the liquid. Another alternative would be to filter off the precipitate.

What is the colour of the precipitate formed in the reaction between aqueous copper(II) sulphate(VI) and aqueous barium (II) chloride?

White.

D. The experiments

You are going to observe what happens to some cations when sodium hydroxide or aqueous ammonia is added to them. These reagents are used to identify unknown cations in QA experiments.

1. Mental preparation

In your mind, rehearse how you would

a. add the solution to be tested into the test tube.
b. add a little reagent.
c. add the reagent till excess.
d. write your observations.

2. Instructions for the experiments:

a. Add aqueous sodium hydroxide to a sample of the given zinc solution until there is no further change. Let the mixture stand for a few minutes. Record your observations in the table below.

E.g. *A white precipitate is formed which dissolves in excess alkali to give a colourless solution. On standing, the colourless solution turns yellow.*

b. Add aqueous ammonia to a new sample of the zinc solution until there is no further change. Let the mixture stand for a few minutes. Record your observations.

c. Repeat steps (a) and (b) with aqueous solutions containing
   i. aluminium ions.
   ii. calcium ions
   iii. copper(II) ions (which you prepared earlier).
   iv. iron(II) ions.
   v. iron(III) ions.
   vi. sodium ions.

3. Reactions of cations with aqueous sodium hydroxide and aqueous ammonia

Solution containing	Addition of aqueous sodium hydroxide	Addition of aqueous ammonia
Zinc ions	*White precipitate soluble in excess aqueous sodium hydroxide to give a colourless solution.*	*White precipitate soluble in excess aqueous sodium hydroxide to give a colourless solution.*
Aluminium ions	*White precipitate soluble in excess aqueous sodium hydroxide to give a colourless solution.*	*White precipitate insoluble in excess aqueous ammonia.*
Calcium ions	*White precipitate insoluble in excess aqueous sodium hydroxide.*	*No visible reaction, a colourless solution remains.*
Copper(II) ions (use the solution that you prepared)	*Light blue precipitate insoluble in excess aqueous sodium hydroxide.*	*Light blue precipitate soluble in excess aqueous ammonia to give a dark blue solution.*
Iron(II) ions	*Green precipitate insoluble in excess aqueous sodium hydroxide.*	*Green precipitate insoluble in excess aqueous ammonia.*
Iron(III) ions	*Reddish brown precipitate insoluble in excess aqueous sodium hydroxide.*	*Reddish brown precipitate insoluble in excess aqueous ammonia.*
Sodium ions (use the solution that you prepared)	*No visible reaction, a colourless solution remains.*	*No visible reaction, a colourless solution remains.*

Which cation(s) give different results with different reagents? Why do these ions give different results with different reagents?

Aluminium ions do not form complex ions with aqueous ammonia while copper(II) ions do. Calcium hydroxide is slightly soluble so the small amount of calcium hydroxide formed with aqueous ammonia (weak base, lower hydroxide ion concentration) dissolves to give a colourless solution.

III. Ammonium experience

A. Odour of ammonia

1. Pour 1 cm height of aqueous ammonia into a test tube. **Gently** fan the vapour towards you and smell the vapour **cautiously**.

2. Ammonia gas has a characteristic odour. You need to remember it. Describe the odour.

Pungent.

B. Use of litmus paper

1. Wet a red and blue litmus paper with deionised or distilled water. Put both moist litmus papers at the mouth of the test tube containing aqueous ammonia and observe. The litmus papers must not touch the wall of the test tube. Why?

It might be contaminated by the reagent present in the test tube.

Moist red litmus	Moist blue litmus
Red litmus turns blue.	*No visible reaction.*

Why must the litmus papers be moist?

Ammonia gas ionises in the water present in the moist red litmus paper to liberate hydroxide ions which react with the red dye changing it to blue.

B. Reaction of ammonium chloride with aqueous sodium hydroxide

1. Add solid ammonium chloride into a test tube until it fills the bottom hemisphere. Add aqueous sodium hydroxide to a height of 2 cm. Is there any visible change? Cautiously smell the mixture.

2. Using a non-luminous flame with the gas tap half opened, hold the test tube using a test tube holder about 4 mm away from the tip of the blue cone. Direct the flame at the liquid near the top of the test tube and shake the test tube frequently. Why is it not advisable to heat the bottom of the test tube?

The liquid may shoot out of the test tube.

3. Place moist red litmus paper at the mouth of the test tube and observe. Can you smell any gas evolved?

Yes.

4. What is the reaction involved?

Sodium hydroxide reacts with ammonium chloride to form ammonia, sodium chloride and water.

5. Why is it unnecessary to use blue litmus paper in this case?

Only ammonia gas may be liberated when sodium hydroxide is used and it is basic.

6. Why can't we use aqueous ammonia instead of aqueous sodium hydroxide?

Aqueous ammonia decomposes to form ammonia and water.

V Exercise - test for ammonium ions.

1. Determine whether solids A and B, and solutions C and D contain ammonium ions.

Sample	Yes / No
A	
B	Y
C	Y
D	

2. Checklist

Item	I am able to:	My partner is able to:
Gently heat a solution		
Use litmus paper		
Conduct test for ammonia gas		

IV. Application

Determine the cations present in the three solids given.

Procedure	Observation	Conclusion
Sample F		
Add dilute nitric(V) acid to F.	*Colourless solution is obtained.*	
To a portion of the solution, add aqueous sodium hydroxide.	*A white precipitate is obtained which is insoluble in excess aqueous sodium hydroxide.*	*Ca^{2+} may be present.*
To a portion of the solution, add aqueous ammonia.	*No visible reaction, a colourless solution remains.*	*Ca^{2+} is present.*
Sample G		
Add dilute nitric(V) acid to G.	*Green solution is obtained.*	
To a portion of the solution, add aqueous sodium hydroxide until the mixture is just alkaline, and then to excess.	*A green precipitate is obtained which is insoluble in excess aqueous sodium hydroxide.*	*Fe^{2+} may be present.*
To a portion of the solution, add aqueous ammonia until the mixture is just alkaline, and then to excess.	*A green precipitate is obtained which is insoluble in excess aqueous ammonia.*	*Fe^{2+} is present.*
Sample H		
Add dilute nitric(V) acid to H.	*A colourless solution is obtained*	
To a portion of the solution, add aqueous sodium hydroxide.	*A white precipitate is obtained which is soluble in excess aqueous sodium hydroxide to give a colourless solution.*	*Al^{3+}, Zn^{2+} or Pb^{2+} may be present.*
To a portion of the solution, add aqueous ammonia.	*A white precipitate is obtained which is soluble in excess aqueous ammonia to give a colourless solution.*	*Zn^{2+} is present.*

Worksheet 3 Gases

I. Gas Experience

A. Observe the colour and odour of the given gases.

Follow the instructions carefully so that only a small amount of gas is produced.
The gases are **POISONOUS. DO NOT** BREATHE IN DEEPLY.

Procedure	Colour	Odour
Sulphur dioxide Add solid sodium sulphate(IV) to a test tube until it just fills the hemisphere at the bottom of the test tube. Use a test tube holder to hold the test tube. Add dilute hydrochloric acid till it reaches a height of 2 cm. Shake the mixture. Gently fan the gases above the opening of the test tube towards your nose.	*Colourless.*	*Pungent.* *(firecrackers)*
Chlorine Add solid manganese (IV) oxide to a test tube until it just fills the hemisphere at the bottom of the test tube. Use a test tube holder to hold the test tube. Add a few drops of concentrated hydrochloric acid. Shake the mixture. Gently fan the gases above the opening of the test tube towards your nose.	*Yellowish green gas.*	*Pungent.* *(swimming pool)*
Nitrogen dioxide Add copper turnings to a test tube until it just fills the hemisphere at the bottom of the test tube. Use a test tube holder to hold the test tube. Add a few drops of concentrated nitric(V) acid. Shake the mixture. Gently fan the gases above the opening of the test tube towards your nose.	*Brown gas.*	*Pungent.* *(antiseptic)*

B. Reactions which result in the evolution of gases.

In QA, gases are often produced in reactions. These gases indicate the ions present in the unknown sample.

Gases	Ions/substances indicated	Reactions which produce the gas
Hydrogen	hydrogen ion, metals	Acids + metals → salt + hydrogen
Oxygen	nitrate(V)	Thermal decomposition of nitrate(V)
Carbon dioxide	hydrogen ion, carbonate, hydrogencarbonate	Acid + carbonate / hydrogencarbonate → salt + water + carbon dioxide Thermal decomposition of carbonate/hydrogencarbonate
Sulphur dioxide	hydrogen ion, sulphate(IV)	Acid + sulphate(VI)→ salt + water + sulphur dioxide Thermal decomposition of sulphate(IV)
Chlorine	chloride, oxidising agent	Oxidation of chlorides
Nitrogen dioxide	Nitrate(V), reducing agent	Thermal decomposition of nitrates Reduction of nitrates
Ammonia	ammonium ion, alkali	Ammonium salts + alkalis → Salt + water + ammonia

II. Redox Experience

A. Sulphur dioxide + acidified aqueous potassium manganate(VII)/ aqueous potassium dichromate (VI).

1. Procedure

a. Pour about 5 ml of aqueous potassium manganate(VII) in a beaker.
b. Add an equal volume of sulphuric acid to the aqueous potassium manganate(VII). You now have acidified aqueous potassium manganate(VII).
c. Dip a strip of filter paper into the mixture.
d. Add solid sodium sulphate(IV) to a test tube until it just fills the hemisphere at the bottom of the test tube. Add dilute hydrochloric acid till it reaches a height of 2 cm.

e. Place the strip of paper dipped in acidified aqueous potassium manganate(VII) at the opening of the test tube and observe any changes.

f. Record your observations in the table below.

2. Repeat steps 1(a) to (f) using aqueous potassium dichromate (VI) instead of aqueous potassium manganate(VII).

Using acidified aqueous potassium manganate(VII)	Using acidified aqueous potassium dichromate (VI)
The gas decolourises acidified potassium manganate(VII).	*The gas turns orange acidified potassium dichromate(VI) green.*

3. What is responsible for the colours in aqueous potassium manganate(VII) and in aqueous potassium dichromate (VI)?

Manganese (VII) present in potassium manganate(VII) and the chromium (VI) present in the potassium dichromate (VI).

4. Explain what happens when sulphur dioxide reacts with aqueous potassium manganate(VII) and with aqueous potassium dichromate (VI)

The sulphur dioxide reduces the manganese (VII) present in potassium manganate(VII) to manganese (II), and the chromium (VI) present in the potassium dichromate (VI) to chromium (III).

5. Why is aqueous potassium manganate(VII) and aqueous potassium dichromate (VI) acidified with dilute sulphuric(VI) acid and not dilute nitric(V) or hydrochloric acid?

The oxidising agents will oxides hydrochloric acid to give chlorine while nitric(V) acid itself is an oxidising agent and may complicate further reactions. Sulphuric(VI) acid does not react (is not oxidised) with the oxidising agents.

B. **Zinc + aqueous copper(II) sulphate**

Procedure	Observation
Add aqueous copper(II) sulphate(VI) to a height of 3 cm in test tube. Add 3 pieces of zinc. Shake regularly for 2 minutes. Observe.	*A brown solid is obtained. The solution turns lighter blue in colour and finally colourless.*

What happens when the aqueous solution of copper(II) sulphate (VI) react with zinc. Why?

Since zinc is a more reactive metal than copper, it displaces copper form the solution copper(II) sulphate(VI) to form copper (brown solid) and zinc sulphate(VI) (colourless solution). As more copper is displaced from copper(II) sulphate(VI), the solution lightens in colour and finally turns colourless.

C. **Iron(II) and iron(III) compounds.**

1. List of oxidising and reducing agents.

Oxidising agents	Reducing agents
acidified aqueous potassium manganate(VII) acidified aqueous potassium dichromate (VI) hydrogen peroxide	potassium iodide metals hydrogen

2. You are to change a given solution containing iron(II) ions to iron(III) ions.

   a. Describe what you would do to change iron(II) to iron(III).

   Add an oxidising agent to the iron(II) solution.

   b. Describe how you would confirm that the iron(III) is produced.

   Add aqueous sodium hydroxide to see whether a brown precipitate is formed.

   c. Carry out your plan. How do you know whether your plan has worked?

   Depends on student.

3. You are now going to change a given solution containing iron(III) ions to iron(II) ions.

   a. Describe what you would do to change iron(III) to iron(II).

      Add a reducing agent to the iron(III) solution.

   b. Describe how you would confirm that the iron(II) is produced.

      Add aqueous sodium hydroxide to see if a green precipitate is formed.

   c. Carry out your plans. How do you know whether your plans has worked?

      Depends on student.

III. Salt-Acid Reaction Experience

A. Aqueous sodium carbonate + acid.

Procedure	Observations
Add aqueous sodium carbonate to 1 cm height in a test tube. Add twice amount of any dilute acid to the aqueous sodium carbonate. Observe.	*A colourless gas is evolved.*

1. Did you expect to observe any reaction? Why?

   Depends on student.

2. Is the choice of acid to be added important in the above reaction? Why?

   No. All sodium salts are soluble so reaction will go to completion.

B. Aqueous sodium carbonate + aqueous barium nitrate(V) + dilute nitric acid

Procedure	Observations
Add aqueous sodium carbonate to 1 cm height in a test tube. Add an equal amount of aqueous barium nitrate(V) to the aqueous sodium carbonate. Observe.	*A white precipitate is formed.*
Divide the above mixture into 3 parts.	
a. To one part, add dilute nitric(V) acid until there is no further change. Observe.	*The white precipitate reacts with the acid to form a colourless gas and solution.*
b. To the second part, add dilute sulphuric(VI) acid until there is no further change. Observe	*A colourless gas is evolved and a white precipitate is left.*
c. To the third part, add dilute hydrochloric acid until there is no further change. Observe	*The white precipitate reacts with the acid to form a colourless gas and solution.*

1. Explain what happened when aqueous barium nitrate(V) was added.

   A double decomposition reaction occurred resulting in the formation of insoluble barium carbonate.

2. Explain what happened when dilute nitric(V) acid was added.

   The acid reacted with barium carbonate to produce carbon dioxide and soluble barium nitrate(V).

3. Does it matter if dilute sulphuric(VI) acid or dilute hydrochloric acid is used in place of dilute nitric(V) acid? Why?

   Dilute sulphuric(VI) acid or dilute hydrochloric acid should not be used because you will be introducing foreign ions e.g. sulphate(VI) or chloride into the mixture.

4. Can aqueous barium chloride and dilute hydrochloric acid be used instead of aqueous barium nitrate(V) and dilute nitric(V) acid? Why?

   Yes because adding aqueous barium chloride and dilute hydrochloric acid will give the same results as adding aqueous barium nitrate(V) and dilute nitric(V) acid.

IV. Exercise on Testing of Gases

A. Introduction.

1. You must be able to test for gases in QA. The exercises below will help you master the techniques required. You must also be able to record positive tests for gases.

2. Before you use litmus papers, remember to wet them. Hold the litmus papers at the opening of the test tube without touching the walls of the test tube.

B. The tests

1. Hydrogen

a. Things to prepare:

Light a bunsen burner. Have a few wooden splint on hand.

b. To produce hydrogen:

Put a 2 cm strip of magnesium ribbon into a test tube. Add dilute hydrochloric acid (why?) to a height of 2 cm in a test tube. Close the opening of the test tube with your thumb (why?).

To prevent the gas from escaping/to collect a sufficient amount of gas

c. To test for hydrogen

Procedure	Observation
1. Test the gas with moist litmus papers. 2. Set the end of a wooden splint burning and place it about 1 cm into the opening of the test tube.	*The colourless gas evolved is neutral to litmus and it extinguished the lighted splint with a 'pop' sound.*

d. Explain the reaction between the lighted splint and hydrogen.

The lighted splint initiates the reaction between hydrogen and oxygen resulting in a small explosion.

2. Oxygen

a. Things to get ready

Light a bunsen burner. Have a few wooden splint on hand.

b. To produce oxygen

Add solid manganese (IV) oxide to a test tube until it just fills the hemisphere at the bottom of the test tube. Add hydrogen peroxide to a height of 2 cm to the manganese (IV) oxide (what is its function?). Heat the mixture gently if necessary (why?).

To speed up the reaction.

c. To test for oxygen

Procedure	Observation
1. Test the gas with moist litmus papers 2. Introduce a glowing splint halfway into the test tube.	*The colourless gas evolved is neutral to litmus and it relighted the glowing splint.*

d. Explain the reaction between the glowing splint and oxygen.

There is a greater concentration of oxygen in the test tube compared to that in air, so the glowing splint burns more vigorously.

3. Test for carbon dioxide

a. Things to prepare

Put limewater to about 1 cm depth in a test tube. Put the long end of a delivery tube into the test tube, making sure that the end is long enough to be immersed into the limewater (why?). *Otherwise the gas produced will escape and not react with the limewater.*

b. To produce carbon dioxide

Add solid copper(II) carbonate to a test tube until it just fills the hemisphere at the bottom of the test tube. Add dilute sulphuric(VI) acid (why?) to a height of 2 cm to the copper(II) carbonate. Fix the delivery tube onto the test tube (why?).

The acid will react with the carbonate while the delivery tube directs the gas produced into the limewater.

c. To test for carbon dioxide

Procedure	Observation
1. Test the gas with moist litmus papers 2. Bubble the gas into the limewater.	The colourless gas evolved turned moist blue litmus paper red and gives a white precipitate with limewater.

d. Explain the reaction between carbon dioxide and limewater. On prolonged bubbling, the precipitate will disappear and a colourless solution is obtained. Why?

The carbon dioxide will react with the limewater to produce insoluble calcium carbonate. On prolonged bubbling, the calcium carbonate will react with the carbon dioxide and water to produce soluble calcium hydrogencarbonate.

4. Sulphur dioxide

a. Things to prepare

Place about 5 ml of acidified aqueous potassium manganate(VII) or acidified aqueous potassium dichromate (VI) into beaker. Dip a strip of filter paper into the reagent.

b. To produce sulphur dioxide

Add solid sodium sulphate(IV) to a test tube until it just fills the hemisphere at the bottom of the test tube. Add dilute sulphuric acid (why?) to a height of 2 cm to the sodium sulphate(IV). Close the opening of the test tube with your thumb.

The acid will react with the sulphate(IV) to produce sulphur dioxide.

c. The test for sulphur dioxide

Procedure	Observation
1. Test the gas with moist litmus papers 2. Hold the filter paper dipped in acidified aqueous potassium manganate(VII) or acidified aqueous potassium dichromate (VI) at the opening of the test tube without touching the walls of the test tube.	*A colourless gas was evolved which turned moist blue litmus paper red and decolourised acidified aqueous potassium manganate(VII) or turned orange acidifed aqueous potassium dichromate (VI) green.*

d. Explain the reaction between sulphur dioxide and acidified aqueous potassium manganate(VII)/dichromate (VI)

The sulphur dioxide will reduce the two oxidising agents.

5. Nitrogen dioxide

a. To produce nitrogen dioxide

Add copper turnings to a test tube until it just fills the hemisphere at the bottom of the test tube. Using a test tube holder to hold the test tube, add a few drops of concentrated nitric(V) acid (why?).

The concentrated nitric(V) acid will oxidise the copper and nitrogen dioxide is formed in the process.

b. To test for nitrogen dioxide

Procedure	Observation
1. Note the colour of the gas. 2. Test the gas with moist litmus papers	*A brown gas is evolved which turns moist blue litmus paper red.*

6. Chlorine

a. Things to prepare

A strip of filter paper soaked in potassium iodide and starch mixture.

b. To produce chlorine

Add solid manganese (IV) oxide to a test tube until it just fills the hemisphere at the bottom of the test tube. Using a test tube holder to hold the test tube, add concentrated hydrochloric acid (why?) till it reaches a height of 1 cm. Heat the mixture gently

The concentrated hydrochloric acid will be oxidised by the manganese (IV) oxide to form chlorine gas.

c. To test for chlorine

Procedure	Observation
1. Note the colour of the gas. 2. Test the gas with moist litmus papers	*A yellowish green gas was evolved which turned moist blue litmus paper red and finally bleached it.*
3. Test the gas with the strip of filter paper soaked in aqueous potassium iodide and starch.	*The gas turned the potassium iodide-starch paper dark blue.*

d. Explain the reaction between litmus and chlorine.

The chlorine dissolves in the moist litmus to form two acids which will turn the blue dye red. One of the acid, chloric (I) acid will then oxidise the red dye, decolourising it.

e. Explain the reaction between potassium iodide-starch and chlorine.

The chlorine gas displaces the iodide ion to liberate iodine which turns starch solution blue.

C. Checklist

Test for	I can do it	My partner can do it
Hydrogen		
Oxygen		
Carbon dioxide		
Sulphur dioxide		
Nitrogen dioxide		
Chlorine		

Worksheet 5 Gases (continued)

V. STRATEGIES FOR TESTING GASES

A. Introduction.

1. Gases are frequently produced during reactions in QA.
2. Identifying the gases evolved gives clues to the identity of the substances present in an unknown sample.
3. Testing of gases should be done in a logical, systematic and well-prepared manner.

    a. You need to be able to determine whether a certain procedure will result in the formation of gases.
    b. You need to prepare the necessary apparatus and reagents before you carry out the procedure (why?).

    The liberated gas will escape into the air.

    c. You need to be aware of other clues such as colour and odour of the gases.

B. Questions to ask yourself

1. Addition of dilute acid to an unknown sample

    a. What gases may be evolved?

    Carbon dioxide, sulphur dioxide and hydrogen (if sample is metallic).

    b. How do I prepare to test for these gases?

    Carbon dioxide – limewater
    Sulphur dioxide – acidified potassium dichromate (VI) or manganate(VII)
    Hydrogen – lighted splint

2. Addition of an oxidising agent

    a. What gases may be evolved?

    Chlorine.
    (NB. If manganese (IV) oxide is added to a colourless liquid, oxygen may be evolved. However, the manganese (IV) oxide here is acting as a catalyst)

b. How do I prepare to test for these gases?

Chlorine – blue litmus.

3. Addition of aqueous sodium hydroxide (especially if the procedure also states gentle heating)

   a. What gases may be evolved?

   Ammonia.

   b. How do I prepare to test for these gases?

   Red litmus.

4. Heating of samples

   a. What gases can be evolved?

   Carbon dioxide, sulphur dioxide, oxygen and nitrogen dioxide.

   b. How do I prepare to test for these gases?

   Carbon dioxide – limewater
   Sulphur dioxide – acidified potassium dichromate (VI) or manganate(VII)
   Oxygen – glowing splint
   Nitrogen dioxide – colour of gas and blue litmus.

VI. APPLICATION

Testing for unknown gases

Procedure	Observations	Inferences
Add dilute hydrochloric acid sample J.	*A colourless gas is evolved which turns blue litmus red and orange acidified potassium dichromate (VI) green.*	*Sulphur dioxide is evolved,* SO^{3-} *is present*
Add solid K to a test tube. Add aqueous sodium hydroxide to K and heat gently.	*A colourless, pungent gas is evolved which turns red litmus blue.*	*Ammonia gas is evolved,* NH_4^+ *is present.*
Add solid L to a test tube until it just fills the hemisphere at the bottom of the test tube. Heat strongly.	*A brown gas is evolved which turns blue litmus red. Another gas is evolved which relights a glowing splint. The solid turns yellow when hot and white when cool.*	*Nitrogen dioxide and oxygen are evolved,* NO_3^- *is present.* Zn^{2+} *may be present.*

Worksheet 6 Anions

I. Heating experience

A. Heating zinc nitrate(V)

Procedure	Observations
Add solid zinc nitrate(V) until it just fills the hemisphere at the bottom of a test tube. Heat for 5 min. using a non-luminous flame. Record any colour changes or evolution of gas	*A brown gas is evolved which turns blue litmus red. Another gas is evolved which relights a glowing splint. The solid turns yellow when hot and white when cool.*

Explain why there may be colour changes and evolution of gases when substances are heated.

Some substances decompose on heating to liberate gases and the solids left behind are new substances which may have different colours from the original solids.

B. Heating potassium/sodium nitrate(V)

Procedure	Observations
Add solid potassium/sodium nitrate(V) until it just fills the hemisphere at the bottom of a test tube. Heat for 5 min. using a non-luminous flame. Record any colour changes or evolution of gas	*The white solid melts and turns yellow. A gas is evolved which relights a glowing splint. On cooling, a white solid remains.*

Compare the results obtained with the heating of zinc nitrate(V). Explain the similarities and/or differences between the two.

Sodium/potassium nitrate(V) decomposes to form sodium/potassium nitrate(III) and oxygen whereas zinc nitrate(V) decomposes to form zinc oxide, nitrogen dioxide and oxygen.

C. Ammonium chloride

Procedure	Observations
Add solid ammonium chloride until it just fills the hemisphere at the bottom of a test tube. Heat using a non-luminous flame. Record any colour changes or evolution of gas	*The white solid "sublimes" and a white solid forms at the upper regions of the test tube.*

Compare the results obtained with the heating of zinc nitrate(V). Explain the similarities and/or differences between the two.

Ammonium chloride dissociates on heating to form ammonia and hydrogen chloride which recombines on cooling to form ammonium chloride again whereas zinc nitrate(V) decomposes on heating and does not reform on cooling.

D. Carbon + copper(II) oxide

Procedure	Observations
Add the mixture of carbon and copper(II) oxide until it just fills the hemisphere at the bottom of a test tube. Heat using a non-luminous flame. Record any colour changes or evolution of gas	*A gas is evolved which turns blue litmus red and gives a white precipitate with limewater. The mixture glows when heated and a shiny brown metal is formed.*

Explain what happened when the mixture was heated.

Carbon reacts with the copper(II) oxide to give carbon dioxide and copper. Carbon also reacts with oxygen in the air to give carbon dioxide.

II. Precipitation experience

Anions can be identified by the formation of insoluble barium, silver or lead(II) salts when barium chloride/nitrate(V), silver nitrate(V) or lead(II) nitrate(V) solutions are added. They are further distinguished by the addition of acid.

A. Aqueous sodium chloride + aqueous silver nitrate(V) + dilute nitric(V) acid / aqueous ammonia

Procedure	Observation
To aqueous sodium chloride, add an equal amount of aqueous silver nitrate(V). Divide the resulting mixture into two portions.	*A white precipitate is formed.*
To one portion, add dilute nitric(V) acid until there is no further change.	*No visible reaction, the white precipitate remains.*
To the other portion, add aqueous ammonia until there is no further change.	*The white precipitate dissolves to form a colourless solution.*

Explain your observations.

Silver nitrate(V) reacts with sodium chloride to form insoluble silver chloride in a double decomposition reaction. Silver chloride does not react with nitric(V) acid but reacts with aqueous ammonia to form a soluble complex salt.

B. Aqueous sodium sulphate(VI) + aqueous barium chloride + dilute hydrochloric acid

Procedure	Observation
To aqueous sodium sulphate(VI), add an equal amount of aqueous barium chloride.	*A white precipitate is formed.*
Add dilute hydrochloric acid until there is no further change.	*No visible reaction, the white precipitate remains.*

Explain your observations.

Barium chloride reacts with sodium sulphate(VI) to form insoluble barium sulphate(VI) which does not react with the acid.

C. Sodium carbonate + barium chloride + hydrochloric acid

Procedure	Observation
To aqueous sodium carbonate, add an equal amount of aqueous barium chloride.	*A white precipitate is formed.*
Add dilute hydrochloric acid until there is no further change.	*A colourless gas is evolved which turns blue litmus red and gives a white precipitate with limewater. A colourless solution is also formed.*

Explain your observations.

Barium chloride reacts with sodium carbonate to form insoluble barium carbonate which reacts with the acid to form carbon dioxide.

D. Aqueous potassium iodide + aqueous lead(II) nitrate(V) + dilute nitric(V) acid

Procedure	Observation
To aqueous potassium iodide, add an equal amount of aqueous lead(II) nitrate(V). Heat gently.	*A yellow precipitate is formed which dissolves on heating to give a colourless solution and reappears on cooling.*
Add dilute nitric(V) acid until there is no further change.	*No visible reaction, the yellow precipitate remains.*

Explain your observations.

Lead(II) nitrate(V) reacts with potassium iodide to form insoluble lead(II) iodide which is soluble in hot water. Lead(II) iodide does not react with nitric(V) acid.

E. Aqueous sodium sulphate(IV) + aqueous barium chloride + dilute hydrochloric acid

Procedure	Observation
To aqueous sodium sulphate(IV), add an equal amount of aqueous barium chloride.	*A white precipitate is formed.*
Add dilute hydrochloric acid until there is no further change.	*A colourless, pungent gas is evolved which turns blue litmus red and orange acidified potassium dichromate (VI) green. A colourless solution is also formed.*

Explain your observations.

Barium chloride reacts with sodium sulphate(IV) to form insoluble barium sulphate(IV) which reacts with the acid to form sulphur dioxide.

F. Some theory

1. Aqueous barium nitrate(V)/chloride, silver nitrate(V) and lead(II) nitrate(V) are used to test for anions in an unknown aqueous sample.

2. If a precipitate is formed, it is due to double decomposition reactions resulting in the formation of an insoluble salt.

3. Whether the precipitate further reacts with dilute acids or ammonia gives clues to the identity of the anion.

4. Does the order of addition of the barium/silver/lead(II) reagents and dilute acids matter?

   If acid is added first, it will react with any sulphate(IV) and carbonate present so that no precipitate is formed with barium/silver/lead(II).

5. It is important that the correct acid is added.
   a. If aqueous barium nitrate(V) is added, it will be followed by dilute nitric(V) acid
   b. If aqueous barium chloride is added, it will be followed by dilute hydrochloric acid
   c. If aqueous silver nitrate(V) is added, it will be followed by dilute nitric(V) acid.
   d. If aqueous lead(II) nitrate(V) is added, it will be followed by dilute nitric(V) acid.

6. Do you see a trend in the acid used above?

7. The following experiments will illustrate point (4)

Procedure	Observation	Explanation
To aqueous sodium chloride, add an equal amount of aqueous barium nitrate(V).	*No visible reaction, a colourless solution remains.*	*No double decomposition reaction occurs.*
Add dilute sulphuric(VI) acid until there is no further change.	*A white precipitate is formed.*	*Insoluble barium sulphate(VI) is formed*
To aqueous sodium nitrate(V), add an equal amount of aqueous silver nitrate(V).	*No visible reaction, a colourless solution remains.*	*No double decomposition reaction occurs.*
Add dilute hydrochloric acid until there is no further change.	*A white precipitate is formed.*	*Insoluble silver chloride is formed*

III. Redox Experience

A. Aqueous copper(II) sulphate(VI) + aqueous potassium iodide

Procedure	Observation
To aqueous copper(II) sulphate(VI), add an equal amount of aqueous potassium iodide. Shake the mixture and allow it to stand for a few minutes (why?)	*A cream/buff precipitate in a brown solution is formed.*

1. Explain your observations.

Copper(II) ions react with iodide ions to form copper (I) iodide and iodine in a redox reaction.

Copper(II) sulphate is used to test for iodide ions. However, if you had added potassium iodide to an unknown sample and the same result is obtained, then this indicates the presence of copper(II) ions.

B. Testing for nitrate(V)

1. Use of aqueous barium nitrate/chloride and silver nitrate will give negative results for nitrate(V).

2. Negative results cannot confirm the presence of the nitrate(V) ion.

3. One method of determining the presence of the nitrate(V) ion is heating the solid sample (and not the solution – why?)

   Waste time in evaporating all the water away.

4. Another method is to heat the nitrate(V) with Devada's alloy / zinc / aluminium and sodium hydroxide. The nitrate(V) will be reduced to ammonia during the reaction.

Procedure	Observation
If solid nitrate(V) is used Dissolve the solid in aqueous sodium hydroxide.	*Depends on which nitrate(V) is used.*
If aqueous solution of nitrate(V) is used.	
Add an equal amount of aqueous sodium hydroxide.	*Depends on which nitrate(V) is used.*
Add a small spatula full of Devada's alloy / zinc powder / aluminium powder to the solution and heat gently. Test for ammonia and hydrogen.	*A vigorous reaction occurs and a gas is evolved which turns red litmus blue. Another gas is evolved which extinguishes a lighted splint with a 'pop' sound.*

5. The presence of nitrate(V) can only be confirmed in the above procedure if ammonium ions are not present in the first instance. Why?

   Ammonium ions would react with the sodium hydroxide to give ammonia.

IV. Exercise on heating

A. Heating

1. Adding reagent

   a. If given a solid sample, add the solid under it fills the hemisphere at the bottom of the test tube.
   b. If given a liquid, add the liquid until it reaches a height of 2 cm in a test tube.

2. Heating

   a. Wear eye protection at all times when heating is involved (why?).
   b. Use a non-luminous flame (why?).
   c. For a solid sample:
      i. Heat gently for 2 min, by putting the test tube 5mm away from the tip of the blue cone, the hottest part of the flame.
      ii. Observe for any colour change or liquid forming in the test tube.
      iii. Heat strongly for 3 min by putting the test tube at the tip of the blue cone.
      iv. Observe for any colour change, change of state, evolution of gases, formation of liquid/solids at the upper region of the test tube

   d. For a liquid sample:
      i. Heat near the surface of the liquid and shake frequently (why?)
      ii. Do not heat at the bottom of the test tube as the liquid may splash out (why?)

3. Heating of copper(II) sulphate(VI)

Procedure	Observation
Heat a sample of solid copper(II) sulphate(VI). Record any changes that occur.	*A colourless gas is evolved which turns blue litmus red. The blue solid turns black on heating.*

Explain your observations

Copper(II) sulphate(VI) decomposes to form sulphur trioxide and copper(II) oxide.

4. Heating of aqueous sodium hydroxide and aqueous ammonium chloride

Procedure	Observation
To aqueous ammonium chloride add an equal amount of aqueous sodium hydroxide. Heat.	*A colourless, pungent gas is evolved which turns red litmus blue. A colourless solution remains.*

Explain your observations

Ammonium chloride reacts with sodium hydroxide to form ammonia, sodium chloride and water.

5. Devadas' alloy/aluminium/zinc test

Procedure	Observation
Add an equal amount of aqueous sodium hydroxide to aqueous sodium nitrate(V).	*A colourless solution is formed.*
Add a small spatula full of Devada's alloy / zinc powder / aluminium powder to the solution and heat gently. Test for the gases evolved	*A vigorous reaction occurs and a gas is evolved which turns red litmus blue. Another gas is evolved which extinguishes a lighted splint with a 'pop' sound.*

Explain your observations.

Nitrate(V) ions react with sodium hydroxide and Devada's alloy / zinc powder / aluminium powder to form ammonia and hydrogen.

B. Checklist

Procedure	I am able to	My partner is able to
Heat a solid sample a. Gently b. strongly		
Heat a liquid sample a. gently b. strongly		

Worksheet 7 Anions (continued)

I. Metacognition

A. What to do when one is required to heat

1. Note the colour of sample as this will give clues to the identity of the cation present.

2. Get ready to test for gases.
   a. litmus
   b. limewater and delivery tube
   c. acidified aqueous potassium manganate(VII) / aqueous potassium dichromate (VI)
   d. wooden splint

3. Heat gently
   a. Use litmus.
   b. Look out for water of crystallisation – cobalt chloride paper.

4. Heat strongly

   a. Note changes in colour of the residue which can give clues to the identity of the cation present.

   b. Note changes in state.
      i. melting
      ii. “sublimation” – ammonium salts

   c. Note the result of litmus test before proceeding further .
      i. No visible change – test for oxygen
      ii. Acidic gas – test for sulphur dioxide and carbon dioxide. Note that if a brown acidic gas (nitrogen dioxide) is evolved, test for oxygen as well (why?).

5. Recording observations

   a. Colour changes of sample during heating and cooling.
   b. Changes of state in sample during heating and cooling.
   c. Appearance of substances in the upper region of the test tube.
   d. Results of tests for gases.

B. Using aqueous barium nitrate/chloride, aqueous silver nitrate(V) and aqeuous lead(II) nitrate(V)

1. Strategies

a. Get ready to test for gases i.e. carbon dioxide and sulphur dioxide (why?)
Gases would escape into the air.

b. Note
- i. colour of precipitate
- ii. reaction with acid
- iii. tests for gases

c. The table below may help you to identify the anions.

Precipitate	Aqueous barium nitrate(V) / chloride	Aqueous silver nitrate(V)	Aqueous lead(II) nitrate(V)
None	Nitrate(V) Chloride Iodide	Nitrate(V) Sulphate(VI) (white ppt if concentrated solution used)	Nitrate(V)
White	Sulphate(IV) Sulphate(VI) Carbonate	Sulphate(IV) Carbonate Chloride	Sulphate(IV) Sulphate(VI) Carbonate Chloride
Yellow		Iodide	Iodide

d. In identifying anions, is possible to add dilute acid first before adding aqueous barium chloride, silver nitrate(V) or lead(II) nitrate(V)? Is the order of addition of the reagents important?

No. If acid is added first, acid-carbonate or acid-sulphate(IV) reaction occurs first. If a precipitate is left, then the precipitate is not a sulphate(IV) or carbonate.

C. Use of aqueous copper(II) sulphate(VI) / aqueous potassium iodide.

Aqueous copper(II) sulphate(VI) is sometimes used to identify iodide ions. Similarly, aqueous potassium iodide is used to identify copper(II) ions.

II. APPLICATION

Identify the anions in the 6 solid samples using two tests, one of which is heating.

	Procedure	Observations	Inferences
M	*Heat M.* *Add dilute nitric(V) acid to M.*	*A colourless gas is evolved which turns blue litmus red and gives a white precipitate with limewater. The solid turns yellow when heated and white when cooled.* *Effervescence occurs. A colourless gas is evolved which turns blue litmus red and gives a white precipitate with limewater.*	CO_3^{2-} *is present.*
N	*Heat N.* *Add aqueous sodium hydroxide and Devada's alloy to N. Heat gently.*	*The white solid melts and turns yellow. A gas is evolved which relights a glowing splint. On cooling, a white solid remains.* *A vigorous reaction occurs and a gas is evolved which turns red litmus blue. Another gas is evolved which extinguishes a lighted splint with a 'pop' sound.*	NO_3^- *is present.*
O	*Heat O.* *Add dilute nitric acid to O.*	*No visible reaction.* *A colourless gas is evolved which turns blue litmus red and orange acidified potassium dichromate (VI) green.*	SO_3^{2-} *is present.*

	Procedure	Observations	Inferences
P	*Heat P.*	*P sublimes on heating and a white solid is formed at the upper regions of the test tube.*	*Cl^- is present.*
	Add aqueous silver nitrate(V) to a solution of P, followed by dilute nitric(V) acid.	*A white precipitate is formed which is insoluble in dilute nitric(V) acid.*	
Q	*Heat Q.*	*A brown gas is evolved which turns blue litmus red. Another gas is evolved which relights a glowing splint. The solid turns yellow when hot and white when cool.*	*NO_3^- is present.*
	Add aqueous sodium hydroxide and Devada's alloy to N. Heat gently.	*A vigorous reaction occurs and a gas is evolved which turns red litmus blue. Another gas is evolved which extinguishes a lighted splint with a 'pop' sound.*	
R	*Heat R.*	*A colourless gas is evolved which turns blue litmus red and orange acidified potassium dichromate (VI) green.*	*SO_3^{2-} is present.*
	Add aqueous barium chloride to a solution of R followed by dilute hydrochloric acid.	*A white precipitate is formed which is insoluble in dilute hydrochloric acid.*	

APPENDIX O

QUALITATIVE ANALYSIS DIAGNOSTIC INSTRUMENT: A MORE GENERAL VERSION

Instructions
Choose the most suitable option and the reason for your choice in each question by filling the appropriate circles in the answer sheet. If you feel that all options given are inappropriate, indicate the question number and write down what you think the correct answer should be behind the answer sheet.

For Questions 1 to 4, refer to Experiment A:

Experiment A

Step	Test	Observations
a	To a sample of aqueous zinc chloride, add aqueous sodium hydroxide until a change is seen.	*A white solid is obtained.*
b	Add excess of aqueous sodium hydroxide to the mixture from (a).	*White solid disappears in excess reagent to give a colourless solution.*
c	Add dilute nitric(V) acid (HNO_3) to the mixture from (b) until no further change is seen.	*White solid reappears. When excess acid is added, the solid disappears giving a colourless solution.*

1. What happens when aqueous sodium hydroxide is added to aqueous zinc chloride resulting in the white solid?

   A Displacement
   B Precipitation
   C Redox

   Reason/Justification

   (1) The solution is too concentrated with sodium chloride so the sodium chloride comes out of the solution as a solid.
   (2) Sodium hydroxide loses oxygen in forming sodium chloride and zinc chloride gains oxygen in forming zinc hydroxide.
   (3) Sodium ion is more reactive than zinc ion.
   (4) Zinc ions combine with the hydroxide ions.

2. In step (b), a colourless solution is obtained because the white solid _____ the excess sodium hydroxide.

A dissolves in B reacts with

Reason/Justification

(1) More solvent is added so there is more space for the white solid to dissolve.
(2) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(3) Sodium ion displaces the cation from the white solid.
(4) The white solid forms a new soluble compound with the excess sodium hydroxide.

3. A student concludes that the white solid observed in step (c) is the same as the white solid obtained in step (a). Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the excess sodium hydroxide to form sodium nitrate(V) which appears as the white solid.
(3) The acid reacts with the zinc compound to form zinc nitrate(V) which appears as the white solid.
(4) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(5) The acid removes the solvent which dissolves the white solid in step (b), so the white solid reappears.

4. The student also concludes that, in step (c), the white solid dissolves because more solvent (dilute nitric(V) acid) is added. Do you agree with the student's conclusion?

A Yes B No

Reason/Justification

(1) Adding more acid dilutes the solution.
(2) Hydrogen is more reactive than the cation in the white solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the white solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the white solid.
(5) The acid reacts with the white solid to form a new soluble compound.

For Questions 5 to 9, refer to Experiment B:

Experiment B

Step	Test	Observations
	Q is an aqueous solution of a compound which containing a cation and an anion which could possibly be chloride.	
a	To a portion of Q, add an equal volume of aqueous silver nitrate(V) ($AgNO_3$). Divide the mixture into 2 portions.	*A white solid is obtained.*
b	To the first portion, add dilute nitric(V) acid.	*No visible reaction. The white solid remains.*
c(i)	To the second portion, add aqueous ammonia.	*White solid disappears and a colourless liquid is formed.*
c(ii)	To the mixture from c(i), add dilute nitric(V) acid until a change is seen.	*White solid appears.*

5. What is the white solid obtained in step (a)?

A $AgCl$
B $ZnCl_2$
C $Zn(NO_3)_2$

Reason/Justification

(1) The silver ions are displaced by the more reactive cations from Q.
(2) The silver ions combine with the chloride ions.
(3) The white solid disappears when aqueous ammonia is added in step c(i).
(4) The nitrate(V) ions are displaced by the more reactive chloride ions.

6. In step (b), the purpose of adding the dilute nitric(V) acid is to:

A acidify the mixture.
B determine if the sample contains carbonate or sulphate(IV) (SO_3^{2-}) ions after identifying the gas evolved (if any).
C dissolve the white solid.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Carbonate and sulphate(IV) ions form a white solid with silver nitrate(V) which will react with nitric(V) acid.
(3) Dilute nitric(V) acid is a strong oxidising agent.
(4) Dilute nitric(V) acid is a good solvent.
(5) So that Q can react properly with silver nitrate(V).

7. In step (b), can dilute hydrochloric acid be added instead of dilute nitric(V) acid?

A Yes B No

Reason/Justification

(1) Both nitrate(V) and chloride ions are already present in the mixture.
(2) Chloride ions from dilute hydrochloric acid will interfere with the test.
(3) Dilute hydrochloric acid can be used as it has similar properties and reactions as dilute nitric(V) acid.
(4) Dilute hydrochloric acid will not react with the white solid.
(5) Dilute hydrochloric acid will react with the white solid.

8. In step (c (i)), it can be concluded that the white solid disappeared because it reacted with the aqueous ammonia to form ammonium chloride.

A True B False

Reason/Justification

(1) Ammonium chloride is a soluble salt.
(2) Chloride ions still present in solution react with the aqueous ammonia.
(3) The ammonium ion is more reactive than the silver ion, so it displaces the silver ion.
(4) The aqueous ammonia reacts with the white solid to produce a soluble compound which is not ammonium chloride.

9. In step (c (ii)), the hydrogen ions in the acid reduce the silver ions present to form the white solid.

A True B False

Reason/Justification

(1) The acid decomposes the ammonium chloride to liberate chloride ions which react with the silver ions present in solution.
(2) The acid reacts with the aqueous ammonia to produce a new insoluble salt.
(3) The acid reacts with the aqueous ammonia and the soluble compound in step (c (i)) to produce the same white solid as in step (a).
(4) The acid removes the ammonium ions so that silver ions can react with hydroxide ions.
(5) The white solid is the element, silver.

10. Will you test for oxygen gas when you heat an unknown solid?

A Yes B No

Reason/Justification

(1) All gases must be tested when a substance is heated.
(2) Oxygen gas is produced only when acids react with compounds containing oxygen.
(3) Oxygen gas will not be liberated during heating, instead it would be used up.
(4) Some compounds decompose on heating to give oxygen gas.

11. A student is given a solution which may contain carbonate or sulphate(IV) (SO_3^{2-}) ions. She decides to add aqueous barium nitrate(V) ($Ba(NO_3)_2$) to the solution first, followed by dilute nitric(V) acid. Is it possible for her to determine whether carbonate or sulphate(IV) ions are present when she carries out the above procedure followed by the identification of the gas involved (if any)?

A Yes B No

Reason/Justification

(1) An insoluble carbonate or sulphate(IV) would be formed leaving no free carbonate or sulphate(IV) ions in solution to react with the acid.
(2) Dilute nitric(V) acid will react with both a soluble and an insoluble carbonate or sulphate(IV).
(3) The above procedure is strictly to test for the presence of sulphate(VI) (SO_4^{2-}) only.
(4) The acid must be added directly to the solution to test for the presence of a carbonate or sulphate(IV).
(5) The unknown compound will only react with the dilute nitric(V) acid and not with the barium nitrate(V).

12. Instead of dilute nitric(V) acid, can the student add dilute sulphuric(VI) acid (H_2SO_4) after the addition of barium nitrate(V) in Question 11?

A Yes
B No

Reason/Justification

(1) Any acid can be used as they have similar properties and reactions.
(2) Sulphate(VI) ions from dilute sulphuric(VI) acid will interfere with the test.
(3) Dilute sulphuric(VI) acid will react with the nitrate(V) ions.
(4) The addition of barium nitrate(V) has already invalidated (spoilt) the test for carbonate or sulphate(IV) ions.

For Questions 13 to 16, refer to Experiment C:

Experiment C

Step	Test	Observations
a	To a sample of aqueous copper(II) sulphate(VI), add aqueous ammonia until a change is seen.	*A light blue solid is obtained.*
b	Add excess of aqueous ammonia to the mixture from (a).	*Light blue solid disappears in excess aqueous ammonia to give a deep blue solution.*
c	Add dilute sulphuric(VI) acid to the mixture from (b) until no further change is seen.	*A light blue solid appears. When excess acid is added, the solid disappears giving a light blue solution.*

13. What happens when aqueous ammonia is added to aqueous copper(II) sulphate(VI) in step (a)?

A Displacement
B Precipitation
C Redox

Reason/Justification

(1) Aqueous ammonia gains oxygen in forming ammonium sulphate(VI) but copper(II) sulphate(VI) loses oxygen in forming copper(II) hydroxide.
(2) Copper(II) ions combine with the hydroxide ions.
(3) Copper(II) ion is more reactive than the ammonium ion.
(4) Copper(II) ion is less reactive than the ammonium ion.

14. In step (b), why does the light blue solid disappear?

A It dissolves in aqueous ammonia.
B It reacts with aqueous ammonia.

Reason/Justification

(1) Ammonium ion displaces the cation from the light blue solid.
(2) More solvent is added so there is more volume for the light blue solid to dissolve in.
(3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added.
(4) There is a chemical reaction between the light blue solid and excess ammonia forming product(s) which is/are soluble.

15. The light blue solid obtained in step (a) and in step (c) is the same.

A True B False

Reason/Justification

(1) Different reagents were used.
(2) The acid reacts with the copper(II) compound to form copper(II) sulphate (VI) which appears as the light blue solid.
(3) The acid reacts with the mixture to reverse the formation of the soluble compound in step (b).
(4) The acid removes the solvent which dissolves the light blue solid in step (b), so the light blue solid reappears.

16. Excess dilute sulphuric(VI) acid acts as a solvent for the light blue solid in step (c).

A True B False

Reason/Justification

(1) Adding more acid dilutes the mixture.
(2) Hydrogen is more reactive than the cation in the light blue solid, so it displaces the cation from the solid.
(3) No further reaction is seen except for the disappearance of the light blue solid, and no new reagent is added.
(4) The acid contains hydrogen ions which reduce the light blue solid.
(5) The acid reacts with the light blue solid to form a new soluble compound.

For Questions 17 to 18, refer to Experiment D:

Experiment D

Step	Test	Observations
	R is a colourless aqueous solution of a compound containing a cation and an anion which could possibly be iodide.	
a	To a portion of R, add an equal volume of dilute nitric(V) acid.	*No visible reaction, a colourless solution remains.*
b	To the mixture from (a), add a small volume of aqueous lead(II) nitrate(V) ($Pb(NO_3)_2$).	*Yellow solid is obtained.*

17. The purpose of adding the dilute nitric(V) acid in step (a) is to

A acidify the mixture.
B determine if R reacts with the acid.

Reason/Justification

(1) All nitrate(V) salts are soluble.
(2) Dilute nitric(V) acid is a strong oxidising agent.
(3) Dilute nitric(V) acid is a good solvent.
(4) So that R can react properly with lead(II) nitrate(V).
(5) The acid will react with any carbonate or sulphate(IV) (SO_3^{2-}) ions if they are present in R.

18. How is the yellow solid formed?

A Displacement
B Precipitation

Reason/Justification

(1) The lead(II) ion is more reactive than the cation from R.
(2) The lead(II) ion is less reactive than the cation from R.
(3) The lead(II) ions combine with iodide ions.
(4) The iodide ions are more reactive than the nitrate(V) ions.
(5) The iodide ions are less reactive than the nitrate(V) ions.

19. A student believes that she has to test for hydrogen and carbon dioxide when she heats an unknown ionic compound (in powder form). Do you agree?

A Yes B No

Reason/Justification

(1) Ionic compounds have strong bonds and do not decompose on heating.
(2) Gases are only evolved when covalent compounds are heated.
(3) Some carbonates decompose on heating to give carbon dioxide but hydrogen is never liberated when any ionic compound is heated.
(4) The ionic compound would react with oxygen on heating to give water and/or carbon dioxide.
(5) Those ionic compounds containing carbonate, hydrogen or hydroxide ions will liberate carbon dioxide or hydrogen on heating.