Science and Mathematics Education Centre

An evaluation of student learning during a tertiary bridging course in chemistry

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Contents

continued →

An evaluation of student learning during a tertiary bridging course in chemistry

> *The shy fruit of pure science is Understanding.*
>
> Lincoln Barnett. 1950

SUMMARY

A new one-semester tertiary bridging course in chemistry was designed with constructivist concept-learning as a major aim. This aim was monitored by Concept-Learning Test Sequences (CLTSs), developed for each of ten fundamental chemical concept-clusters, selected from ten theory-practical work-units of an expressly written book. The concept-clusters were: density, mixture/compound, structure/bonding, base/salt, redox, mole, rate, metal, halogen, hydrocarbon. Each CLTS comprised a pre-instruction item; two-tier multiple-choice item(s); a post-instruction item; each provided data from a class of 21 students of widely different backgrounds. Separate chapters discuss class results and individual results.

Concept-learning Improvement Categories that estimated individual improvement in each CLTS were quantified by assigning numerical values. Summation of these numerical values for all ten CLTSs produced individual Concept-learning Improvement Indices (CLIIs). Improvement in concept-learning appears independent of prior academic background. Rankings by CLIIs and by final assessment percentage were strongly correlated. The mean CLII for the class assessed concept-learning improvement (per concept) at Moderate-to-Intermediate.

Various probes revealed that factors which influenced learning included: pre-laboratory reports; practical work; learning partnership(s); positive personal qualities; mathematical skills; confidence; visualisation; integration of theoretical and practical studies; bench problem-solving; a relaxed tutorial atmosphere; historical approaches to chemical concepts. Students assessed the course overall as 'good'.

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List of Tables

List of Figures

Chapter One - Introduction

1.1 Background to the Research Problem

During the last decade, Australian universities have responded to encouragement in making undergraduate courses more accessible to those students who have lacked either sufficient preparation, opportunity, or support to take part in tertiary education. Policies of equal opportunity have led, among other things, to the offering of bridging (or transition) courses, particularly in the sciences and mathematics, for disadvantaged students (sometimes described as "second chance" or "at risk" students).

The objective of bridging courses is essentially to offer underprepared, disadvantaged or mature-age students the opportunity to develop sufficient knowledge and cognitive skills to permit them to subsequently commence undergraduate courses without academic disadvantage. The need to achieve such an objective in a relatively short time-span (often one semester) poses substantial challenges to the pedagogic skills of those presenting bridging courses.

In response to such challenges, Fensham (1989a) organised a two-day conference for tertiary educators concerned with bridging courses in the physical sciences. Since then the Australian literature has provided a wide range of reports on bridging courses. For example, Treagust, Malone and Fraser (1991) developed bridging programs in chemistry and mathematics for Aboriginal students in Western Australia, while Rae and Pozzobon (1993) investigated and evaluated bridging courses for the sciences in Victorian universities. In a similar vein, Mitchell and de Jong (1994) and Fensham (1997) reported on bridging courses in chemistry and/or physics for "bright" students who were underprepared for engineering courses at Monash University, in Victoria. Bridging (or similar) courses have been conducted in other countries such as South Africa and the USA; however, descriptions of these courses seem to be limited to conference proceedings rather than publications in the research literature (see Rollnick, White and Dison, 1993, for example). Holistic research data on overseas bridging courses is therefore scarce. In Australia, however, a new context for bridging courses arose during the mid-1990s when Australian universities were responding to a general thrust for improvements in tertiary teaching and grants for this purpose became available.

Late in 1994, the writer received an Innovative Teaching and Learning Grant of $7,500 for a project to develop teaching/learning materials for a completely new one-semester chemistry course (04143 Introductory Chemistry) which, together with courses in mathematics and physics, aimed at "bridging" students into high demand degree programs in Applied Science and Engineering at the University of South Australia. The project involved writing the materials in the first semester of 1995, then trialling them during the presentation of the unit in the second semester. The project thus offered a challenge, the acceptance of which involved at least five important steps:

- posing a number of fundamental questions about teaching/learning
- finding answers to those questions
- putting the answers into practical forms
- trialling those forms
- assessing the outcomes.

This challenge and its acceptance became the subject of the present research, summarised as the following research problem.

1.1.1 The Research Problem

Students from a variety of backgrounds desire to enter science-related disciplines, initially by enrolling in tertiary bridging programs.

How can a bridging course in chemistry be designed, presented and evaluated in order to meet the needs both of the students and of the university?

From the research problem were distilled two research questions which gave focus and purpose to the whole research.

1.1.2 The Research Questions

These questions were

- **Research Question One:**
  To what extent did the students develop an understanding of the chemical concepts in the course?
- **Research Question Two:**
  What aspects of the course contributed to student learning?

It seemed that the best approach to answering these questions was to institute a two-phase structure to the research. Essentially Phase One was to be a trial or pilot phase. It comprised the Innovative Teaching and Learning Project conducted over the two semesters of 1995, as described above. Phase Two, commencing in 1996, was to involve modifying the materials and approaches on the basis of the data and experiences of Phase One, to present the revised course (in Semester Two) and to gather data which would provide answers to the Research Questions. Section Three of this chapter provides a more detailed description of the work in each of the phases.

The commencement of Phase One entailed establishing an educational rationale for developing, presenting and assessing the course 04143 Introductory Chemistry.

1.2 Developing the Bridging Chemistry Course - a Rationale

1.2.1 A fundamental question of approach

In responding to the Research Problem, perhaps the most fundamental of questions to be answered before developing the bridging chemistry course was, "How do learners learn best?" or, "What is the current best theory of teaching and learning?" A common answer to this question is that, as a theory of learning, constructivism is widely accepted by theorists and practitioners. It has a history "as old as our traditions" (Hawkins, 1994). What then is constructivism, and how could a constructivistic approach influence the design, presentation and evaluation of teaching/learning materials and the corresponding pedagogy?

Dawson (1994) provides an answer to this question when describing the differences between a constructivist approach to teaching and a transmission approach in which a teacher presents information and students work towards reproducing the information. He indicates that a constructivistic approach embraces two important characteristics, namely, placing importance upon students' prior knowledge, and recognising that learners construct their own understandings.

Dawson (1994) succinctly explains why students' prior knowledge is important:

> Research has demonstrated that students often come to science classrooms with prior conceptions about why certain phenomena in the world occur. These conceptions are of different types, have probably been generated in different ways, and have different strengths. Sometimes they resemble the scientific view quite well, and can serve as a base from which the scientific view can be further developed (remember new information is normally attached to something that is already there). At other times these prior conceptions are quite different from the scientific view, and attachment of new information to them can lead to great difficulties in generating good understanding. (p. 36)

Dawson (1994) also clearly describes how the constructivist model of learning sees effective learning as demanding a much greater participation by each learner in the whole process. If learning is to be at all meaningful, learners are necessarily constructors of their own understanding, not simply absorbers of information. An important aspect of this view is that, to be meaningful, new information must always be integrated into existing understanding. This means that constructivist teaching involves using methods which enable students to build upon appropriate existing knowledge in order that they gradually develop the scientific view. New information has to be actively processed by each learner. It is not enough to copy and learn, rather, the student needs to be actively engaged in working with and transforming new information. Dawson (1994) shows that teaching which encourages students' engagement such as the construction of summaries, flow charts, concept maps, participation in small group discussions of critical questions, and the use of other strategies which demand active participation, will all help with this. Dawson argues that such involvement in learning leads to understandings which are more permanent, which are better integrated, and which are more available for problem solving.

This kind of constructivist methodology continues to generate research (for example, Fensham, Gunstone and White, 1994; Hand and Prain, 1995) particularly in the secondary sector of education. However, apart from the work of Bucat, Chandler, Treagrove, Stick, Simpson, Baker, and Moccerino, (1995), Peterson (1995) and Clark (1996), very little research on the use of constructivist teaching approaches has been reported for the post-secondary sector of education in Australia. Nevertheless, it seems safe to assume that, in this sector, constructivist principles still apply, although the forms of their implementation may differ somewhat from those used in the primary or secondary sectors. Accordingly, it was decided to adopt constructivistic principles for guiding best pedagogical practice in the work based on the Innovative Teaching and Learning Grant and thus for responding to the research problem of this thesis. This decision helped to answer other questions about design, emphasis, content and evaluation of the unit.

1.2.2 Concepts, or phenomena, or ...?

Traditional approaches to secondary and tertiary chemistry courses have long emphasised the importance of acquisition of a considerable body of "factual" knowledge or "content" material by the student. If, however, students in bridging courses were to be equipped to eventually take part in undergraduate studies on the basis of their limited knowledge in chemistry, it was clear that a largely factual content would be unsatisfactory. It was desirable that successful completion of the course be characterised by an understanding of concepts and an ability to use this learning to solve problems - the kind of learning which Fensham (1989b) calls "quality learning". A constructivist perspective to the course would find the pursuit of such characteristics to be mandatory. The chosen approach of pursuing "quality learning" meant that the role of "facts" and phenomena was supportive of, but subordinate to concept learning. The memorisation of unsupported factual material would be discouraged. Further, the adoption of an historical (or evolutionary) approach (Broe, 1959; Matthews, 1994) to the presentation of many chemical ideas appeared to be suited to the satisfactory learning of chemical concepts by novices and to the minimisation of alternative conceptions. It is acknowledged, however, that the literature reveals that the use of multiple models for teaching a particular chemical concept often leads to student difficulties in differentiating them (Garnett, Garnett and Treagust, 1990; Garnett, Garnett and Hackling, 1995). The quality learning approach also meant that problem-solving and critical thinking would need to be incorporated into the teaching/learning of the unit.

The writings of Ennis (1987), Frazer and Sleet (1984), Johnstone (1993) and Sleet, Hagen, Logan, and Hooper (1996) indicate that teaching critical thinking and problem-solving, either at the bench or with pencil and paper, are challenging and complex tasks. In principle, the teaching/learning of problem-solving skills needs to be approached after concept learning has taken place, followed by extended practice (Johnstone, Sleet and Vianna, 1994; Wood with Sleet, 1993). Accordingly, it was decided to incorporate specific instruction on problem-solving into the teaching/learning materials for use at a later stage of the unit.

1.2.3 Dealing with individual differences

To the initial constructivist approach of ascertaining the learner's prior knowledge (Ausubel, 1968), Novak (1981) has added the suggestion that there is also a need to know how the learner *feels* about that knowledge. It is clear that both prior knowledge and attitudes towards learning are quite diverse within a class of bridging course students. Past intakes of the unit under study have included "second-language" students (from a range of cultural inheritances), mature-age students (of both sexes) with new life aspirations, less-than-successful matriculants and, occasionally, students with academic qualifications in other fields. The implication for constructivist teaching/learning in a class of 50 such students is that it is desirable, if not essential, to obtain detailed pre-instructional information about each student's background in chemistry and, if possible, her/his attitude to that background. In the first instance, an appropriate pre-instruction questionnaire would be essential. In the manner of Treagust, Malone and Fraser (1991), the course coordinator and tutors would need to be available to cater for the variety of revealed backgrounds on a needs basis.

The need to ascertain the learners' prior knowledge, as described above by Dawson (1994), has led to a considerable research literature of learners' alternative conceptions (for example, Driver, Squires, Rushworth and Wood-Robinson, 1994; Garnett et al., 1995; Pfundt and Duit, 1994; Wandersee, Mintzes and Novak, 1994). Alternative conceptions have also been described as alternative frameworks, children's science, pre-conceptions, and misconceptions, often according to the researcher's understanding of knowledge. Such alternative conceptions tend to be strongly retained and reluctantly given up, and as such, they are influential in the development of new conceptions (Driver et al., 1994). Awareness of this situation meant that the administration of a pre-instruction questionnaire would not in itself be adequate for dealing with alternative conceptions held prior to, or developed during the teaching/learning of the course. Rather, it would be necessary to monitor the students' learning at regular intervals. A means of doing this was available through the work of Treagust (1988) and Peterson, Treagust and Garnett (1989). They had developed a two-tier multiple-choice test item approach for diagnostic testing of concept learning in chemistry. Significantly, in this approach, distractors in each item can contain relevant alternative conceptions, the choice of which by the respondent provides an appropriate diagnosis of concept learning. Items of this nature have value in both formative and summative assessment. Consequently a decision was made to adopt a two-tier multiple-choice test item approach as a significant major assessment tool during the teaching of the course.

1.2.4 The role of laboratory experiences in learning

For many years it has almost been an act of faith that cognitive learning through laboratory and other practical activities proceeds effectively. In more recent times, however, researchers have been questioning the efficacy of such experiences in developing scientific concepts (Hofstein and Lunetta, 1982; Hofstein, 1988; van den Berg and Giddings, 1992, for example). The literature indicates that much more research needs to be done in order to be confident about what can be achieved through practical work and how to improve learning through practical work.

Van den Berg and Giddings (1992) conceptualise laboratory activity into three distinct roles - *the concept lab* (with emphasis upon teaching concepts and overcoming alternative conceptions), *the process lab* (with emphasis on exercising intellectual skills needed in generating and validating knowledge) and *the skill lab* (with emphasis on learning manipulative skills). They assert that each of these kinds of laboratory activities requires its own teaching methodology and assessment. Accepting these assertions as reasonable but subject to further research, it became clear that a pursuit of "quality learning" would require laboratory sessions to be orientated towards the concept lab and/or the process lab. With the adoption of simple micro-scale practical techniques as the basis of all the laboratory work, it would be possible to teach virtually all the necessary manipulative laboratory skills in the introductory laboratory session, leaving the rest of the sessions for concept and process skill development.

The findings of Johnstone, Sleet and Vianna (1994) suggest that the effectiveness of concept labs and process labs could be enhanced by the use of pre-laboratory thinking tasks and exercises ("pre-labs"), as a preparation for the actual laboratory sessions. The authors report that their students in university classes had developed positive attitudes towards this strategy. It was therefore decided to introduce Pre-laboratory Reports as pre-requisites for entry to each laboratory session of the course , and to research their effectiveness in concept learning. These reports would contain thinking tasks and exercises, based not only upon the laboratory session to come, but also upon the theoretical topics studied during the lead-up to the laboratory. Since it had also been decided to present teaching/learning materials for the semester's work as a series of topics in which theory and practical were integrated, the Pre-laboratory Reports would require the students to make links between theory and laboratory activities, to be integrative or, in other words, to be constructivist in their learning.

Because the laboratory sessions were to be so closely linked to the theory sessions, thinking tasks could be incorporated into the practical tasks, thus making laboratory sessions *joint concept/process labs*. Further, the theoretical work on problem-solving could be harnessed specifically to problem-solving at the bench.

Johnstone and Letton (1991) have pointed out that in the matter of the design and the writing of the laboratory experiences by authors, it is important to help student readers to separate the "signal" (the essential) from the "noise" (the unimportant). They show that much can be achieved by an open layout of the written page, reduction of excess verbiage, clarity and simplicity of expression, the use of icons, and an exposition of objectives. These guidelines were adopted for the production of all of the project's written materials, including laboratory activities.

1.3 Responding to the Research Problem

1.3.1 Phase One

As described in Section 1, the two semesters of work on the Innovative Teaching and Learning Project in 1995 constituted the first of two phases of this research. A focus of Phase One in the first semester was the production and publication of the volume of teaching/learning materials titled *Introducing Chemistry* (Chittleborough, 1995). This book attempted to synthesise the elements of best pedagogical practice as suggested by current research findings and personal experience. Its educational features are outlined in Section 1.3.1.1. Included in the book were introductory sections on learning and laboratory techniques, ten units of work on fundamental chemical topics and an eleventh unit on problem-solving at the bench.

1.3.1.1 Educational features of the book

Characteristic educational features of the book were

- a constructivist emphasis upon learning and teaching
- integration of laboratory experience with theoretical studies
- planned pre-laboratory reading and other activities, the completion of which in a pre-laboratory report were pre-requisite for entry to the laboratory each week
- the development of chemical concepts, *ab initio,* through an historical approach in much of the pre-laboratory reading
- thinking tasks set in both the pre-laboratory reports and the laboratory activities
- the use of micro-scale chemistry techniques for enhanced accessibility to reactions, economy of time and, importantly, a more intense focus upon chemical phenomena which were the subject of many of the thinking tasks.
- a high "signal-to-noise ratio" in the design of all aspects of the book.

Chapter 3 discusses these features in fulfilling the central role of *Meeting Chemistry* (Chittleborough, 1996b) in the teaching program.

1.3.1.2 Development of instruments

Another focus was the development of four sets of two-tier multiple-choice diagnostic assessment items (Treagust, 1988) to assess concept learning in various topics in the unit, using both summative and formative modes. During this time the writer was awarded a grant of $3 000 from the South Australian Universities National Staff Development Fund for Assessing and Examining Projects. This permitted the development of a significant number of extra two-tier multiple-choice tests for the unit, more than sufficient to test each of ten concepts. These tests were to be administered soon after "instruction" in that concept.

Two questionnaires were developed. The first was a Pre-instruction Questionnaire, intended to establish the chemical background of the learner in a number of chemical areas and also to assess general scientific skills such as mass conservation, volume conservation and proportional reasoning. The second instrument was a voluntary anonymous End-of semester Questionnaire to be administered after the completion of the unit. This would give learners an opportunity to comment extensively on all aspects of the unit.

In the second semester of 1995, the emphasis was upon trialling the materials and assessing their effectiveness. This completed Phase One of the research, essentially a development and trialling phase, which provided a significant volume of qualitative and quantitative data from the tests (and other test items), the questionnaires (both pre-instruction and End-of-semester), pre-laboratory reports, laboratory records and informal observation during the course of the unit.

1.3.2 Phase Two

The first task in Phase Two, begun early in 1996, was to use the data of Phase One to revise the book, tutorials, diagnostic tests and other materials, ready for use in the second semester when the course was again to be presented. The revised form of *Introducing Chemistry* was published as a second edition (Chittleborough, 1996a). A new feature of this edition was the inclusion of *Post-Laboratory Review Sheets,* prepared specifically for each unit, to be completed before leaving the laboratory. These sheets focussed on the students' metacognition about the week's work and, in particular, the laboratory session (normally based on one unit from *Introducing Chemistry).* A further addition to the book was an appendix containing discussion of a nuclear-electric model of atoms and Periodic Table relationships.

Another work, published for the course in 1995 as a special edition of an out-of-print book written by this researcher and others, was re-edited in 1996 and published under a complementary title - *Meeting Chemistry* (Chittleborough, 1996b). The function of this Study Book was to provide additional theory, factual information and exercises to support the content of *Introducing Chemistry.*

To extend the monitoring of concept learning, a new set of pre-instruction/post-instruction test items was devised. These items were intended to assess the respective initial and final understandings of ten chemical concepts (or concept-clusters), one from each unit of *Introducing Chemistry.* Presented on Table1.1 are the ten monitored concept clusters and the corresponding units in *Introducing Chemistry.*

Table 1.1 Ten monitored concept-clusters sourced from units in *Introducing Chemistry.*

monitored concept-cluster	unit number and title
1. density	1. Physical Properties and the Kinetic-Molecular Theory
2. mixture/compound	2. Chemical Change, Dalton and Atoms
3. structure/bonding	3. Bonding, Structure and Properties
4. base/salt	4. Acids, Bases and Salts
5. redox	5. Introducing Redox Reactions
6. mole	6. Introducing the Mole
7. rate	7. How Fast?
8. metal	8. Metals and Compounds of Metals
9. halogen	9. Group VII - The Halogens
10. hydrocarbon	10. Organic Chemistry

Each pre-instruction test item was incorporated into the revised Pre-instruction Questionnaire. (For administrative purposes this questionnaire was labelled *Introductory Information and Questionnaire*, but it will be referred to as the Pre-instruction Questionnaire throughout this thesis). Each post-instruction test item included the corresponding pre-instruction item (as Part A) and an extension (Part B) which further tested understanding of the concept. The post-instruction test items became Section One of the final examination paper.

In order to obtain student evaluations of the course, the voluntary and anonymous End-of semester Questionnaire, trialled in 1995, was edited and refined for use at the end of the unit in 1996. Student evaluations of the unit at the end of Phase One had indicated that the unit on problem-solving, undertaken near the end of the semester, would be more fruitful if it were introduced much earlier. The students felt that such a change would be more likely to assist them in tackling the thinking tasks which are a feature of the Pre-laboratory Reports and laboratory activities. Accordingly, the problem-solving unit (No. 11) was inserted into the teaching program after the study of Acids, Bases and Salts (No. 4) and extra practical problems ("Challenges"), focussed on that topic, were devised.

In addition, steps were taken to ensure that the ethical requirements for interviewing students for case study purposes were satisfied for both The University of South Australia and Curtin University of Technology. It was planned to interview about five students concerning their responses to the entire unit.

The totality of these responses to the Research Problem permitted both qualitative and quantitative answers to be given to the two Research Questions.

1.4 Research Methodology

The two Research Questions generated the research methodology.

In respect of Research Question One, significant research tools were the sequences of test items written for each of the designated concept clusters. Each sequence was formed from the pre-instruction/post-instruction items (described above in Section 3) and the available two-tier multiple-choice test items for each concept cluster. Each sequence comprised, in order, a pre-instruction test item, at least one two-tier multiple-choice test item (sometimes as many as four), and a post-instruction item (Parts A and B). The two-tier test items were administered as soon as possible after completion of study of small groups of units in *Introducing Chemistry*. For the purposes of this thesis, these sequences will be called *The Concept-Learning Test Sequences.* A generalised form of the testing program using The Concept-Learning Test Sequences is shown on Table 1.2. This program enabled the researcher to ascertain what the learners knew prior to instruction (and accordingly, what to teach); to use the two-tier tests both summatively and formatively immediately after the tests; and, after further teaching/learning, to assess the final achievements in concept-learning at the end of the unit.

Table 1.2 Generalised Concept-Learning Test Sequences

	Week															
concept	1	2	3	4	5	6	7	8^c	9	10	11	12	13	14^d	15^d	16
1	a					tt										ab
2	a					tt										ab
3	a					tt										ab
4	a								tt							ab
5	a								tt							ab
6	a								tt							ab
7	a												tt			ab
8	a												tt			ab
9	a												tt			ab
10	a												tt			ab

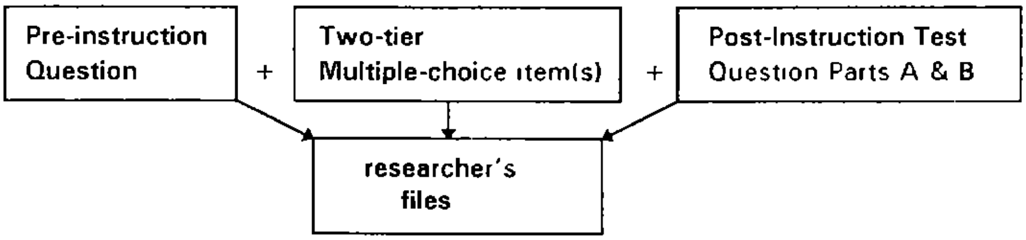
Key: a pre-instruction test ab post-instruction test (Parts A & B)
tt two-tier multiple-choice tests

Notes: c a two-week mid-semester break occurred between Weeks 8 and 9.
d Study Vacation (non-teaching weeks prior to final examinations).

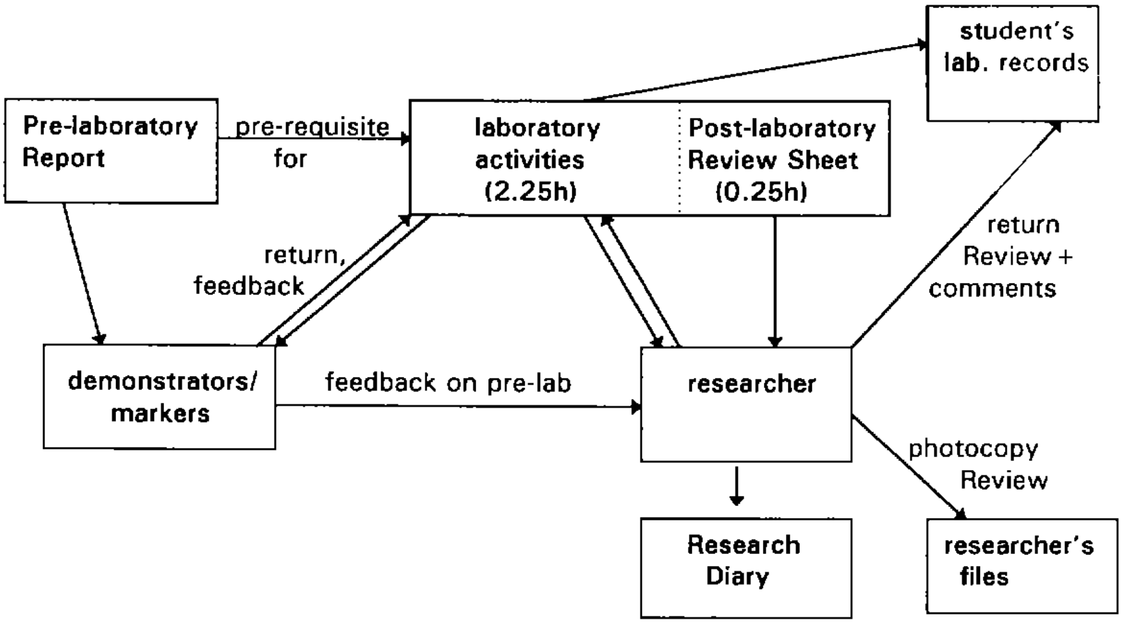
In respect of Research Question Two, the relevant research tools were various, as illustrated in Figure 1.1. The Concept-Learning Test Sequences provided opportunities for formative assessment, particularly after the administration of the two-tier tests. The Pre-Laboratory Reports, (marked during the laboratory session for which they were a pre-requisite) gave an indication of achievement and effort as well as an opportunity for student questions or requests. The written responses to the laboratory tasks revealed aspects of current understandings and difficulties. The Post-Laboratory Reviews gave weekly opportunities for insights into each student's view of her/his learning. Each student's review was photo-copied and filed for further study. The End-of-semester Questionnaire gave a comprehensive and anonymous opportunity for students to describe and evaluate the factors which affected their learning. Additionally, an extended interview with a student volunteer during the post-examination period gave opportunities for a close examination of an individual's experiences of learning during the unit. These student responses gave opportunities for triangulation of data (Merriam, 1988; Patton, 1987). To these research tools were added the informal signs and signals

Figure 1.1: Research tools for Research Question Two

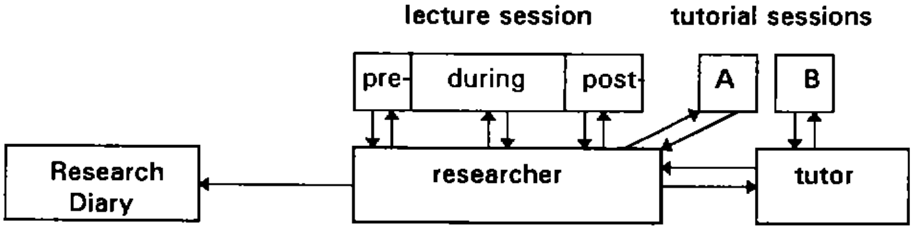
A. Concept Learning Test Sequence for each concept-cluster:



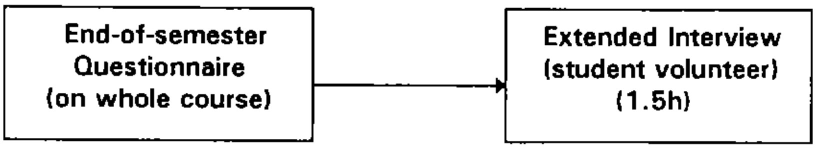
B. Laboratory-oriented activity for each unit in *Introducing Chemistry*:



C. Interactions during classroom teaching/learning



D. Post-examination research tools:



which arose during lectures, tutorials and laboratory sessions. Noteworthy comments or incidents coming to attention of the researcher, a tutor or the two laboratory demonstrators were noted in the Research Diary. After the conclusion of the unit, the data generated were collated and analysed as described in Chapter 4.

1.5 The significance of the research

Research Questions One and Two imply that the significance of this research is to be found in

- the progress and extent of learning of chemical concepts, as monitored by the Concept-Learning Test Sequences and
- an examination of the effectiveness of the pedagogy and teaching/learning materials, as revealed, quantitatively, in the results of the above tests and, qualitatively, in Post-Laboratory Reviews and student evaluations and an interview conducted after the unit.

In respect of Research Question One, The Concept-Learning Test Sequences were significant research tools. Concept-learning could be sampled over the whole semester, ultimately giving indications of the learner's readiness for undergraduate study. Such sequences of concept-testing appear to be rare, if not unique in the research literature.

In respect of Research Question Two, it was expected that significant influences upon the outcomes of student learning would be the features of *Introducing Chemistry* (and of the corresponding approaches to teaching) as outlined in Section 3. This meant that in studying the various evaluations by students and staff, the researcher would be seeking to discover the influences upon learning of the following aspects of the unit: constructivistic approaches, laboratory-centred learning and its integration with theory, the pre-laboratory reports, the post-laboratory reviews, historical treatments, practical problem-solving at the bench, and micro-scale laboratory techniques. Evidence would also be sought in the results of the test sequences.

The data, *in toto,* would be significant in offering solutions to the Research Problem of this thesis, *viz.,* providing assessments of the effectiveness of the bridging unit's design, presentation and evaluation methods in meeting the needs both of the students and of the University of South Australia.

1.6 Limitations of the research

Perhaps the most important limitation of the research was the small sample. There were 35 students at the first meeting of the class but only 21students completed the unit.

The maximum sample for all the tests was thus limited to 21. Of these, only 12 contributed input to the voluntary End-of-semester Questionnaire. Despite several invitations to the class, only one student volunteered to take part in an interview. Accordingly, any generalisations made by the researcher on the basis of the class data must be quite tentative. Clearly the "drop-out" rate was large (but not unusual) and perhaps, if time had been available, a useful research study of the students who withdrew from the unit could possibly have been made.

The Concept-Learning Test Sequences were rarely uniform in their degrees of difficulty, either within a sequence or in comparison with each other. This was partly due to the intrinsic difficulties of each concept cluster and partly because of the lack of suitable distractors for the Two-tier Multiple-choice items. Further, students' understandings of some concept clusters were more intensively tested than others, because some chemical topics were more suited than others to the development of appropriate two-tier multiple-choice diagnostic items. Accordingly, students were tested on some concepts only once by such items whereas on other concepts they were tested as many as four times.

Apart from the unit on problem-solving at the bench, it was not easily possible to systematically monitor the students' attempts at their laboratory thinking tasks, largely because of staff commitments in other tasks. This meant that the Post-laboratory Reviews were the most systematic means of monitoring the students' learning in the laboratory and what they thought about it.

1.7 Summary of this thesis

This chapter has given an overview of the research which concerns this thesis. The chapters which follow are more detailed. Chapter 2 reviews additional relevant literature. Chapter 3 outlines the Teaching Program, especially as it relates to *Introducing Chemistry*. The methodology used in the present research is detailed and evaluated in Chapter 4. The data obtained from the Concept-Learning Test Sequences are presented and analysed in in two chapters - Chapter 5 gives a class perspective, Chapter 6 provides the perspective of individual student's results. A Case Study of the learning of an individual student, BR, is presented in Chapter 7. Chapter 8 records the students' evaluation both of the course and of their own learning. Finally, Chapter 9 responds to each research question and provides an evaluation of the program. It concludes with a summary, reflections, and recommendations.

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Chapter 2

Contributions from the Literature

Overview

An introduction to representative examples of the literature relevant to this thesis has already been presented in Chapter 1, Sections 1.1 and 1.2. Accordingly, this present chapter on contributions to the literature is briefer than normally might be the case. Additional literature is discussed during consideration of the relevant aspects of the results pertaining to the learning of particular chemistry concepts.

As indicated in Chapter 1, there is a paucity of published research literature on bridging courses conducted outside Australia, most available reports being provided only as conference proceedings. Other Australian contributions in this field, but not mentioned in Chapter 1, are the papers by Taylor, Malone and Treagust (1989), Fraser, Malone and Taylor (1991).

In the much wider field of science education, however, there has been considerable output in research and publication. Over the last ten years some of the significant books or major handbooks of general relevance to this thesis include those of Fensham (1988), Fraser and Tobin (1997), Fraser and Walberg (1995), Gabel (1994) and Glynn and Duit (1995a). Particular chapters from these larger works are relevant to three principal areas of interest to this thesis: meaningful learning, constructivist approaches to teaching/learning, and evaluation. A discussion of the literature relevant to these areas, including chapters from the above major works, is presented in the sections below.

2.1 Meaningful learning

Goal 1 of the Mission Statement of the University of South Australia (within which the bridging course under study was taught) is "to provide quality teaching which facilitates independent learning". In relation to quality teaching, Fensham (1989b) states that

> Quality Teaching is what leads to Quality Learning and Quality Learning is indicated by the amount of Knowledge about a topic that is retained and by its Power, that is, the extent to which its bits can be inter-related and drawn on to solve a wide range of types of problems. This meaning for Quality Learning relates closely to what Ausubel (1968) called *meaningful* learning and what Ormel (1979) and White (1988) call *understanding*. It is the combination of knowledge retained and its accessibility for use in various ways that is the indication of quality. A lot of retained knowledge that is unassociated and

> cannot be put to use in novel problems is indicative of a lot of learning but not of *quality learning* in my meaning. (p. 5)

That the nature of understanding (or quality learning, or meaningful learning) is both complex and important is evident from the fact that White and Gunstone (1992) devote their entire first chapter to the topic. Indeed, the literature, not surprisingly, continues to verify the importance of the nature of understanding as a field for research and practice, with the publication of related books such as that by Glynn, Yeaney and Britton (1991); book chapters such as those by Glynn and Duit (1995b), Kracjik (1991) and Lawson (1994); and papers by Carr (1984), Duschl and Gitomer (1991), Eylon and Linn (1988), Skemp (1976), Nickerson (1985) and Prawat (1989). Heffernan (1980) contributed a thesis.

2.2 Constructivist approaches to teaching and learning

In Chapter 1, a quotation from Dawson (1994) indicated that a constructivist approach to teaching and learning embraces two important characteristics, namely, placing importance upon students' prior knowledge, and recognising that, in the learning process, learners construct their own understandings by integrating new knowledge into existing understandings. Thus, for those who adopt a constructivist approach, research into students' prior knowledge has become a *sine qua non* for successful teaching and learning. As Wittrock (1994) has written:

> These student conceptions represent a fundamental component of the model of generative [essentially constructivist] science teaching. They represent the knowledge base for the building of relations between the concepts to be learned and experience summarized in alternative frameworks. The generation of meaningful, scientific conceptions involves these often unscientific conceptions. The identification of these conceptions implies an advance in the design of science teaching for all students. No longer can science teaching focus only on presenting the scientists' views of physical events, or on covering the subject matter of science. Science teaching also involves understanding the students' views of science concepts. (p. 32)

Accordingly, a significant proportion of science research over the last 25 years has been concerned with investigating students' prior knowledge (also known as alternative conceptions, alternative frameworks and, less commonly, misconceptions). Initially fostered by Ausubel (1968) and amplified by Novak (1981), this fundamental aspect of constructivism has, in recent times been enriched by books by Driver, Guesne and Tiberghien (1985), Driver et al. (1994), Osborne and Freyberg (1985), and extensive bibliographies for subject disciplines by Pfundt and Duit (1994). In a book chapter, Wandersee, Mintzes and Novak (1994) provided an introduction to the literature of alternative conceptions in science with a selective overview thereof. Papers in this field which are relevant to the present research include those by Cros, Maurin, Amouroux, Chastrette, Leber and Fayol (1986), Garnett and Treagust (1992a and 1992b), Garnett, Garnett and Hackling (1995), Mitchell and Gunstone (1984), Nakhleh (1992), Peterson, Treagust and Garnett (1989) and Treagust (1988).

With a wider and growing knowledge base of alternative conceptions, science education research could now be regarded as "theory driven" (Novak, 1988) instead of "method driven", as pertained during the previous 50 years. Many researchers proposed and have investigated constructivist approaches to teaching and learning. This work has generated a number of significant books, such as Baird and Mitchell (1987), Baird and Northfield (1992), Dawson (1991), Driver (1988), Fensham (1988), Fensham, Gunstone and White (1994), Grant, Johnson and Sanders (1990), Hand and Prain (1995), Tobin (1993) and Treagust, Duit and Fraser (1996). Relevant and significant chapters of books include those of Duit and Treagust (1995), Fensham (1994), Glynn and Duit (1995b), Gunstone (1995), Hofstein (1988), Krajcik (1991), Novak (1995), Novak and Wandersee (1990, a complete journal issue), Scott, Asoko, Driver and Emberton (1992), Thiele (1995), Tobin, Tippins and Gallard (1994) and Treagust (1995). A selection of papers generated with similar objectives includes those by Ben-Zvi, Eylon and Silberstein (1987), Bodner (1986), Boylan (1989), Bucat et al. (1995), Francis and Hill (1990), Garnett, Garnett and Treagust (1990), Herron (1984), Hill and Francis (1990), Laverty and McGarvey (1991), Nakhleh (1994), Novak (1984), Rowell, Dawson and Lyndon (1990), Tasker, Chia, Bucat and Sleet (1996) and Watts and Bentley (1987).

Clearly, such a wealth of research findings and thinking about constructivism has produced the opportunity, even a mandate, for substantial changes in classroom approaches to teaching and learning. Such changes are not only markedly different from the transmission methods of the past, but also involve a comprehensive re-examination of the whole gamut of educational activity. Accordingly, the findings in the above literature place the learner and the constructive learning process as central, they change the role of the teacher to that of facilitator/enabler, and challenge the learner to view meaningful learning as her/his own responsibility. The literature shows that the adoption of a constructivist approach requires a re-examination and modification of teacher education, of curricula, of content, of the formulation of textbooks and of diagnostic and assessment methods. Not least in a constructivist re-orientation is a need for innovative teachers to use and develop a range of pedagogic ploys that seek out the nature and sources of alternative conceptions and the means to modify them, to encourage metacognition and to acknowledge and stimulate social interaction as a medium for constructivistic learning. The literature also indicates that the constructivistic teacher will need to be ready to incorporate into his/her professional skill bank the results of research studies on topics as diverse as learning probes, learning cycles, the use of analogies, the role of visualisation, the diagnostic and remedial use of concept mapping, new roles for the laboratory, learning through practical problem-solving, making molecular models, insightful approaches to scientific literacy, role playing, interaction with word-processors, and the pedagogic applications of learning diaries. The research clearly implies that learning and teaching in a constructivist classroom can, and must be, diverse, absorbing, challenging and rewarding.

2.3 Evaluation

In the pursuit of quality learning, the processes of teaching and learning need to be intimately connected to the processes of assessment and evaluation. This principle has been emphasised by Linn (1989):

> [T]he design of tests useful for the instructional decisions made in the classroom requires an integration of testing and instruction. It also requires a clear conception of the curriculum, the goals, and the process of instruction. And it requires a theory of instruction and learning and a much better understanding of the cognitive processes of learners. (p. 6)

With the same sympathies, but from a slightly different perspective, White and Gunstone (1992), in the general pursuit of understanding, "advocate the use of diverse probes [tests] of understanding as an effective means of promoting high quality learning" (p. vii) because "the validity of assessment of understanding increases with the range of appropriate probes that is used" (p. 187). Their book devotes a chapter each to ten classes of such probes. Black (1993), in a context of teaching and learning in science, subscribes to the views of White and Gunstone (1992), in that he considers that a range of probes is more likely to correctly diagnose the learning needs of the students. Black (1997) provides a review, mainly of formative assessment. Wiliam and Black (1996) show that formative assessment methods can be drawn upon for summative purposes, the difference between these two functions being in the way the data is interpreted and not in the nature or mode of collection of the data. Useful general reviews of assessment have been published by Ebel and Frisbie (1991), Griffin and Nix (1991). Doran, Lawrenz and Helgeson (1994) have reviewed the research literature on assessment in science education. Treagust, Duit and Fraser (1996) provide reports of many methods of detailed diagnosis of alternative conceptions in science education.

The literature thus indicates unequivocally that, from the constructivist perspective, the pursuit of quality learning needs assessment methods which go well beyond the traditional tests of recall, characteristic of transmission methods of teaching. Since, as White and Gunstone (1992) have it, understanding is both "an elusive quarry" (p. *vii*) and a continuum (p. 6), its pursuit demands alternative procedures suited to formative assessment and to the acknowledged existence of a number of different forms of knowledge or information. These forms of knowledge include beliefs (propositions), episodes, mental images, intellectual skills, motor skills as well as cognitive strategies - broad, generic thinking and learning skills. The literature describes an array of suitable performance tasks which include concept-mapping, Predict-Observe-Explain tasks, solving genuine problems, making relational diagrams, making drawings, interviews about instances/events or about concepts, word association, and question-production. The literature also supports portfolio production, which "involves structured sampling of a students's work from, for example, a whole year's problems in different areas of science content" (Fraser and Walberg, 1995, p. 65). There is also support for qualitative questions about scientific phenomena, as exemplified by Treagust's (1988) two-tier multiple-choice items in which the first tier of choices tests factual knowledge and the second tier examines the reasoning behind the choice.

In pursuing quality learning in the conduct of the present research, assessment probes and tests were used with both formative and summative functions. In particular, the Two-tier Multiple-choice items, segments of the Concept-learning Test Sequences, were devised with a diagnostic function in the manner of Treagust (1988) and Peterson, Treagust and Garnett (1989) while accessing reference sources of alternative conceptions such as Garnett, Garnett and Hackling (1995), *inter alia*. Relevant and useful general approaches to the development of single tier multiple-choice items are discussed by Ebel and Frisbie (1991), Isaacs (1994) and Wesman (1971).

In relation to research methodology for the present work, triangulation of data was sought (Merriam, 1988; Patton, 1987). Evaluation of the research methodology was conducted by reference to the criteria of Guba and Lincoln (1989) together with an interpretation of the authenticity criteria of those authors by Taylor (1996).

2.4 Summary

The chapter begins by showing that, in contrast to the literature on bridging courses, the last decade in particular has seen a considerable output of books, book-chapters and papers based on research in science education. In particular, this output has occurred in the fields of alternative conceptions and constructivist approaches to teaching and learning. Section 2.1 briefly reports current views on the nature of meaningful learning and indicates a representative selection of publications concerning research and thinking in this field. Section 2.2 initially establishes the importance of ascertaining students' prior conceptions in developing a constructivist approach to learning and teaching and refers to relevant significant contributions to the research literature. Subsequently the Section indicates that science education research, now "theory driven", has generated a large body of literature relating to constructivist approaches to teaching and learning. A representative listing of this literature is presented. Section 2.2 also discusses the diverse range of pedagogic ploys and skills investigated and reported for use in the constructivist classroom and laboratory. Section 2.3 concludes the chapter by considering the intimate connection between constructivist approaches to learning/teaching and the methods of its evaluation. Accordingly, it describes the range of available methods of assessment and indicates the literature which reports and describes these methods. The Section concludes with a referenced description of the approaches to evaluation which have been used in the present research.

****

Chapter Three

The Teaching Programme

3.1 Introduction

As shown in Chapter One, educational materials were developed during Phase 2 of this research for the pursuit of 'quality learning' (Fensham, 1989) of chemical concepts and the monitoring of such learning with a range of tests and questionnaires. The array of such materials which were available at the commencement of Semester Two of 1996 is presented as Resource A in Figure 3.1. The Information Sheets listed therein provided an overview of the set texts, contact hours, the teaching programme and assessment, as shown in Figure 3.2. They also provided a statement on the University's policy on academic misconduct. Attached to the Information Sheets was a listing of useful reference material which was available in the Library, presented here as Figure 3.3. (The listing of problems on specific topics (Section G) is not presented here). The weekly contact-time commitment of six hours was programmed as shown in Figure 3.1 (as Resource B). Staff allocated to the presentation of the course are also listed in Figure 3.1 (as Resource C). Their various tasks centred around *Introducing Chemistry*. Likewise, enrolling students were advised that possession of a copy of this book was essential, as it played a central role in the presentation and development of the course.

3.2 The central role of *Introducing Chemistry*

In Chapter One, Sections 1.3.1 and 1.3.2 have described the educational rationale behind the writing of the first and second editions of *Introducing Chemistry*. For the second edition, the characteristic educational features which were intended to contribute to quality learning during the course could be summarised as

- an emphasis upon constructivist learning and teaching
- integration of laboratory experience with theoretical studies
- a compulsory pre-laboratory report
- the development of chemical concepts, *ab initio,* through an historical approach in much of the pre-laboratory reading
- thinking tasks set in both the pre-laboratory reports and the laboratory activities
- post-laboratory review sheets to be completed before leaving the laboratory.
- the use of micro-scale chemistry techniques
- a high "signal-to-noise" ratio in design, layout and word usage.

Resource A: Materials for teaching and learning

- *Introducing Chemistry (second edition)*
- *Meeting Chemistry*
- sets of tests and questionaires (including or incorporating the Pre-instruction Questionnaire, Two-tier Multiple-choice items, the Post-Instruction Test Questions Parts A and B, the End-of semester Questionnaire)
- sets of tutorial questions and problems for each teaching week, with Tutor's Guides
- The film *The States of Matter* and the video *The Chemistry of Pure Substances. I. Ionic and Covalent Bonding*
- Information Sheets for enrollees

Resource B: Time - Programme of weekly contact (six hours)

Wednesday	9am - 10am:	lecture/class meeting
Thursday	9am - ~10.30am:	lecture/class meeting
Thursday	~10.30am - 1.00pm:	laboratory work
Thursday	2pm - 3pm:	tutorial (Group A)
Friday	9am - 10am:	tutorial (Group B)

Tutorial groups A and B each comprised about half of the whole class.

Resource C: Staff of the School of Chemical Technology

- Glen Chittleborough (coordinator; all lecture/class meetings; tutor, Group A; supervisor of laboratory work),
- Arthur Davies (tutor, Group B)
- Brian Wing (laboratory technician; health and safety officer)
- Jun Mu (marker/demonstrator)
- Shiaw Hui (marker/demonstrator).

Figure 3.1: Some resources for teaching and learning in 04143 Introductory Chemistry

In this context, editing the content and layout of the 287-page first edition of *Introducing Chemistry* led, in 1996, to a rather more spaciously presented Second Edition of 374 pages. In part, the increase in the number of pages was brought about by a general increase in the amount of blank "working space" provided for the student to enter responses, observations, results, inferences, or calculations at appropriately located places in the Pre-laboratory Reports, the laboratory activities and the Post-laboratory Reviews. As in the first edition, the range of laboratory work in each unit was more extensive than might have been required for a group with a relatively uniform background. (This is especially evident in Unit 4 - *Acids, Bases and Salts*, which is presented in its entirety in Appendix 3.1 as a typical example of the approach and format). This provision enabled the writer to ensure that those with little practical chemical knowledge were able to experience and consolidate the basic and essential

School of Chemical Technology - University of South Australia
Applied Science and Engineering Bridging Program
Unit 04143 Introductory Chemistry
Semester 2, 1996

Texts

Chittleborough, G., *Introducing Chemistry.* Second Edition UniSA (1996).
Chittleborough, G., (ed.), *Meeting Chemistry.* A special edition for 04143 published by the editor (1996).

Reference

Daintith, J., (ed.), *Minidictionary of Chemistry.* OUP (1988). Note: soon to be out of print.

Reference texts:

See separate list

Proposed teaching/learning programme

This programme centres upon *Introducing Chemistry,* an essential book specially written for the course. *Meeting Chemistry* is closely linked in most cases to *Introducing Chemistry.* It adds theoretical material to the practical work and theory of *Introducing Chemistry.*

Contact hours: laboratory (2.5 hours), tutorial (1 hour), class meetings (2.5 hours). The sequencing of the practical course is as follows. Lectures relate to and expand the units in *Introducing Chemistry* as indicated.

Week no.	Monday date	Unit No.	Unit title	Notes
1	29/7	Introduction	Introduction, Microchemistry	Pre-instruction questionnaire film on Unit 1
2	5/8	1	Physical Properties and K.M. Theory	
3	12/8	2	Chemical Change Dalton and Atoms	
4	19/8	3	Bonding, Structure and Properties	Video available; modelling tute
5	26/8	4	Acids, Bases and Salts	
6	2/9	4,11	Solving problems (acids, bases, salts)	**Test** 1 - topics 1,2,3
7	9/9	5	Introducing Redox Reactions	
8	16/9	6	Introducing the Mole	
Break	23/9 30/9			
9	7/10*	7	How fast?	**Test 2** - topics 4,5,6
10	14/10	8	Metals and Compounds of Metals	
11	21/10	9	Group VII - The Halogens	
12	28/10	10	Organic Chemistry (properties)	
13	4/11	10	Organic Chemistry (syntheses)	**Test 3** - topics 8,9,10 (props)
14	11/11	(teach/study)		
15	18/11	(study)		
16	25/11	(exam week)		**Exam**; voluntary questionnaire

*Labor Day Public Holiday

Assessment

- Tests, examinations and reports will assess in particular the development of chemical concepts through **both the practical and theoretical** aspects of the course.

- **Assessment Weighting**

end-of-semester exam (no more than 2.5 hours)	**90 marks**
three short tests during semester (each 10 marks)	**30 marks**
eleven completed units (each 5 marks) **(prelab 3marks, lab record 1 mark, postlab 1mark)**	**55 marks**
Total =	**175 marks** (scaled to 100%)

- **Pre-laboratory reports:** A carefully completed pre-laboratory report is a **prerequisite for entry to the laboratory.**

- **Laboratory records or reports** will be marked on the basis of care, thoroughness, effort and achievement **during the laboratory session.**

- **Sickness and laboratory work**
  Only after the presentation of a medical certificate for the appropriate period of time can the process of averaging marks be applied. Students are asked to leave a message about absence from laboratory work (through sickness) with the School Office (tel: 302 3072) or the coordinator (302 3723) **before** the relevant session, if possible.

Figure 3.2 Preliminary information for students in the bridging program

* * *

Unit 04143 Introducing Chemistry: Reference texts and other materials

A. Dictionaries of chemistry (alternatives to the recommended volume)

Sharp, DWA, (ed.), *The Penguin Dictionary of Chemistry.* (2nd edition) 1990.

Scott, WAH, (ed.), Gem *Basic Facts Chemistry* (3rd edition) Collins 1991.

B. Texts for reference only

Bucat, RB, (ed.), *Elements of Chemistry, Volumes 1&2.* Australian Academy of Science 1983.

Chang, R, *General Chemistry.* Random House 1986.

Corwin, CH, *Concepts and Chemistry Connections.* Prentice Hall 1994.

Critchlow, P, *Mastering Chemistry.* Macmillan (1982). (Also published as *Basic Chemistry*).

Daub, GW & Seese, WS, *Basic Chemistry* (6th edition). Prentice Hall. 1992.

Malone, LJ, *Basic Concepts of Chemistry* (4th edition). JWiley 1994.

Stoker, HS, *Introduction to Chemical Principles* (4th edition). MacMillan 1993.

C. Worked problems and problems with answers

Nyman, CJ, King, GB and Weyh, JA, *Problems for General Chemistry and Qualitative Analysis* (4th edition) Wiley 1980.

Schaum, D, *Schaum's Outline of Theory and Problems of College Chemistry (5th edition)* Schaum Publishing Company 1966.

Smith, RN & Pierce,WC, *Solving General Chemistry Problems. (5th edition)* WHFreeman 1980

See also problems in the relevant chapters in texts in Section B above.

D. Video

Hicks, P, Chemistry of Pure Substances 1. *Ionic and Covalent Bonding.* Classroom Video 1991. (27 min).

E. Chemical arithmetic (exponential numbers, logarithms, proportional reasoning)

(See the relevant chapters or appendices of ***Schaum, Smith & Pierce or Nyman et al*** *(see Section C above).* ***Unit 7*** *of Introducing Chemistry discusses proportionality at some length).*

Logarithms are used only briefly (in Unit 7, How fast?).

Depending upon need, a special handout may be produced.

It may be helpful to talk to academic staff in the School of Mathematics if particular problems arise.

F. Chemical Data

The two-sided **Periodic Table** to be provided (produced by **EH Sargent & Co.**, 1962), has most of the quantitative data likely to be of interest to students in the Bridging Program. A simplified credit-card-sized Periodic Table will be available (free) from National Chemistry Week and the Royal Australian Chemical Institute.

Aylward & Findlay's ***SI Chemical Data*** *(3rd edition)* is a very useful source of extra data, if needed.

G. Problems on specific topics - density, percentage composition, formulae and equations.

* * *

Figure 3.3 Reference material for students (attached to Preliminary Information Sheet) aspects of concepts before proceeding further, but by no means to the end of the available chemical experiences. At the same time, those with more extensive experience were invited to commence their laboratory studies at a more advanced stage of development of a chemical concept, if confident. The writer expressed and emphasised a general expectation for laboratory activity: to use each session for quality, not necessarily quantity, of experience. It was nonetheless important to ensure that test or examination items incorporating aspects of laboratory experiences did not disadvantage the less experienced students.

Introducing Chemistry was published by The University of South Australia and sold at cost price as an unbound, soft-covered manual, wrapped in plastic film, its pages punched ready for use in a hard-covered two-ring folder. The volume comprised thirteen sections, each paginated independently: a two-part introduction, eleven units for study, and an appendix. The inside front and back covers were printed with Laboratory Safety Regulations and Atomic Weights respectively. Table 3.1 displays the contents of the book.

Table 3.1 The contents of ***Introducing Chemistry***

		number of pages
Laboratory safety regulations (inside front cover)		
Introduction		10
Introducing micro-scale techniques		11
Units		
1	Physical Properties and the Kinetic-Molecular Theory	39
2	Chemical Change, Dalton and Atoms	33
3	Bonding, Structure and Properties	37
4	Acids, Bases and Salts	41
5	Introducing Redox Reactions	25
6	Introducing the Mole	35
7	How Fast?	31
8	Metals and Compounds of Metals	27
9	Group VII - The Halogens	25
10	Organic Chemistry	23
11	What's your problem? The art of solution-finding	21
Appendices		12
Atomic Weights (inside back cover)		

The ten-page *Introduction* set the cognitive and attitudinal scene for the imminent student-centred approach to teaching and learning. An early section explained the origin and place of the unit 04143 Introductory Chemistry within The University of South Australia and stated that the book achieved three important goals:

- the introduction of micro-scale practical chemistry
- linkage between practical and theory
- student-centred learning.

A subsequent section pointed out that the intended student-centred learning was directed towards the (university's) goal of quality learning. Quality learning and teaching was discussed at some length - in the context of constructivism and the responsibility of the student for her/his own learning. Thus in this section

- quality learning and teaching were defined in terms of what they meant to Fensham (1989b), Ausubel (1968), Ormel (1979) and White (1988).
- constructivist and transmission models of teaching and learning were described and contrasted (as by Dawson, 1994), pointing out that quality (constructivistic) learning involves active participation in the processing of new knowledge. The construction of summaries, flow charts, concept maps and active participation in focussed small group discussions would help.
- a figure representing the model of Krajcik (1991) for conceptual change was presented and discussed, particularly in reference to discrepant events.
- indicators of different levels or quality of student learning (Heffernan, 1980) were tabled.
- metacognition was described and encouraged.
- a table of 14 contrasting student beliefs about teaching and learning (those of the passive learner and the metacognitive learner: Mitchell, 1992) was presented together with
- a list of 25 constructive learning behaviours (Mitchell, 1992).

The task ahead was to use these ideas for teaching/learning as effectively as possible.

The *Introduction* went on to show that the research of Johnstone, Sleet and Vianna (1994) had revealed that, in a laboratory context, significantly improved learning had occurred with the introduction of

- sessions devoted to the development of manipulative skills
- compulsory pre-laboratory exercises

  practical problem-solving related to newly acquired knowledge and concepts
- improved "signal-to-noise ratios" (fewer words, clearer instructions) in the language and layout of the laboratory manual.

This led the author to make an extended statement of guidance for students about the design, layout and effective use of *Introducing Chemistry*. It also gives the reader of this thesis an overview of the nature of the book. Figure 3.4 presents that statement.

...you will therefore find:

- an **introduction to microscale laboratory techniques** later in this section. The first laboratory session of the semester will provide opportunities for practising these techniques. (You can prepare for this by reading the section 'Introducing Microscale Techniques' in advance).
- That each of the eleven ... units has the same general **format**.
    - ♦ **Section A** which contains **pre-laboratory reading** (often linked to *Meeting Chemistry*) and thinking tasks, both of which relate to Section B, the practical work to be done.
    - ♦ **Pre-lab report sheets** forming part of Section A and printed on [pale green] coloured paper.
      These sheets must be completed before the laboratory session starts and are to be presented as you enter the laboratory.
      Please note:
      Because Section A has been prepared to assist your understandings and approaches to the practical work, *you will not be admitted to the laboratory unless you present a properly completed pre-laboratory report before the commencement of the laboratory session.*
    - ♦ **Section B**, the laboratory activities proper, the manuscript of which has a layout designed for clarity of instruction and purpose.
      Forming part of Section B is a separate sheet (printed on [yellow] coloured paper) for you to record your reflections upon your own learning during the laboratory activities of Section B.
- **Thinking tasks** incorporated into the pre-lab report and the laboratory work itself. These tasks are intended to improve the quality of your learning by clarifying concepts, doing calculations or making links to earlier concepts or practical observations.
- **Practical problem-solving at the bench**
  Unit 11 centres on practical problems. Some of the other units have bench problems 'built in'. If you have mastered the appropriate concepts, practical problem-solving should be an enjoyable experience. Many students have found this to be so.

Many of the microscale practical techniques and activities in this volume were developed on South Australian secondary schools some years ago as **small scale** practical chemistry. I pay tribute my colleagues and my reliance upon our publications (Eberhard et al. 1965-74) in this present volume.

To use this volume with maximum effect upon the quality of your learning, you will need to begin your reading and study of Section A of a particular unit well in advance, say a week at least. Sometimes the contents of Section A are not available in *Meeting Chemistry*, sometimes there is a close and detailed usage. In any case you will usually find a challenge to be met in this section - my recommendation is - **always start your preparation early!**

Figure 3.4: Extract from *Introducing Chemistry*: *Introduction* (p. 12)

As the *Introduction* indicated, successful use of the book for quality learning depended partly upon the teaching staff, partly upon the content of the book itself and partly, and importantly, upon the students. The task ahead was to achieve a successful amalgamation of these three in pursuing the objectives and methods outlined and explained in this Introduction.

The section *Introducing Micro-scale Chemistry Techniques* used 11 pages to outline and illustrate elementary micro-scale techniques and to provide exercises for practising and acquiring them. Techniques included

- handling solids with a micro-scale spatula
- handling liquids, using teat pipettes or a plastic squeeze bottle,
- shaking and/or stirring solid/liquid mixtures
- heating liquids (in a test tube, in a beaker or flask, on a microscope slide or on a watchglass)
- handling gases (pipetting gases; gas collection by displacement of air or water)
- glass working - to cut and fire-polish glass tubing; to make a glass stirring rod; to make a "blown" test tube; to make a teat pipette; to make a micropycnometer for use in the next practical session;
- cleaning and drying micro-scale glassware.

After acceptable development of these (largely) motor skills, students would be more able to concentrate upon aspects of the laboratory sessions which related to the understanding of chemical concepts.

3.3 *Meeting Chemistry*

The evolution of *Meeting Chemistry* as a complementary reference-text for the bridging course began many years earlier than the creation of *Introducing Chemistry*. The Innovative Teaching and Learning grant of $7,500 which led to the writing of *Introducing Chemistry* arose from an application for $20,000 to prepare, among other things, *two* books for the Bridging Chemistry course - *Introducing Chemistry* and *Introducing Practical Chemistry*, a student-learning resource book and a laboratory manual respectively. The lesser amount of available money funded the production of only one book. It seemed best therefore to produce a single book which integrated chemical theory and practical work. This meant that some of the theory and descriptive or "systematic" chemistry could only be developed or presented with the aid of additional existing written material. In the absence of a book in print which could satisfactorily complement the content of the new book as envisaged, it was decided to consider the accessible but out-of-print *Chemistry Study Book - Leaving* (Eberhard, Eyers, Chittleborough, Morley, Schodde, Sanderson, and Blanksby, 1973). This 234-page work had been written through five editions for the (one-year) Leaving (later, Year 11) chemistry syllabuses of the then Public Examinations Board of South Australia (subsequently to become the Senior Secondary Assessment Board of South Australia). *Chemistry Study Book - Leaving* had itself been produced to complement *Small Scale Practical Chemistry for Schools - Senior Book I*, written and published by four of the above writers (Eberhard, Eyers Chittleborough and Morley, 1965-1974), through a number of editions for the same chemistry courses. Although constructivism was not then known as such to the authors, some of its spirit was in evidence, as a statement in the preface to the fourth edition (1969) indicates:

> The authors have not aimed specifically at writing either a text or a set of notes, rather at something between these extremes. Blank pages have been included to allow a student to be active in lessons and in private study, thus compiling a useful record of the year's work. This activity is encouraged by incorporating exercises and practical work in to the development of the text. (p. 2)

Such an orientation and characteristics encouraged further consideration of *Chemistry Study Book - Leaving* as a complementary volume. It also contained a section of twelve chapters of physical and theoretical chemistry in which fundamental chemical concepts were well-developed, if at times pithily, and at the approximate cognitive level to which the bridging course would aspire. Furthermore, there were twelve other chapters devoted to inorganic and organic chemistry, and from which a smaller number could be selected to provide examples of descriptive and systematic chemistry for the bridging course. Each chapter had a succinct end-of-chapter summary and a number of relevant exercises. It became clear that, with relatively little editing, *Chemistry Study Book - Leaving* could be used as a complementary book. Accordingly, once *Introducing Chemistry* had been written and its purview established, minor changes to the body of the text of *Chemistry Study Book - Leaving* were made, the appendices were supplemented and rearranged and the name changed to *Meeting Chemistry*, which suggested a complementary character to *Introducing Chemistry*. The knowledge that such a book was to be available was invaluable in the writing of *Introducing Chemistry*. It meant that due attention could be given in it to an historical and gradual development of chemical concepts. Indeed the first three units of *Introducing Chemistry* were written without reference to, or need for, *Meeting Chemistry*. However, in the fourth unit, Acids, Bases and Salts, there began a steady, useful and continuing complementarity.

Meeting Chemistry was printed by the university and published by the present writer, with copyright reserved for the original authors. It was made available to students as a reference-text at a price based solely on costs.

3.4 Implementing the teaching programme

The implementation of the teaching programme can best be considered by describing the "scene-setting" first week in some detail, then showing how subsequent weeks fitted into a more typical general routine.

3.4.1 The first week

The first week of the course was, as in many other courses, not typical of the remainder. Undoubtedly it was important in orienting and introducing students to each other and to the teaching and laboratory staff, to routines, to expectations and standards, to new ideas and, for many, to new approaches to learning and teaching.

The very first session of the week (Wednesday) was largely based upon an explanation and discussion of the contents of the preliminary information sheets (presented here as Figure 3.1). The centrality of *Introducing Chemistry* was emphasised. The beginnings of a weekly routine were made by giving the class the task of reading and studying the two introductory sections and a part of Section B of Unit 1 of *Introducing Chemistry* before the next day's four hours of contact. (The teaching in subsequent weeks would commence on the assumption that preliminary reading for the programmed Unit of *Introducing Chemistry* had been completed by each student). Pre-instruction Questionnaires were administered.

In general, the Thursday morning blocks of four hours of contact had three parts - an initial lecture/class meeting (of at least one hour) in which mainly theory was to be discussed, a concluding laboratory session of at least 2.5 hours together with a preceding period of discussion of those laboratory activities and their relation to the theory. On the first Thursday, however, the initial emphasis and discussion in the class meeting was upon the content of the Introduction to *Introducing Chemistry,* that is, upon the nature of quality learning/teaching and the role of constructivism in achieving quality learning. Then, in order to emphasise the importance of discussion with others in constructive approaches to learning, an informal "meet-a-buddy" session was held - each student was asked to discover, by questioning within a limited time, as many things as possible about the person seated next to her/him. An informal census of the amount of learned data for each person led to a discussion about the importance and role of asking questions, particularly "quality" questions, in the pursuit of quality learning. To encourage questioning, particularly by the shy or diffident, it was announced that a question box would be placed near the entrance to the lecture and tutorial rooms to receive written questions either before or after the sessions. Further, the course coordinator would be available in the teaching room for questions for 15-20 minutes prior to each class meeting. (This was particularly desirable from the students' viewpoint because the lecturer had teaching duties on another campus of the university for the equivalent of half of each week). The asking of questions during formal presentations ("lectures") and in tutorials would also be encouraged. In the same vein, it was pointed out that each Pre-laboratory Report had a cover sheet which gave an opportunity for raising questions about difficulties met during preparation for the forthcoming week's work.

The initial Thursday session continued with the showing of the film *The States of Matter* (17 minutes). This film served as an introduction, not only to the following week's study of Unit 1 - *Physical Properties and the Kinetic Molecular Theory*, but also to the general notion of a Pre-Laboratory Report and to active learning: a significant proportion of the Pre-Laboratory Report of Unit 1 incorporated questions, the answers to which required close attention to, and understanding of, the details of the film. The film was to be shown at least once more - during the week's tutorial session, and a third opportunity was offered in the following week.

The session continued, after a short break, with a discussion of *Introducing Micro-scale Chemistry Techniques*, emphasising the careful acquisition of techniques and attention to laboratory safety. A brief adjournment enabled the class members to go to the Chemistry Laboratory, to meet their laboratory partner, to familiarise themselves with the equipment and to proceed with the development of techniques as listed in Section 3.2.

On Thursday afternoon and Friday morning, the week's tutorial (A or B respectively) provided more opportunities to discuss quality learning and "good" studentship. Then, following another viewing of the film *The States of Matter*, the students were again able to raise questions about the concepts presented. This tutorial thus set the scene for the more intensive study of Unit 1 in Week 2. Indeed, the whole of Week 1 was intended to a provide a possible generic approach to the course.

3.4.2 The programme in subsequent weeks

Teaching and learning in each subsequent week was generally focussed upon only one unit of *Introducing Chemistry*, as indicated in Figure 3.2. An exception occurred with the linking of problem-solving (Unit 11 - *What's your problem?*) with a second week of Unit 4 (*Acids, Bases and Salts*). One other exception occurred in Weeks 12 and 13 when the teaching and learning of organic chemistry (which contained a substantial amount of descriptive chemistry of the hydrocarbons, especially methane, ethene and ethyne) was divided into separate studies of properties and syntheses.

The usual approach each week was that discussion of the main concepts of the programmed unit would be introduced in the Wednesday class meeting. At the Thursday class meeting these concepts would be amplified or extended. Then, after a discussion of the unit's laboratory work, the students would move to the Laboratory where, upon entering, they would present their Pre-laboratory Report for marking by the marker/demonstrators. Submission of this Report was a prerequisite for commencing the practical work. This condition was instituted to ensure that all the appropriate theoretical studies had been made and that all students were aware of the nature and pedagogic intentions of the laboratory work. It was intended that there would be no "recipe-following". The practical activities of Part B were intended to assist in the understanding of the concepts which had been introduced in Part A of the Unit. The various thinking tasks, inserted between steps and stages of the practical instructions, were designed to do this. (The laboratory sessions were, after all, "concept/process labs", as described in Section 1.2.4). While the students were conducting their laboratory studies under the supervision of the present writer, the marker/demonstrators marked the Pre-laboratory Reports, using the criteria set by the supervisor. After conferring with him on the outcomes of their marking, the marker/demonstrators returned the marked Report to each student, together with written and verbal feedback. The marker/demonstrators then reverted to their role as laboratory tutors (conventionally known as laboratory demonstrators).

With about 20 minutes of the laboratory session remaining, the class was advised that the practical work, *per se*, should be concluded in order that they had time to complete and submit their Post-laboratory Review by the end of the session.

Throughout the semester, students were encouraged to be responsible for their own learning. Nevertheless, the laboratory work was normally done with a regular partner with whom discussion of the physical observations and the answers to thinking tasks was encouraged. Some students established study-pairs for tackling the thinking tasks in the weekly Pre-laboratory Reports (and other study tasks). These were encouraged, on the understanding that the eventual reports were the student's own work. (Marker/demonstrators were alerted to the possibility of academic dishonesty).

Formal opportunities to apply constructivist principles were provided in several tutorial activities involving group work. These included concept mapping (Week 2), molecular model-making (Week 4) and problem-solving (Week 9). The programme of tutorial topics is presented in Table 3.2.

Table 3.2 Schedule of tutorial topics

Week	Unit number & title		Main Topics
1		Introduction/Introducing micro-scale	View/discuss film; "molecule" concept; chemical literacy; glossary of terms
2	1	Physical Properties & K-M Theory	Literacy: symbols & names of elements; glossary; group concept maps on K-M Theory
3	2	Chemical Change, Dalton and Atoms	Partner's tests: symbols/density; % comp'n; chloride test; chem change concept map, p11.
4	3	Bonding, Structure and Properties	Molecular model-making: concepts of molecule, covalence, formula, chemical change, equation
5	4	Acids, Bases and Salts	Problem: 5 methods for making magnesium sulfate? precipitation; select pairs of reagents for 3 salts
6	11/4	What's your problem?/Acids, Bases, Salts	Activity series & displacement: predict salt formation; ionic equations for precipitation
7	5	Introducing Redox Reactions	Discuss test; review K-MT concept of a gas
8	6	Introducing the Mole	Review Oxidation Numbers; review mole using quantitative problems on Zn/sulfuric acid
9	7	How Fast?	Problems on Rate Law: effect on R, k of changing conc'n, temperature; relate to lab activities
10	8	Metals & Compounds of Metals	Discuss test; define metal, metallic behaviour, generalisations w.r. to atomic & macro props
11	9	Group VII - The Halogens	'chlorine water': other halogens with water, link to P/Table, redox, polarity; identify unknown halide
12	10	Organic Chemistry (Properties)	Ethene: properties via structure; reaction types ethyne: properties/structure; unique test
13	10	Organic Chemistry (Synthesis)	Discuss test; general question time.

Occasionally the class meeting was subdivided into interactive groups, as was the case when, as groups of two or three, the class studied and discussed "Chemistry in a Zip-Lok Bag" (Phenol Red solution added to solid samples of calcium chloride and sodium hydrogen carbonate in a sealed plastic lunch bag). The laboratory work of Week 6 (practical problem-solving in a context of acids, bases and salts) provided an extensive opportunity for constructivist learning. A graded practical problem-solving task (called a Challenge during the course) was allocated to each team of 2 students, paired according to their stated previous experience in chemistry. The Challenges are listed on Table 3.3. On the basis of the theory of problem-solving outlined in Unit 11 and the knowledge of acids, bases and salts gained during the study of Unit 4 in the previous week, the teams of students were expected to analyse their Challenge, collect necessary data and plan experimental procedures before the commencement of Week 6. Communication between teams with the same Challenge was not allowed. All this work was submitted as the Pre-laboratory Report for Week 6, and for which assessment marks were allocated in the usual way. Once each team's procedures were approved as safe by the marker/demonstrators (but not necessarily as likely to be successful), the team was free to proceed with their experiments to meet the Challenge during the laboratory session. Near the end of the session, each team was given an informal assessment of their results and efforts. The usual Post-laboratory Review was completed.

3.4.3 Assessment

Figure 3.1 includes statements of the number, relative weighting of marks and the programming of assessments for the course. The three short tests and the end-of-semester examination contained not only the assessment items discussed fully in Chapter Four, but also other items, usually descriptive questions, not forming part of this research (being concerned generally with topics other than the ten concept-clusters which are the focus of this study). Each of the short tests comprised two parts of about equal assessment weighting. One part comprised a group of Two-tier Multiple-choice items (which were of interest to this research as components of the Concept Learning Test Sequences). The other part contained questions, not forming part of this study, but which contributed to the broadening of the scope of the summative assessment for the part of the course which was being examined at the time. Each of these tests took about 40 minutes, except for the second-language students who, in accordance with university policy, were given an extra 10 minutes of reading time. The tests were held at the beginning of the Thursday class meeting on the dates indicated in Figure 3.1. The short tests were also used formatively, the Two-tier Multiple-choice items being discussed at the Thursday class meeting following the test, the remainder at the next tutorial.

The end-of-semester examination contained three sections, of which the first and third were of interest to this research. (The second section contained three lists of four topics. From each list, one topic was to be chosen by the examinee to demonstrate

Table 3.3 Problem-solving "Challenges" for Week 6

No.	Level[b]	Challenge
1[a]	10	You are provided with a sample of lead carbonate. Prepare a moist sample of lead iodide without any bubbles of gas being seen during the process.
2[a]	10	You are provided with a sample of lead carbonate. Prepare a moist sample of lead iodide which does not turn litmus red.
3[a]	11	A catalyst is a substance or species which speeds the rate of a reaction. What is the best catalyst for the reaction between zinc and hydrochloric acid? Possible catalysts are supplied.
4	12	The following extract from the literature shows that anthocyanins, the pigments in red cabbage, are capable of producing at least 10 different colours, provided that the pH is adjusted suitably. [*1.3 pages of extract follow*]. **The challenge** is to produce at least 10 colours from your prepared sample of red cabbage extract.
5	11	You are provided with magnesium ribbon and solutions of hydrochloric acid and tartaric acid of the same concentration. **Your challenge** is to provide experiment-based quantitative answers to the questions • As an acid, how much weaker is tartaric acid than hydrochloric acid of the same concentration? • Does this quantitative relationship hold for a range of concentrations of the two acids?
6	11	A catalyst alters the speed (rate) of a chemical change. You are provided with magnesium ribbon, dilute solutions of copper sulfate, tartaric acid and hydrochloric acid. **Your challenge** is to provide experiment-based quantitative answers to the questions • To what extent, if any, is copper sulfate a catalyst for the formation of solutions of the magnesium salts of the above acids? • Does your answer apply to a range of concentrations of the acids?
7	12	The store holds samples of a green solid labelled "basic copper carbonate". The theoretical formula of this substance is $CuCO_3.\ Cu(OH)_2$. Clearly a salt and a base are both present. When heated, the substance readily decomposes - according to the equation $CuCO_3.\ Cu(OH)_2 \rightarrow 2CuO + CO_2 + H_2O$. ...**Your challenge** is to provide experiment-based quantitative answers to the questions • Does the available sample really have this formula? • Does this formula apply to a sample of copper carbonate made by you in the laboratory by "double decomposition"?

a: source: Hadden (1991).

b: Levels 10,11 & 12 were judged to be of appropriate difficulty for those with experience at Years 10, 11 & 12 respectively.

her/his understanding of particular parts of the course). The first section of the examination contained the ten Post-instruction Questions, Parts A and B, as described in Section 1.3.2. They represented the final item in each of the Concept Learning Test Sequences for the ten concept clusters of interest in this research. The remaining section of the examination contained five Two-tier Multiple-choice items. These supplemented the sampling of concept learning already conducted in the short tests, thus contributing further to the scope of some of the Concept Learning Test Sequences.

Assessment weightings of the weekly work in each of the eleven units (Pre-laboratory Report, laboratory record and Post-laboratory Review) were allocated as indicated in Figure 3.1, but the approach and methods will not be described here because they are not within the scope of this research. However, the students' responses to this aspect of assessment will be considered in the presentation of their course evaluation in Chapter Six.

3.5 Summary

Section 3.1 introduced the reader to the teaching programme by presenting the resources which were available to pursue quality teaching and learning. Listed as Resource A in Figure 3.1, the teaching/learning materials which were available included *Introducing Chemistry, Meeting Chemistry,* a film and a range of assessment test items and questionnaires. Also listed in Figure 3.1 was the programme of weekly contact time (as Resource B) and, as Resource C, staff and their roles in the course. An Information Sheet for students and a listing of reference materials are presented as Figures 3.2 and 3.3 respectively.

The central role of *Introducing Chemistry* in the teaching programme is discussed at some length in Section 3.2. Eight educational features are listed as important aspects of this 374-page book. The contents page is presented, showing a two-part introduction, eleven units for study and an appendix. Each of the eleven units has the same general format. As a typical example of the approach and format, Unit 4 - *Acids, Bases and Salts* is presented in full as Appendix 3.1. An extended discussion of, and quotation from the Introduction demonstrates the flavour of the pedagogical approach to quality learning. The role of the acquisition of laboratory skills, as indicated in *Introducing Micro-scale Techniques*, is one of support for quality learning.

Section 3.3 discusses the evolution of the role of *Meeting Chemistry* as complementary to *Introducing Chemistry*.

Section 3.4 is concerned with the implementation of the teaching programme. In Section 3.4.1,6 a number of aspects of the first week of the course are shown to be "scene-setting" for the rest of the course. Section 3.4.2 describes how the programme usually focussed upon the teaching and learning of one unit per week and how this focus was put into practice. A schedule of tutorial topics is presented as Table 3.2. The section discusses various opportunities for group work as aspects of constructivistic learning. The laboratory work of Week 6 (practical problem-solving in a context of acids, bases and salts) is shown as providing an extensive opportunity for constructivist learning. The problems ("challenges") are listed on Table 3.3. Section 3.4.3 concludes the discussion with a review of the approach to, and content of, the assessment programme.

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Chapter Four

Research Methodology

4.1 Introduction

The Innovative Teaching and Learning Grant described in Chapter 1 led to the Research Problem which is the subject of this thesis: *How can a bridging unit in chemistry be designed, presented and evaluated in order to meet the needs both of the students and of the university?* To address this problem, two Research Questions guided the study:

- **Research Question One:** *To what extent did the students develop an understanding of the chemical concepts in the unit?*
- **Research Question Two:** *What aspects of the unit contributed to student learning?*

The methodology used to answer these questions is described in this chapter. Previously in Chapter 1, Section 1.4 outlined the range of research instruments used in the pursuit of answers to these Research Questions. These instruments and their use are discussed in greater detail in Section 4.4.

4.2 Research Methodology and the need for a bridging course

The need for a bridging program at the University of South Australia sprang from the University's Mission Statement, which included a commitment to student access and equity. Subsequently in 1995, the Faculty of Applied Science and Technology developed a Quality Improvement Strategy, Goal 5 of which was "to promote access and equity in applied science and technology courses and ensure that teaching and research programs identify, respond to and support the needs of all our students" (p. 4). The Applied Science and Engineering Bridging Program (which includes the course 04143 Introductory Chemistry) pursued such a goal. Its statement of aim in the *Handbook of the University of South Australia* (1995) makes this clear.

> The course [program] offers an alternative method of entry for people who do not meet standard admission requirements. It prepares students for entry to undergraduate applied science and engineering courses offered at The Levels campus of the University of South Australia and undergraduate engineering courses offered at The Flinders University of South Australia, through the Joint Faculty of Engineering. It should be noted that applicants who satisfy standard entry requirements for the University's degree courses will not normally be admitted to this program. The course also provides an avenue for women who wish to enter non-traditional areas, Aboriginal and Torres Strait Islanders and those who have experienced educational disadvantage. (p. 90)

In a subsequent note on entrance to university courses, the Handbook adds the warning, "for high demand courses such as Computer Systems Engineering and Electronic Engineering, only students with credit grade average or better are guaranteed entry".

4.3 The Research Population

The enrolments for the Bridging Program included students from a very wide range of backgrounds: some with little experience of science; some of mature age; migrants or students from other countries for whom English was a second language; some with very high motivation to enter a particular undergraduate course; women looking for a new career after raising a family at home; mature-age men intending to improve their employment prospects with tertiary qualifications; and younger people who had personal difficulties in completing recent Matriculation examinations. The sponsoring faculties also used courses within the Bridging Program for remedial purposes - undergraduate students who performed inadequately in the first semester of the academic year were required to satisfactorily complete designated bridging courses (offered in the second semester) before being allowed to continue as undergraduates in the following year.

Such a diversity of students meant that there were challenges, not only in designing, presenting and evaluating a bridging unit in chemistry which met both student and university needs, but also in developing a research methodology for evaluating student learning outcomes in such a context.

Of the 35 students who enrolled in the course Introductory Chemistry, 21 completed it. These 21 students were the research population for almost all of the studies which constitute this research. The voluntary anonymous End-of-semester Questionnaire on the whole course was attempted by 12 of these students. Later, one student volunteered to take part in an extended interview after the final results for the course were published. Background information concerning each student is presented on Table 4.1. Much of this information was obtained from Part A of the Pre-Instruction Questionnaire (presented in Appendix 4.1), which was administered at the first class meeting. (For administrative convenience, this document was titled the *Introductory Information and Questionnaire* document). Included are samplings of four general science aptitudes - Conservation of Mass and Conservation of Volume, Logical Reasoning, Proportional Reasoning. These samplings were made on the basis of student responses to four puzzles - Changes inside a Terrarium (Mitchell and Gunstone, 1984), The Volume Puzzle, The Mealworm Puzzle and "Shorty and Lofty" (Karplus et al, 1977)

- in Part B of the Pre-Instruction Questionnaire. The age data were obtained from the faculty's Student Records Office.

Table 4.1 Characteristics of the research population at enrolment (N = 21)

Initials	Age	Sex	First	Previous study:		Conservation:		Reasoning:	
			Language	Year	Subject	Volume	Mass	Logical	Propnl
MAb	20	M	English	11	chem	N	N	N	N
MAr	21	M	Oromic	12	chem	Y	N	N	Y
CB	17	M	English	12	chem	Y	Y	N	Y
AC	29	M	English	10	chem	N	N	nr	Y
BE	21	M	English	11	chem	Y	Y	Y	Y
PF	23	M	English	12	chem	Y	Y	N	Y
JG	24	M	English	12	chem	Y	Y	N	Y
VG	22	M	English	11	chem	Y	N	N	Y
CG	31	M	English	11	science	Y	Y	N	Y
MG	23	M	Egyptian	10	science	Y	N	N	Y
NH	21	M	Persian	12	science	Y	N	Y	Y
MNI	25	M	Tigré	12	chem	Y	N	N	Y
EK	20	F	English	10	science	N	N	Y	Y
TK	24	M	English	11	chem	N	N	Y	Y
SL	20	M	English	12	chem	Y	Y	Y	Y
GM	18	M	English	12	science	N	N	N	Y
LN	42	F	English	10	science	Y	N	Y	Y
BR	42	F	English	11	chem	Y	N	Y	Y
AR	19	F	English	11	chem	Y	N	N	Y
JV	33	M	English	12	chem	Y	nr	Y	Y
SW	18	M	English	12	chem	Y	N	N	Y
Totals:		M: 17	English:17	Year10: 4		Y: 16	6	8	20
		F: 4	Other: 4	Year11: 7		N: 5	14	12	1
				Year12: 10		nr: 0	1	1	0

Age ranges
17-20: 7
21-24 8
25-30: 2
30-35: 2
>40: 2

Key:
Y: good evidence for this aptitude.
N: evidence that this aptitude is incompletely developed.
nr: no response offered.

The diversity of backgrounds made for a number of teaching challenges, not least of which was the rate of coverage of topics, and hence the timing of their assessment. Confidence was a problem, especially for those who had left school 10-25 years earlier and also for those with only a Year 10 background in science. A single example of both these groups was a 29 year-old student who thought that sulfur is a metal. Those for whom English was a second language had difficulties with both spoken and written language, (although the University provided individual assistance on a voluntary basis). For example, one particular student, who subsequently withdrew from the course, at times asked the instructors to slow their speech. He explained that his language background of German, Spanish and English caused him to think in German, to translate his thoughts into Spanish before writing lecture notes in English.The process was reversed when he attempted to read an English language text. The two African students who continued in the research population had difficulties with written English - one, in particular, had difficulty with the psycho-motor skills of writing legible cursive or printed English words. (It would appear that his first language used a script different from the alphabetic characters used in English written language). At times his writing was virtually indecipherable and this was exacerbated (from the reader's standpoint) by a limited grasp of the language itself. Another "second language" student spelled his written work phonetically. In assessing and researching the learning achievements of such students, the approach was always to try to discover or interpret what concept development had been achieved and to disregard the imperfections of spelling, idiom or grammar.

The most noticeable aspect of the wide age range was that the older students had generally high levels of motivation and perseverance. Anecdotal evidence indicated that a number of the students over 25 years of age (and their partners and/or families) were making sacrifices in order to take part in the course and to begin undergraduate studies later. Accordingly, they were motivated to be particularly regular in attendance, conscientious in the writing of reports, in their performance of laboratory tasks and in their preparation for tests. On the other hand, a younger student confided that he was a sufferer from severe Chronic Fatigue Syndrome. He had stated this at enrolment, and had been encouraged by the administrative officer to "battle on". He indicated to the researcher that his condition severely reduced his capacity to study at night. He also claimed that his short term memory often let him down, but he did indeed "battle on".

Cultural influences on student performance and behaviour were almost certainly present and sometimes very significant when the student's national culture was quite different from the Western culture which pertains in Australia. Anecdotal evidence of these influences came from the Campus Study Adviser when the Pilot Course for Introductory Chemistry was being offered in 1995. A female student from the Middle East had consulted the Study Adviser about improving her results in the Bridging Program. This was surprising because the student was already achieving very well, receiving top marks in an early chemistry test. She already had given evidence of her enthusiasm by asking many questions of the chemistry teaching staff outside of contact time, sometimes to the point of becoming too persistent over small points. The Study Adviser (a female) discovered that the student was under great pressure from her husband who, as head of the household, had granted her permission to enrol in the Bridging Program, but on the condition that he expected her to achieve 100% of the possible marks. The pressure became very evident at the final examination when the student, on receiving her examination paper, began to exclaim in a loud, distressed voice about her perceived difficulties in understanding the contents of the paper. Fortunately no such strong pressures on students appeared to be evident during the 1996 course, although the fairly high withdrawal rate (characteristic of the several previous years of the Bridging Program) was evidence of other kinds of stress.

In terms of each student's cognitive development, the responses to the four puzzles gave a sampling of the relevant level. The aptitude for Volume Conservation is an indication of the development of thinking processes from Concrete Operations towards Formal Thinking (Shayer and Adey, 1981). In the research population, at least three respondents (14%) apparently did not leave Concrete Operations in attempting The Volume Puzzle - mass, volume and density appear not to have been differentiated. As for mass conservation (Changes inside a terrarium), only 6 respondents (29%) seemed to have developed it, although 11 respondents (52%) believed that atoms were conserved. Two students (9%) appeared to believe in spontaneous generation of matter, or a Vital Force. The logical reasoning test (The Mealworm Puzzle), which needed very careful thought, especially in interpreting the word 'response', was successfully negotiated by 9 respondents (43%). The group's success (95%) in the proportional reasoning test (Shorty and Lofty) compared very favourably with the 76% success rate achieved by a composite 1995 class (containing a total of 62 Bridging and Education students).

In summary, the 21 students comprising the research population was as diverse a group as could be found in either a secondary or a tertiary undergraduate class.

4.4 Research Instrumentation

In Chapter 1, the range of research instrumentation used to pursue the two Research Questions is described in Section 1.4. These instruments can be categorised as tests, probes, an interview and the Research Diary. Each category is described and exemplified in the following sections. Table 4.2 provides a summary of this instrumentation together with the location of the instruments in the Appendix.

4.4.1 Tests

The tests were instruments which provided quantitative data. The Concept Learning Test Sequences, described in Section 1.4, each comprised three kinds of test - the Pre-Instruction Question, the Two-tier Multiple-choice item, the Post-instruction Question Part A together with the Post-Instruction Test Question Part B. The Post-instruction

Table 4.2: Research instrumentation

Instrument/Section		Description	Quoted Example	Appendix
4.4.1 Tests				
	4.4.1.1	Pre-instruction Questions: Concepts 1-10	Question 3 (Salt: Structure?)	4.1b
	4.4.1.2	Two-tier Multiple choice items	Concept 3, Item 1 (B_4C structure)	4.4.1.2
	4.4.1.3	Post-instruction Questions Parts A & B: Concepts 1-10	Question 3, Part B (BaO: mp; r(Ba^{2+})	4.4.1.3
4.4.2 Probes				
	4.4.2.1	General science aptitudes: four pre-instruction puzzles	Description in text	4.1a
	4.4.2.2	Pre-laboratory Reports	Note 3, cover sheets	nil
	4.4.2.3	Post-laboratory Reviews	Unit 1 Section B Pt 5. Unit 8: Preamble of Post-lab Review Sheet	nil nil
	4.4.2.4	End-of-semester Questionnaire	Description in text	4.4.2.4
4.4.3 Interview			Transcript extracts Focus Sheet Protocol document	4.4.3a 4.4.3b 4.4.3c
4.4.4 Research Diary			Discussion in text	nil

Question Part A was simply a retest of the Pre-Instruction Question. Administration of the tests for each concept-cluster was accomplished according to the generalised schedule indicated in Table 1.2. (Some concept-clusters contained several Two-tier Multiple-choice items). A description of each kind of test follows with examples drawn from Concept Learning Test Sequence Number 3 (Structure/Bonding). Correct responses are marked with an asterisk.

4.4.1.1 The Pre-instruction Questions

One question for each of the 10 concept-clusters was posed in the Pre-instruction Questionnaire. Each question (item) was intended to assess the respondent's initial understandings of an aspect of the concept-cluster.

Example (Question 3):

Consider the following statements.

- *Iris says that Table Salt, sodium chloride, is an* ***ionic*** *substance.*
- *Mavis claims that it is a* ***molecular*** *substance.*

Who is correct? Please tick the box - I (Iris), M (Mavis) or U (if you are uncertain).

I	*M*	*U*
☑	☐	☐

Please tick the box for the most likely melting point of Table Salt, sodium chloride (given as Celsius degrees).

-80^{o}	80^{o}	300^{o}	800^{o}	*U*
☐	☐	☐	☑	☐

4.4.1.2 Two-tier Multiple-choice items

The structure of these test items is particularly suited to ascertaining alternative conceptions and/or incomplete concept-learning. The first tier, in conventional fashion, contains a stem and a choice of 3-5 responses, some of which may contain distractors involving known alternative conceptions. The second tier of the test item contains a stem with a choice of 3-5 reasons for choosing the response in the first tier. Again, the available choices may involve alternative conceptions as distractors.

Example (Concept-cluster 3, Item 1):

Sodium chloride has a melting point of $801^{o}C$. The compound boron carbide, B_4C, has a melting point of $2350^{o}C$. B_4C is an electrical insulator above and below $2400^{o}C$.
In the solid state B_4C is likely to be a

(1)	*metallic lattice*
(2)	*covalent molecular substance*
**(3)*	*continuous covalent lattice*
(4)	*continuous ionic lattice*

Reasons:

(A)	*The high melting point and low conductivity indicates very strong bonding forces between the molecules of B_4C.*
(B)	*The non-conductivity of B_4C is evidence that the molecules are strongly bonded to each other.*
**(C)*	*Non-conducting properties in the molten state prove that the bonding must be covalent in a continuous lattice of atoms.*
(D)	*Since boron is present as B^{3+}, the ions present are unable to dissociate during melting.*

In a particular Concept Learning Test Sequence, there were as many as five Two-tier Multiple-choice items. In such cases (as with Concept-clusters 3 and 5), the items were shared between two of the four assessment tests. Figure 4.3 displays the distribution of the Two-tier Multiple-choice items forming part of the four assessments held during the course.

Table 4.3 Distribution of Two-tier Multiple-choice items across concepts

Concept	Assessment Number 1	2	3	4
1 Density	Item			
2 Mixt/Compound	Item			
3 Struct/Bonding	Item 1			Items 2, 3, 4
4 Base/Salt		Item		
5 Redox		Items 1, 2, 3		Items 4, 5
6 Mole		Item		
7 Rate			Items 1, 2, 3, 4	
8 Metal			Item	
9 Halogen			Item	
10 Hydrocarbon			Item	

Note: Assessments 1, 2, 3 and 4 were held in Teaching Weeks 6, 9, 13 and 16 respectively.

4.4.1.3 The Post-instruction Test Questions Parts A and B

The Post-instruction Question Part A, as a re-test of the Pre-Instruction Question, simply established whether learning had occurred in this context during the course. Part B was a test of additional learning which had occurred for this concept-cluster.

Example: (Question 3, Part B)

The melting point of MgO is 2800^0C. The radius of the metal species in MgO is 65pm (picometres).
Please tick a box to indicate the most likely value of each of these properties for BaO.

Melting point (^0C)	*100* ☐	*4000* ☐	*2000* ☑
Radius of Ba species (pm)	*59* ☐	*135* ☑	*65* ☐

4.4.2 Probes

These instruments provided qualitative data. They included open-ended responses in The Pre-laboratory Reports, The Post-Laboratory Reviews, The End-of-semester Questionnaire and the Post-examination Interview of a student. The researcher kept a Research Diary into which were entered notes about significant events or incidents which arose during teaching/learning situations involving the tutor, the demonstrator/markers or himself.

4.4.2.I General science aptitude puzzles

These puzzles have been discussed in Section 4.3.

4.4.2.2 The Pre-laboratory Reports

Although the Pre-laboratory Reports concentrated upon thinking tasks, calculations and other activities related to the concepts introduced in the particular unit, the standard cover sheet accompanying the Pre-laboratory Report sheets provided the student with an opportunity to alert the researcher to any difficulties s/he may have experienced during preparation of the Report. The third note on the cover sheet was

> *3. Please clarify the following in tutorials or lecture meetings.*

A space of about half a page followed for such requests. Laboratory demonstrator/markers reported any such requests to the researcher.

4.4.2.3 The Post-laboratory Reviews

An extract from Unit 1 of *Introducing Chemistry* (Section B Part 5, pages 37-38) offers insights about the intended uses of the Post-laboratory Reviews.

> One important purpose of the Post-lab Review is to help you to reflect upon and review your laboratory learning experiences. This can lead to improved understanding and deeper learning. Another purpose is to help teaching staff to improve the quality of learning experiences which the laboratory work offers. Your frank but considered responses to the guidelines of the post-lab can be valuable contributions to this improvement.
>
> The following material offers guidelines for your reflection. Please respond on the separate coloured sheet titled 'Post-laboratory Review' [at the end of the unit].
>
> 5.1 Look again at Sections A and B [theory and practical sections respectively]. Try to see whether they *link* satisfactorily with what you saw, thought and recorded in the laboratory.
>
> 5.2 Write down carefully
>
> - What *new things* you learned
> - what *changes* or improvements you have made in your understandings
> - *Links* you have been able to make with your previous knowledge
>
> 5.3 What practical experiences actually helped to improve your understandings? How did this happen?
>
> 5.4 What practical experiences proved unhelpful or confusing? Suggest ways this may be so and how it can be changed.
>
> 5.5 Add any other comments which you think may be relevant.
>
> Having thought about these matters, go to the Post-lab Review Sheet and enter your responses. [The sheet contained questions with answer spaces keyed to 5.1 - 5.5].

This kind of formal framework was retained for the first three Post-Laboratory Reviews of *Introducing Chemistry* in order to give the students practice in writing in this reflective way. Subsequently they were asked to establish their own unique format, although each Post-Laboratory Review Sheet provided a set of questions which were intended to stimulate some metacognitive thinking. Accordingly, the preamble to the Post-Laboratory Review Sheet for Unit 8 (page 25) read

> In this review of your learning you may come to reflect upon the differing contributions of Parts A and B [theory and practical sections respectively] to learning the sum total of the topic. *Which part was the more useful? Why? What was the role of each part? Did Part B assist your understanding of Part A? Did Part B have effects upon your attitudes? For example, did the colours of the Transition metal compounds add to interest and enthusiasm or disinterest or negative attitudes? What role did the actual experimentation have upon you understandings?* Feel free to record any other aspects of you learning in this unit.

The preambles to the Post-laboratory Review sheets of the remaining units of *Introducing Chemistry* were similar in approach.

4.4.2.4 The End-of-semester Questionnaire

This was a comprehensive, voluntary and anonymous questionnaire which sought an evaluation of the course by the respondents after they had completed the final examination. The full questionnaire is presented in Appendix 4.4.2.4. Opinions and suggestions were sought in the following areas.

- The context of the course (the subject-matter - each unit of *Introducing Chemistry*, for example)
- particular aspects of the unit (such as pre-labs, laboratory work, post-labs, constructivism, thinking tasks, *Meeting Chemistry*)
- learning and teaching (for example, "pluses and minuses" of teaching)
- assessment (in each of the forms met during the course)
- general comments (included an opportunity to grade the course on the scale 1-10).

4.4.3 Interview

General permission to interview students about the subject of this research was sought from and granted by Curtin University of Technology on the researcher's candidature documents in March 1996. Approval to conduct interviews of students of the Bridging Program of The University of South Australia was obtained from the Human Research Ethics Committee of that university after submission, amendment and approval of the required Human Research Ethics Protocol. Subsequently, in October 1996, each member of the class received an envelope containing three documents (Appendix 4.4.3c) approved by that Committee: an explanatory letter (Document 1), an information sheet (Document 2), and a Consent Form for the project (Document 3). The documents explained that the proposal was to conduct an extended interview (50-60 minutes) of each of 5-10 students about their perceptions of the teaching and learning of concepts during the course. The participants' rights and the researcher's obligations were clearly stated. The letter invited volunteers for interview. In due course, after the final examinations had been completed, only one student, BR, volunteered to be interviewed.

The Focus Sheet (Appendix 4.4.3b) was used as the basis of the interview. The obverse of the sheet listed the ten concept-clusters which are the focus of this research. The reverse side (headed "TEACHING: providing opportunities for meaningful learning") listed 15 different opportunities for meaningful learning provided by the course and two simple statements defining this term. The Consent Form was explained to BR, whose signature was counter-signed by the researcher. The interviewee agreed that the interview would be based upon the Focus Sheet, upon which she could freely comment. The interview was to be recorded on an audio-tape run by a voice-activated audio-recorder. It was expected that the interview would take under an hour. In the event, it took about I.5 hours, punctuated (by agreement) with a 15 minute rest period about 50 minutes from the start of the interview.

The audio-tape was transcribed by a professional person specialising in this work. A copy of the Focus Sheet and an additional list of chemical terms and phrases was provided for her guidance. However, the transcript was edited by the researcher to the extent of adding words which, on the tape, the transcriptionist could not understand on account of their chemical idiom. This edited transcript became the research data for analysing the interview. In turn, the researcher used the edited transcript to produce the document presented as Appendix 4.4.3a, which comprises notes and extracts of all significant points about teaching and learning made by the interviewee during the interview. This document is the principal basis for discussion in Chapter 7.

4.4.4 Research Diary

Chapter 1 has indicated that a Research Diary was used to record a range of informal observations, notes, comments and incidents which arose in relation to any aspects of the course which related to teaching/learning. An important function of the Diary was to provide triangulation of data obtained elsewhere (Merriam,1988; Patton 1987).

Another function was to record insights into student learning difficulties arising during class contact. A third use was to record ideas of approach for informal trialling in subsequent contact with the class.

4.5 Data analysis

4.5.1 Quantitative data

Raw data from the Concept Learning Test Sequences were available from the Pre-instruction Questionnaire and the four assessments held during and at the end of the instruction period. It was decided that analyses of these data were best achieved by arranging them in two ways. One form of arrangement would permit a separate study of the learning of the whole group for each of the ten concept-clusters. The other arrangement would enable a study to be made of the learnings of any particular individual with respect to all ten concept-clusters. Accordingly, two kinds of single-sheet forms were devised for the entry of data - *CLTS Data Form A: Class results for a single concept-cluster* and *CLTS Data Form B: Individual results for ten concept-clusters.* For the sake of brevity it is proposed to refer to the two forms as Form A and Form B. In practice, Form A was the generic layout of ten somewhat different forms, Forms A1, A2,...A10, which made allowances for the differences in the formats of the various pre- and post-instruction questions as well as the differing numbers of Two-tier Multiple-choice items used in the Concept Learning Test Sequences.

The hand-written generic Form A was produced in "landscape" orientation with five major columns. These columns were headed "Respondent", "Pre-Instruction Question", "Two-tier Multiple-choice Item(s)", "Post-instruction Question Part A", "Post-Instruction Test Question Part B". The first column contained the 21 names of the class in alphabetical order. Ten photocopies of this generic Form A were produced, one for each of the ten concept-clusters. Unique Forms A1, A2,...A10, titled according to the concept-cluster's number and name, were developed by vertically subdividing the respective columns to make minor columns relevant to the various part-questions or items of each Concept Learning Test Sequence. The subdivisions were headed with an easily identifiable abbreviation of the relevant part-question. Various means of indicating the correct answer to each part-question were incorporated into the Forms. Horizontal lines drawn beneath each of the names of the respondents were continued across the page to create a set of empty "boxes" into which entries of data could be made. Space was provided at the bottom of the Form to record totals of the various answers in each of the minor columns. In effect, the Forms A were blank tables for the insertion of data which could be totalled and analysed with respect to class trends and achievements for each of the part-questions and items, as is accomplished in Chapter 5.

The blank version of Form B was similar in layout to that used in Table 4.4 (itself a blank form used to enter the individual student data presented in Chapter 6), differences being that

- "landscape" orientation of the page was adopted
- separate columns were allocated to the Pre-instruction Question and the Post-instruction Question Part A. Longer check-lists of items in such columns (as in concept-clusters 3 and 8) were presented in a single line.
- questions about confidence in understanding the concept (which began each Pre-Instruction Question and Post-instruction Question Part A), were included.

One such Form B was produced for each respondent.

Pre-instructional Background, a simple form of five columns, bearing an individual respondent's pre-instructional data (which was used to prepare Table 4.1), was stapled to the corresponding Form B.

Following the preparation of the Forms A and B, the five assessment and questionnaire scripts of each student were bundled and fastened together. The hard data from each bundle was then transcribed to the respective Forms A and B. On the Forms A, totals for each answer and percentages of the class for each total were calculated. The data on these forms were used to produce summary tables for each of the Concept Learning Test Sequences.

To permit a detailed scrutiny and analysis of the 21 Two-tier Multiple-choice items, as is conducted in Chapter 5, the Forms A were also used to produce tables of responses and reasons for each of these items. Table 4.5 presents an example of such a table, using data from Form A2 (used for Concept-cluster 2 - Mixture/compound).

Table 4.5 Example of a results table for a Two-tier Multiple-choice item
(data from Form A2 - Concept-cluster no.2: Mixture/compound)

	Number of choices (N=21) Reason				
Response	A	B	C	D	Total responses
1	3	0	5	0	8 (38%)
2	1	5	2	3*	11 (52%)
3	1	0	1	0	2 (9%)
Total reasons	5	5	8	3	21

*Best choices: 14%

Table 4.4 **Concept-Learning Test Sequences: Summary of results for student no. n - XY** (blank)

Concept Pre-/Post-Instruction Part A	Two tier tests		Post-Instruction Part B
	item	solution choice	
1 **Density** *Water vapour: density is 500g/litre?* T F* U pre- post-	1 $d(CO_2)$ 2 box, T↑	[2+D] [4+A]	*Vol of 100g of ice?* [109mL] Answer: mL
2 **Mixture/cmp'd** *Compound (C) or mixture (M)?* glass [M] sugar [C] b/soda [C] pre- post- rubber [M] curry [M)] wine [M] pre- post-	1 % comp	[2+D]	*Fe + S → FeS; Fe = 8g, S = 4g* *Residual mixture after heat?* **[Fe = 1g, S = 0g; FeS = 11g]** Answer: Fe = g, S = g; FeS = g
3 **Structure/bonding** *NaCl (ionic/molecular)?* I* M U pre- post-	1 B_4C 2 HF e^- 3 Vaseline 4 Gp I&VII	[3+C] [1+C] [1+C] [2+B]	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$ $T_m(BaO)$? $R(Ba^{2+})$? T_m (BaO) 100 4000 2000
Melting Pt of NaCl? -80^0 80^0 300^0 **800^0** U pre- post-			$R(Ba^{2+})$ 59 135 65
4 **Base/salt** *Which are bases?* **limestone*** vinegar salt **carb soda*** pre- post- **ammonia*** sugar alcohol pre- post-	1 Ba CO_3	[2+B]	*Formula of a base in Part A?* *Equation for that base?* balanced, appropriate: balanced, other base: inappropriate choice:
5 **Redox:** *Hydrogen can reduce copper oxide?* **T*** F U nr pre- post-	1 Fe + $CuSO_4$ 2 Red. Agent 3 Cell A/A^+//.. 4 $CO_3^{2-} + H^+$ 5 Cell I/MnO_4	[2+A] [2+C] [1+D] [3+C] [4+C]	*In C + CuO → CO + Cu,* *Cu gains electrons:* **T** ( ) F ( ) *Cu gains electrons:* T ( ) F ( ) *Ox N of O: -2→+2:* T ( ) **F** ( )
6 **Mole:** *Eight calculations:* no. 1 2 3 4 5 6 7 8 pre- post-	1 Cu^{2+}/OH^-	[3+E]	*Weight (mass) of* *$1.5x10^{21}$ molecules of SO_3 ?* **[0.2g]** answer:
7 **Rate:** *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?* **[R_2 = 50]** pre: post-:	1 Mg + H^+ 2 P/Q data 3 Plots/data 4 H_2/I_2	[1+D] [2+C] [5+A] [4+D]	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,* *$C_2 = 0.5$?* **[$R_2/R_1 = 1/4$]** ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ), $R_2 = R_1/4$ ( ), $R_2 = R_1/2$ ( )
8 **Metals** (statements): Cu/metal brass/metl brass/elt pencil/lead pre- [T] [F] [F] [F] post-] [T] [F] [F] [F] granite/nm Si/nm Ne/nm Fe ore/metallic pre- [F] [T] [T] [F] post-- [F] [T] [T] [F]	1 Metals/PT	[3+A]	*List 5 gen phys props of metals* No of props: 1 2 3 4 5 *Name two exceptional metals:* (1) (2)
9 **Halogen:** *Use or application?* Cl F I pre- post-	1 ICl + H_2O	[2+A]	*Hypochlorous acid:* *formula* **[HOCl]**: *ox no of Cl* [+1]:. *equation with HOCl* :
10 **Hydrocarbon:** *Chemical names:* pre: post: *one common property:* pre: post:	1 $C_4H_6 + Br_2$ also	[1+D] [4+A]	*4th member of $C_nH_{(2n-2)}$:Name?* stem **[pent-]**: **-yne**: *structural formula?* **C≡C:** skeleton **[5 carbons]**:

A completed Form B for each student is presented in Chapter 6. Each Form gives a single-page overview of the student's development of concept-learning over the duration of the course. The Forms B can therefore be used for case studies of individual students or groups of students. Such a case study is discussed in Chapter 7.

The various tables of data could now be used to analyse the components of each of the Concept Learning Test Sequences. This analysis was drafted "by hand" in a Data Analysis Book. For each Concept Learning Test Sequence, the order of consideration of the parts of the sequence was

- the responses to the Pre-Instruction Question and the Post-instruction Question Part A
- the Responses and Reasons in the Two-tier Multiple-choice item(s)
- the answers to the Post-Instruction Test Question Part B.
- a brief summary of the data for the whole Concept Learning Test Sequence with comments relating to Research Question Number One.

For each item or question, the analysis proceeded with

- a presentation of the question or item in full
- a tabulation of the data representing the answers/Responses/Reasons, usually expressed as a percentage of the whole class
- a comments section which could include an explication of the chemistry or arithmetic of the expected correct answer, relationships with other concept-clusters, the possible alternative conceptions, sources of error, pitfalls, knowledge gaps, teaching/learning contexts and sometimes a comparison with the results of the 1995 class or with literature data.

Editing of the entries in the Data Analysis Book was followed by their transcription and presentation as the major portion of Chapter 5.

4.5.2 Qualitative data

Qualitative data relevant to Research Questions One and Two were obtainable from the Pre-laboratory Reports, the Post-laboratory Reviews, the End-of-semester Questionnaire, the extended interview of a volunteer student and the Research Diary. The data from each source were analysed with a view to making summaries, where possible, of the points relevant to the Research Questions.

The Pre-laboratory Reports provided information concerning difficulties with concept-learning, either through a direct request made by the student on the cover-sheet, or through diagnosis by the Laboratory Demonstrator/markers during the marking process. In either case the nature and frequency of the difficulties were referred to the researcher, who made appropriate entries in the Research Diary. These and other entries were studied for their relevance and importance in making a contribution to Chapters 6, 7 and 8.

Each week the Post-laboratory Reviews were photo-copied and filed after they had been read and annotated. In due course, these Reviews were again read, relevant points were extracted and referenced by the date and nature of the class contact in which they occurred. The resulting summary was filed as a document titled *Post-laboratory Reviews: Extracts relevant to learning.* Subsequent analysis for significance and relevance led to a contribution to the presentation in Chapter 8.

Relevant comments by respondents to the End-of-semester Questionnaire were entered on to a blank Questionnaire, with source noted. A summary of entries was then typed and filed for further study as the document *Summary of Twelve Responses to Student Evaluation of the unit - 1996.* Further analysis for relevance and significance led to the presentation of material on course evaluation in Chapter 8.

The interview of the student BR was analysed initially by listening to the audio-tape with a copy of the transcript at hand. Aspects of the interview relevant to the Research Questions were annotated on the transcript, enabling the preparation of a summary document filed as *Interview with BR, 11/10/96 - Notes of possible significance for Case Study.* The document contained a summary of relevant points under headings derived from the Focus Sheet together with selected quotations from the transcript, referenced to the pagination. A more detailed analysis of both summary and transcript followed, leading to a major portion of the Case Study reported in Chapter 7.

At the end of the course, the Research Diary was reviewed and annotated. A summary document titled *Research Diary: Extracts for discussion* was prepared, locating relevant comments and incidents under headings related to the teaching week and the kind of class meeting or personal contact. This document was used to contribute relevant aspects to Chapters 6, 7 and 8.

4.6 Evaluating the research methodology

In research such as that presented in this thesis, the basic evaluative question must be asked: "To what extent can the researcher and the reader trust the qualitative findings of the study?" In other words, "Has the research been concerned with producing qualitative knowledge in an ethical manner?" These questions are answerable in terms of the criteria put forward by Guba and Lincoln (1989) for evaluating a research programme from a constructivist viewpoint. These authors describe specific criteria in each of two major areas of evaluation, Trustworthiness and Authenticity. An examination of the methodology of this research, in terms of the criteria listed under each of these areas, should serve to answer the above questions.

4.6.1 Trustworthiness

Trustworthinessis is an area of evaluation comprising what Guba and Lincoln (1989) call The Parallel Criteria, so called because, in the constructivist paradigm, they parallel the criteria for rigour in the logical positivist paradigm. In the latter paradigm, the criteria include internal validity, external validity, reliability and objectivity. Guba and Lincoln (1989) state that, in this paradigm, internal validity "is nothing more than an assessment of the degree of isomorphism between a study's findings and the 'real' world" (p. 236). In other words, it is a means of establishing the "truth value" of a research, establishing "how things really are and really work" (p. 234). In the same paradigm, external validity is "a concept that embodies the very essence of generalizability", while reliability "is essentially an assessment of stability - of the phenomena being assessed and of the instruments used to assess them" (p. 236). Objectivity (which is applied to *method* in this paradigm) is "concerned with assuring that data, interpretations and outcomes of inquiries are rooted in contexts and persons apart from the evaluator and are not simply figments of the evaluator's imagination" (p. 243). By the very nature of the constructivistic paradigm, these evaluation criteria, as such, are unsuitable for use in it. Accordingly, in their place, Guba and Lincoln (1989) propose the Parallel Criteria: credibility, transferability, dependability and confirmability respectively, and suggest a range of techniques for applying them to the research in question. These criteria are examined in turn and some relevant techniques are applied to the present research.

4.6.1.1 Credibility

The credibility criterion is the constructivist parallel of internal validity. Guba and Lincoln (1989) describe credibility as "isomorphism between constructed realities of respondents and the reconstructions attributed to them" (p. 237). This can be taken to mean that the constructed realities of the respondents are represented correctly. Guba and Lincoln (1989) recommend six techniques for increasing the probability that the required isomorphism is achieved. Four of these: prolonged engagement, persistent observation, peer debriefing and member checks, are relevant in this research.

Prolonged engagement and persistent observation were criteria which, in this research, could be described as extensively met - the researcher was in contact with the students for at least five hours per week over the 13-week duration of the course. An encouraging teaching/learning environment was actively sought on all such occasions. Throughout the semester, the Research Diary was kept to record significant observations and incidents.

Each week the researcher conferred at least once with the tutor of Tutorial Group B, to exchange impressions and to recount events relating to the quality of learning and teaching in the course, thus contributing to peer debriefing.

Each week also provided the opportunity to receive member checks on progress through the Pre-laboratory Reports, as reported by the marker/demonstrators, and by the researcher cross-checking individual examples of those Reports. Additionally, the weekly Post-laboratory Reviews gave member checks of views about their own learning and their approaches to the work of the week just completed.

4.6.1.2 Transferability

This criterion is the constructivist parallel to external validity or generalizability. In contrast to generalizability, transferability is relative and depends upon the degree to which there is a match between the conditions of the contexts between which transfer is attempted. To make adequate transferability judgements, Guba and Lincoln (1989) recommend the technique of "thick" description, the object of which is to set out all the working hypotheses of the research and to provide as complete a database as possible for those who may wish to apply the research to their own situations.

In relation to the present research, the study has been described in extensive detail and the data have been presented in several forms, either in the body of the text (with extended commentary) or in the various appendices.

4.6.1.3 Dependability

Dependability is the constructivist parallel to the positivist criterion of reliability. Guba and Lincoln (1989) indicate that this criterion enables evaluation of how well the reader can trace any changes in the methodology of the research. This, effectively, is the "dependability audit". In the present chapter of this thesis, Section 4.4 (Research Instrumentation) provides a means of ascertaining whether changes of methodology have occurred.

4.6.1.4 Confirmability

Use of this criterion gives assurances of the integrity of the findings of the research. It is the parallel of the positivist criterion of objectivity. Guba and Lincoln (1989) state that confirmability allows data to be tracked to its sources and that the logic used to make interpretations of the data is clearly evident in the description of the study. In other words, where it exists, researcher bias can be revealed. Such revelations are made by the "confirmability audit". In this research, this audit is possible through a perusal of the discussions of data in Chapter Five wherein the results of each of the items in each of the Concept Learning Test Sequences is discussed at some length. Similarly, the commentary on the results of the End-of-semester questionnaire and the Case Study can be checked against the raw data presented in the appendices.

4.6.2 Authenticity

Guba and Lincoln (1989) point out that, while useful in a constuctivist context, the trustworthiness criteria, being parallel criteria, have their roots and origins in positivist assumptions. They are primarily criteria of methodology. Their use alone would not necessarily consider all aspects and rights of the stakeholders in research studies. Accordingly, these authors devised several authenticity criteria which derive from the assumptions of constructivism itself. Four of these criteria are of relevance here: fairness, educative authenticity, ontological authenticity and tactical authenticity. Taylor (1996) has interpreted these criteria as fairness, education, improvement and empowerment. Under these headings the authenticity criteria relating to the present research will be discussed.

4.6.2.1 Fairness

Fairness is indicated by the extent to which different constructions and values are sought and honoured in the evaluation process. In regard to the present research, fairness can be measured in the conduct of the End-of-semester Questionnaire, which was both voluntary and anonymous. The approach to, and conduct of extended personal interviews (after the completion of the course), adhered not only to the ethical requirements of The Curtin University of Technology, but also to the extensive requirements of the Ethics Protocol of the Human Research Ethics Committee of The University of South Australia. *Inter alia*, this protocol protected the possible participants from invasions of privacy, from breaches of confidentiality, from pressure to take part, from pressure to continue to participate if experiencing a change of mind, and from any researcher influence upon the student's academic results.

In the general teaching of the course, where the asking of questions by the students was permanently encouraged, the lecturer was always at pains to make clear that the simplest of questions was worthy of asking and that no members of the class should disparage the questionner for asking such questions.

4.6.2.2 Education and 4.6.2.3 Improvement

Research which meets these two criteria allows the reader to examine how much the respondents have learned from their participation and to what extent they have improved their performances. In this research, the data of the ten Concept Learning Test Sequences have provided the researcher and the reader with extensive and detailed opportunities for assessing the extent of improvement in concept-learning which each student has experienced.

4.6.2.4 Empowerment

As described by Taylor (1996), the empowerment criterion permits evaluation of the extent to which the respondents have been given real opportunities to have a significant role in the research. In the present research, the students were introduced to constructivistic approaches to teaching and learning. They were encouraged to be responsible for their own learning and were thus empowered to profit from their own alternative conceptions. Examples of this empowerment included the formative use of the Two-tier Multiple-choice items as diagnostic tools during the semester, emphasis upon and opportunities for asking questions, and the opportunities for group work in the solving of practical problems. The students were further empowered to have a significant role in this study when they were offered opportunities to volunteer "feedback" on the course, either anonymously through the End-of-semester Questionnaire or through personal interview.

4.7 Summary

The chapter has described how, in a context of access and equity (Section 4.2), a research population of substantial diversity (Sections 4.2, 4.3 and Table 4.1) and numbering 21 respondents, has been studied in response to the Research Problem - that of ascertaining how the design, presentation and evaluation of a tertiary bridging course in chemistry can meet the needs both of the students and the university concerned.

The two derivative Research Questions (Section 4.1), focussing upon the development of understanding of 10 chemical concept-clusters (Research Question 1) and the aspects of the course which contributed to this learning (Research Question 2) were shown to have generated a range of research instrumentation (listed on Table 4.2). The Concept Learning Test Sequences, comprising three types of question/item (described in Section 4.4.1) and devised in response to Research Question 1, produced an array of quantitative data concerned with the learning of the 10 concept-clusters over the whole semester (reported in Chapter 5). A one-page data summary for each student's responses to these 10 test sequences was prepared (and presented in Chapter 6). The chapter also shows how a range of research probes (Section 4.4.2, Table 4.2), an extended interview (Section 4.4.3) and a Research Diary (Section 4.4.4) generated qualitative data for analysis in response to Research Question 2. Section 4.5 provides an outline of approaches to the analysis of research data. Concluding the chapter, Section 4.6 provides an evaluation of the research methodology. Eight criteria from two areas of evaluation of research in a constructivistic paradigm have been described and applied to a range of aspects of the present research.

* *

Chapter 5

Results from the concept-learning test sequences

Introduction

Chapter One described how, in response to Research Question One, the Concept-Learning Test Sequences (CLTSs) were developed to monitor and to diagnose the extent of learning of concepts thoughout the semester. Chapter Four has shown how the CLTSs were administered. In this chapter, each of the ten CLTSs is considered as a whole. The component tests of each CLTS are presented with a tabulation of results and a discussion. For each CLTS the relevant tests are presented in the following order

- the Pre-instruction Question and the Post-instruction Question Part A (identical questions for comparison)
- the Two-tier Multiple-choice item(s)
- the Post-instruction Test Question Part B.

Presentation

Each test item is indented and presented in an *italic* font, related data are in regular font. In most cases, results are quoted as a percentage of the class, normally 21 respondents. Correct numerical answers are quoted or, in the items of choice, marked by an asterisk. An asterisk in tables also marks data for correct answers. The letters nr used in tables indicates that no response was made by the respondent(s). The acronym 2TMC is used for Two-tier Multiple-choice item(s). When discussing 2TMC items, a selected answer to a first tier is called a Response. A selected answer to a second tier is called a Reason. Specific combinations of Response and Reason are quoted inside square brackets, [ ], with the numeral of the Response and the letter of the Reason joined by a plus sign. Thus [3 + D] refers to the combination of Response 3 with Reason D in a particular Two-tier Multiple-choice item.

An overview and a discussion of the implications of the outcomes of each CLTS follows. A summary of the results of the CLTSs concludes the chapter.

5.1 Concept-cluster 1 - Density

5.1.1 The Pre-Instruction Question and the Post-Instruction Question Part A

*The **density** of liquid water is very close to 1000 grams per litre.*
Do you think that you understand the term density?
Please indicate yes (Y), no (N) or uncertain (U) .

		Y	*N*	*U*	
		☐	☐	☐	nr
Results:	Pre:	57	5	38	0
	Post:	95	0	0	5

Consider the following statement.

The density of water vapour is about 500 grams per litre.

True, false or uncertain?

		T	*F**	*U*	
		☐	☐	☐	nr
Results:	Pre:	19	9	67	5
	Post:	29	62	9	0

Comment

1. A first reaction to the low (57%) positive response to the pre-instruction question about understanding could be one of surprise, since density concepts are normally taught, learned and used from junior secondary science onwards. However, second thoughts could take this as a realistic and truthful response from the class. Shayer and Adey (1981), for example, note that handling density concepts involves, in Piagetian terms, late formal thinking. Other authorities (Herron, 1975; McKinnon and Renner, 1971) report that, in the United States of America, as many as 50% of entrants to the tertiary system are still operating at the concrete operations stage of thinking. In short, the concept of density was not expected to be an easy one for many of the entrants to the Bridging Course. The high confidence rate post-instruction (95%) is discussed further in Section 5.1.3.

2. The second statement and its question are as much a check upon the respondent's appreciation of the relative magnitudes of the densities of a pure liquid and its vapour as it is a test of understanding of the concept of density. (Kinetic Molecular Theory and density were topics met in the first week of the unit). In another sense, the statement and question are a check on the notion that the ratio of the *volumes* of a given mass of liquid and its vapour is of the order of 1:1000, or at least, very large. That two-thirds of the class, pre-instruction, were unsure of this notion is not surprising, since it is a consequence of the Kinetic Molecular Theory and is less likely to have arisen in a quantitative sense in a secondary science curriculum.

The post-instruction success rate (62%) of this part of the question is a substantial improvement indeed, but it remains disappointing that 6 respondents (29%) could still view the density of water vapour as about half that of liquid water.

5.1.2 The Two-Tier Multiple-Choice Items

Item 1

Under ordinary laboratory conditions, gaseous carbon dioxide has a density near 2 grams per litre.

Liquid carbon dioxide is likely to have a density of about

(1) *2.5 grams per litre*
**(2)* *2000 grams per litre*
(3) *0.002 grams per litre*
(4) *0.20 grams per litre*

Reason

(A) *In the gaseous state the molecules of carbon dioxide weigh less than those in the liquid state.*

(B) *One gram of liquid carbon dioxide is about one thousand times heavier than a gram of gaseous carbon dioxide.*

(C) *The much smaller volume of 2 grams of liquid carbon dioxide leads to a smaller density for the liquid.*

**(D)* *In the gaseous state the molecules of carbon dioxide are much further apart than those in the liquid state.*

Results: Number of choices (N=21)

	Reason				
Response	A	B	C	D	Total responses
1	1	0	0	3	4 (19%)
2	0	5	0	11*	16 (76%)
3	1	0	0	0	1 (5%)
4	0	0	0	0	0
Total reasons	2	5	0	14	21

*Best choices: (52%)

Comment

This item pursues the notion that the density of a pure liquid is many (about 1000) times that of the same substance in the gaseous state. That 16 respondents (76%) chose the correct density (Response 2) is some evidence of understanding of this notion, with 11 of these respondents (52%) choosing the correct Reason (D) as well. That 5 respondents (24%) chose Reason B with Response 2 indicates that there remained, post-instruction, a significant confusion between mass and density, a characteristic of learners in pre-formal stages of thinking: Reason B, standing alone, is itself a nonsense statement.

The selection of Response 1 by four respondents (19%) indicates *some* appreciation of differences in density between liquid and gaseous states, but a failure to appreciate the real magnitude of the difference.

Two respondents chose Reason A to match their (incorrect) responses. This reason was included to ascertain whether any student believed (as those mentioned by Garnett, Garnett & Hackling,1995 believed) that the mass of a molecule can change with changes of state.

Item 2

A rigid box containing only air at 20°C is firmly sealed. The temperature is raised to 100°C.

Which of the following properties of the air would experience an increase?

(1) viscosity and density
(2) average intermolecular distance
(3) cohesive forces and compressibility
**(4) average molecular velocity*

Reason

**(A) increased molecular motion is indicated by increased temperature of the air.*
(B) the increased pressure increases the density and thus the cohesive forces of the molecules.
(C) the molecules of air expand on heating, increasing the intermolecular forces and the compressibility.
(D) intermolecular distances increase with increasing energy of the molecules.

Results: Number of choices (N=21)

	Reason				
Response	A	B	C	D	Total responses
1	0	0	0	0	0
2	1	0	0	3	4 (19%)
3	0	0	1	1	2 (9%)
4	**14***	0	1	0	15 (71%)
Total reasons	15	0	2	4	21

*Best choices: 67%

Comment

Although intended to test aspects of the Kinetic Molecular Theory, this item gave the opportunity to choose Response 1 or Reason B. Such a choice would indicate a belief that density in this case is not constant (even though mass and volume are). Neither choice was made. On the other hand, four respondents (19%) selected Reason D, which *implies* a change of volume and thus density. This implication may not have been noticed by the students who answered the question.

5.1.3 The Post-Instruction Test Question Part B

The density of ice is 0.92g/mL. What is the volume of 100grams of ice?

	Correct answer:	109mL
Results:	correct answer:	17 (81%)
	concept only correct:	2 (9.5%)
	wrong:	2 (9.5%)

Comment

The high level of confidence (95%), expressed in the Post-Instruction Part A question, is justified in these results where 81% of respondents obtained the correct answer. At least in calculational aspects of the relationship D = M/V, the concept seems to be well developed. As mentioned earlier, the Part A response to the density of water vapour (62%) was as much a test of the implications of the Kinetic Molecular Theory as a test of the grasp of the concept of density. Accordingly the Part B result is *some* extra evidence of improvement in concept-learning.

5.1.4 Summary for the concept *density*

The success rates for the Concept Learning Test Sequence, in chronological order are (as percentages):

Pre instruction	2TMC No1	2TMC No2	Post-Inst. Part A	Post-Inst. Part B
9	52	67	62	81

This improvement was paralleled by a large pre-/post-test increase in expressed confidence (from 57% to 95%).

5.2 Concept cluster 2 - Mixture/Compound

5.2.1 The Pre-Instruction Question and the Post-instruction Question Part A

*Air is a **mixture**, water is a **compound**.*

*Do you believe that you have a good understanding of the terms **mixture** and **compound** ? Please tick yes (Y), no (N) or uncertain (U).*

	Y	*N*	*U*	nr
	☐	☐	☐	
Results: Pre:	52	9	33	5
Post:	86	0	9	5

Please mark the boxes with the letter C (compound) or M (mixture) in the examples given below:

	glass	*sugar*	*baking soda*	*rubber*	*curry powder*	*wine*
	☐	☐	☐	☐	☐	☐
Results:						
answer:	M	C	C	M	M	M
Pre:	38	76	57	29	91	76
Post:	62	95	81	48	95	76

Comment

During instruction the nature of compounds and mixtures was discussed in terms of two simple criteria outlined in Section 5.2.2. In some of the examples above (such as glass, rubber and curry powder) discussion was quite brief. The increase in expressed confidence from 57% to 86% (post-instruction) in the concepts mixture/compound may reflect acceptance of the presented criteria and their use in assessing the quoted examples. In any case, the increased confidence is validated by the general substantial improvement in success rates.

The classification of wine was exceptional in that there was no change in the overall assessment of wine as a mixture (76%). Indeed, the number of respondents classifying wine as a compound increased from 3 (pre-instruction, 14%) with 2 (9%) not responding, to 5 (post-instruction, 24%). Why this should be so, particularly as there had been a laboratory activity involving the distillation of an ethanol/water analogue, is mystifying.

5.2.2 The Two-Tier Multiple-Choice item

The following data were reported by an accomplished chemist, Jules, after analysis of the contents of containers X and Y, both known to contain only the elements A and B either as a mixture or a compound.

analysis	*1*	*2*	*3*	*4*	*5*
%A in X	*35.96*	*38.41*	*41.05*	*33.72*	*40.26*
%B in X	*64.04*	*61.59*	*58.95*	*66.28*	*59.74*
%A in Y	*36.40*	*36.38*	*36.41*	*36.36*	*36.39*
%B in Y	*63.60*	*63.52*	*63.59*	*63.64*	*63.61*

Another person, Hector, claimed that Jules' data proved that the substance in Y was a compound of A and B.

Which of the following statements best represents your opinion of Hector's claim?

(1) Hector's claim is correct.
*(2) Jules' data are good evidence for a compound in Y, but do not prove it to be so.
(3) The data could be proof of a pure compound if more precisely measured.

Reason:

(A) The Principle of Constant Composition is the only criterion which must be met to prove the presence of a compound.

(B) The presence of a compound is only indicated when the substance has properties different from those of the constituent elements. There is no evidence of this here.

(C) The proportions of the sample by weight must reflect a simple ratio of atoms of the elements in a compound.

**(D) The virtually constant composition in Y may simply reflect a very uniform mixture.*

Results: Number of choices (N=21)

	Reason				
Response	A	B	C	D	Total responses
1	3	0	5	0	8 (38%)
2	1	5	2	3*	11 (52%)
3	1	0	1	0	2 (9%)
Total reasons	5	5	8	3	21

*Best choices: 14%

Comments

Dawson (1995) has pointed out that, with difficulties in adequately defining the term *compound*, teachers need to introduce a definition which, although limited, gives certainty in the early stages of learning chemistry In the course Introductory Chemistry, compound formation was characterised by the presence of two or more elements together with

Criterion 1: acquisition of properties different from those of the constituent elements *and*

Criterion 2: obedience to the Principle of Constant Composition.

Mixtures were characterised by retention of properties of the components (albeit to a diluted extent) and were capable of variable composition.

This question tests recognition of the need for both criteria to be met if the formation of a compound is to be declared. Thus the choice of

- Response 1 indicates belief in the sufficiency of the second criterion alone (a choice of 8 respondents (38%)).
- Response 3 indicates a similar notion to that in Response 1.
- Response 2 correctly indicates that the second criterion is insufficient (chosen by 11 respondents (52%)), implying that the first criterion is also necessary.

It was surprising that almost half the class (10 respondents, 48%) supported the Principle of Constant Composition as a sole criterion for compound formation (as Response 1 or 3). This strong support may initially have emanated from considerable exposure to laboratory and theoretical problems based on weight composition of compounds.

It would have been hoped that more than eleven respondents (52%) could have supported Response 2, but the range of Reasons chosen by those eleven indicates that their thinking and understanding was not at all clear.

The choice of

- **Reason A** (5, 24%) simply supports choice of the second criterion, as in Responses 1 or 3,
- **Reason B** (5, 24%) supports the first criterion only.
- **Reason C** (8, 38%) indicates that the respondents were distracted by a true but irrelevant statement.
- **Reason D** (3, 14%) implies the view that the first criterion also needed to be satisfied in order to substantiate Hector's claim. This was the best choice, being an explanation for the absence of proof.

This item is one in which there is insufficient evidence for Hector's claim. No conclusion as to the presence of a compound can be made unless evidence of properties different from those of the elements A and B is available. The combination of Reason B with Response 2 gets close to this position, but the inclusion of the word 'only' in Reason B turns it into a sole criterion or characteristic. In these circumstances, Response 2 with Reason D is the better combination (three respondents, 14%). The eight respondents (38%) who chose the irrelevant but true Reason C statement indicated that their thinking in this matter was limited.

5.2.3 The Post-Instruction Test Question Part B

(modified layout)

A test tube contains 8.0 grams of iron powder and 4.0 grams of powdered sulfur, well mixed. When the test tube is heated, iron combines with sulfur, forming iron sulfide, FeS.

$$Fe + S \rightarrow FeS$$

No reactant or product escapes from the test tube and the reaction is as complete as the proportions of the mixture allow. The Relative Atomic Weights of Fe and S are 56 and 32 respectively.

Are the final contents of the test tube only FeS? If so, how much FeS is formed?

If not, what is the composition of the mixture?

Correct answer: FeS = 11g, Fe = 1g, no sulfur remains.

Results*:* These are discussed in the following comments section

Comments

1. **Notions** needed to successfully complete this question are:

- Fe and S react, and FeS forms, in the **mole ratio** governed by the equation given, viz., 1:1:1, and **no other.**
- Accordingly the reacting weight (mass) ratio is that of the Atomic Weights (molar masses) of the Fe and S.
- $n = m/M_r$ for each species. (n = number of moles; m = mass (g); M_r = molar mass
- excess of one reagent will remain after the reaction if the masses of Fe and S initially present are not in the ratio of their molar masses.

2. **The calculations**

- mixture composition: n(Fe) = 8/56 = 1/7 mole; n(S) = 4/32 = 1/8 mole.
- weight (mass) ratio in reaction:
  - (a) Mole ratio: Since 1/7 mole > 1/8 mole, then 1/8 mole of each of Fe and S react. Excess reagent is Fe, all S is used.
  - (b)Reacting weights: m(Fe) = nM_r = 1/8 x 56 = 7g; m(S) = 4g

Excess **Fe** is (8 – 7) = **1g**; **m(FeS)** = **11g**

3. **Responses**

The responses can be divided into four groups.

- those which obtained the correct answer: (5 respondents, 24%)
- those which assumed that the reaction is completed in the proportions of the initial mixture (33%)
- those which believed that an excess of Fe is involved, but calculations or concepts were in error (4, 19%)
  - one student apparently believed that Fe and S reacted on a gram-for-gram basis. Thus 4g of Fe reacted with 4g of S, leaving 4g of Fe unreacted. Mass is conserved!
  - Three others performed various calculations of moles indicating an excess of Fe but other errors led to non-conservation of mass which was not noticed or dealt with.
- those in which no clear concepts were evident (4, 19%)
  The absence of working on the page of the test booklet made interpretation impossible. One student did not attempt the problem, one had both Fe and S consumed forming $FeSO_4$!

4. Discussion

Set at the conclusion of instruction, this question understandably proved challenging to most of the class. The simpler aspects of the concepts mixture/ compound were extended to use the mole concept and its application to an equation. The difficulties of teaching/learning aspects of the mole concept are well known. Nevertheless it was disappointing that post-instruction, one-third of the class had the notion that combination of Fe and S proceeded in the proportions of the mixture provided. The mole concept appeared not to be considered. Even the Principle of Constant Proportions, introduced with Atomic Weights very early in the semester, appeared to be ignored - yet it could have been used to solve the problem without considering moles *per se.*

5.2.4 Summary for the concept-cluster *mixture/compound*

The success rates for the Concept-Learning Sequence, in chronological order are (as percentages):

Pre inst. (range of 6 items)	2TMC	**Post-Inst. Part A** (range of 6 items)	**Post-Inst. Part B**
mean: 61	14	mean: 76	24

While the data of the Pre-Instruction/Post-Instruction Part A comparisons indicate an improvement, this improvement is essentially in experience of the mixture/compound phenomena. The much more challenging Two-tier Multiple-Choice Test and Part B of the Post-Instruction Test revealed that concept-learning for this concept-cluster was inadequate.

5.3 Concept-cluster 3 - Structure/Bonding

5.3.1 The Pre-Instruction Question and the Post-instruction Question Part A

Consider the following statements.

- *Iris says that Table Salt, sodium chloride, is an* ***ionic*** *substance.*
- *Mavis claims that it is a* ***molecular*** *substance.*

Who is correct? Please tick the box - I (Iris), M (Mavis) or U (if you are uncertain).

		I	*M*	*U*	nr
Results:		☐	☐	☐	
	Pre:	**48***	24	24	5
	Post:	**100***	0	0	0

Please tick the box for the most likely melting point of Table Salt, sodium chloride (given as Celsius degrees).

		-80^{0}	80^{0}	300^{0}	800^{0}	*U*
Results:		☐	☐	☐	☐	☐
	Pre:	0	29	24	**24***	19
	Post:	0	9	5	**86***	0

Comments

Although, before instruction, half of the respondents chose the correct structural units for sodium chloride, there appears to be little correlation between the respondents' choice of structural units and their selection of melting point. The following table illustrates this point.

Respondents' choices pre-instruction (N = 20)
Melting point chosen (^{0}C)

Structural units chosen	–80	80	300	800	U	nr	Total
Ionic	0	4	2	3	0	1	10
Molecular	0	0	2	2	1	0	5
Uncertain	0	1	2	2	0	0	5

The results suggest that there was an initially low appreciation of the nature of these two kinds of structural unit and of a link between bonding and structure as revealed by the melting point. Post-instruction, the learning achievement with respect to sodium chloride was very high, possibly assisted by laboratory efforts to melt the compound.

5.3.2 The Two-Tier Multiple-Choice items

Four of these items were used during the semester. The first item was administered soon after the initial teaching/learning had been completed. The other three items formed part of the final examination.

Item 1

Sodium chloride has a melting point of 801^{0}C. The compound boron carbide, B_4C, has a melting point of 2350^{0}C. B_4C is an electrical insulator above and below 2400^{0}C.

In the solid state B_4C is likely to be a

- *(1) metallic lattice*
- *(2) covalent molecular substance*
- **(3) continuous covalent lattice*
- *(4) continuous ionic lattice*

Reasons:

- *(A) The high melting point and low conductivity indicates very strong bonding forces between the molecules of B_4C.*
- *(B) The non-conductivity of B_4C is evidence that the molecules are strongly bonded to each other.*
- **(C) Non-conducting properties in the molten state prove that the bonding must be covalent in a continuous lattice of atoms.*
- *(D) Since boron is present as B^{3+}, the ions present are unable to dissociate during melting.*

Results: Number of choices (N = 21)

Response	Reason A	B	C	D	Total responses
1	1	0	0	0	1 (5%)
2	1	0	0	0	1 (5%)
3	6	0	10*	0	16 (76%)
4	0	3	0	0	3 (14%)
Total reasons	8	3	10	0	21

*Best choices: 48%

Comment

The item tests understanding of the simple broad classification of the structure/bonding of pure matter based on melting point and electrical conductivity (in solid and melt). Accordingly, the item should be a straightforward test of students' notions. The high melting point together with the insulating property of B_4C signify the continuous covalent structure of the compound. That the compound comprises only non-metals confirms its non-ionic nature. Alternative conceptions are revealed, as usual, by an analysis of the choices of Responses and Reasons.

Reason A contains the contradiction of high melting point arising from the presence of supposed molecules of B_4C.

Reason B contains the fallacy that non-conductivity is an indication of the presence of molecules as well as strong inter-molecular forces.

Reason C is a true statement.

Reason D contains two errors - first, the ionic character attributed to boron, second, the notion that ions cannot dissociate in the melt. The avoidance of this Reason as a choice could imply some understanding, either of melting or of boron as a non-metal.

Strong support for a continuous covalent lattice (Response 3, 76%) is tempered by the fairly strong support for two Reasons. In the choice of the correct combination [3 + C] (48%), support for a continuous covalent lattice may in part have been assisted by the recognition of two non-metals which, of course, bond covalently. The choice of [3 + A] (6 respondents, 29%) implies the students' conception that the structural unit B_4C is itself a molecule with strong intra-molecular forces approximately equal to the inter-molecular forces of attraction.

The three combinations [1 + A], [2 + A] and [4 + B] may simply be the results of guesses or random selection. For example, [1 + A] and [4 + B] each embrace contradictory bonding concepts. The combination [2 + A] indicates a fundamental misunderstanding that molecular lattices have very strong intermolecular forces.

Item 2

Which of the following diagrams best represents the position of the shared electron-pair in the HF molecule?

**(1)* $\mathrm{H} \qquad :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{F}}}:$ *(2)* $\mathrm{H} \; : \; \underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{F}}}:$

Reason:

(A) *Non-bonding electrons influence the position of the bonding (shared) electron-pair.*

(B) *Since hydrogen and fluorine form a covalent bond, the electron-pair must be centrally located.*

**(C)* *Fluorine has a stronger attraction for the shared electron-pair.*

(D) *Fluorine is the larger of the two atoms and hence exerts greater control over the shared electron-pair.*

Results:

	Number of choices (N = 21) Reason				
Response	A	B	C	D	Total responses
1	1	0	12*	2	15 (71%)
2	0	6	0	0	6 (29%)
Total reasons	1	6	12	2	21

*Best choices: 57%

Comment

This item tests the understanding of the nature and influence of the highly electronegative fluorine upon the shared electron-pair of a single covalent bond. Only about half (57%) of the class selected the correct combination in what was thought to be an easy choice. Surprisingly six respondents (29%) thought that the electron-pair of the bond was centrally located between the atoms. Presumably the concept of electronegativity and fluorine's high value of it had been forgotten, ignored or not understood.

Selection of Reason D involves another students' conception, namely that the size of an atom has a dominating influence upon its attraction for electrons.

In Table 5.1 interesting comparisons can be made between the Response/Reason combinations for the 1995 and 1996 Bridging students and the groups studied by Peterson, Treagust and Garnett (1989) using the same test, actually devised by them. Although the differing sizes of the groups prevent rigorous comparisons from being made, it is interesting to note that the success rates (choice of [1 + C]) for the Bridging groups are close to that of the Year 12 group and are quite superior to that of the

Table 5.1 Comparison of four groups for Item 2
(success rates, percentage of class)

Combination	Bridging '95 (N = 31)	Bridging '96 (N = 21)	Year 11[a] (N = 159)	Year 12[a] (N = 84)
*[1 + C]	65	57	43	61
[2 + B]	16	29	33	30

a Peterson et al (1989)

Year 11 group. The 'misconception rate' for the combination [2 + B] is comparable for three groups, with a surprisingly low rate in the 1995 Bridging group.

Item 3

The commercially available substance 'Vaseline' has a thick, smooth, cream-like structure. On the basis of this information, 'Vaseline' would be classified as having

*(1) a covalent molecular structure
(2) a continuous covalent structure*

Reason:

(A) The substance has a continuous linear lattice structure.

(B) The high viscosity of the substance results from the continuous covalent

**(C The molecules of the substance experience weak cohesive forces and can move easily to accommodate changes in shape .*

(D) The bonds within the molecules of the substance break easily to accommodate changes in shape.

Results: Number of choices (N = 21)

	Reason				
Response	A	B	C	D	Total responses
1	0	1	12*	2	15 (71%)
2	0	3	3	0	6 (29%)
Total reasons	0	4	15	2	21

*Best choices: 57%

Comment

Here is a probe of understanding of the link between weak intermolecular (cohesive) forces and physical properties arising from the molecular structure. That only 12 respondents (57%) exhibited this understanding (choices [1 + C]) was disappointing, particularly as this item was set at the end of the semester, when it might be expected that sufficient time had been available for the development of understanding. The four respondents (19%) who chose Reason B failed to realise that continuous covalent structures produce high melting solids. The two respondents selecting Reason D were under the misapprehension that intramolecular (bonding) forces are weak.

Table 5.2 provides comparisons of success rates by four different groups attempting this Two-tier Multiple-choice item. As in Table 5.1, the groups were 1995 and 1996 Bridging students and the Year 11 and Year 12 students studied by Peterson, Treagust and Garnett (1989) who devised the test item.

Table 5.2 Comparison of four groups for Item 3 (success rates, percentage of class)

Aspect	Bridging '95 (N=31)	Bridging '96 (N=21)	Year 11[a] (N=159)	Year 12[a] (N=84)
Response 1	74	71	56	79
*[1+C]	68	57	37	63

a Peterson et al (1989)

The two Bridging groups were markedly more successful than the Year 11 group, in both the first tier and the two-tier combination and their success rates are comparable with those of the Year 12 group.

Item 4

A student wrote a series of statements about the elements of Groups I (one) to VII (seven) on the Periodic Table.

(a) In any Period the atomic radius increases with Atomic Number.

(b) In any Group the non-metallic character of the elements increases with Atomic Number.

(c) The bonding between any Group I (one) element and any Group VII (seven) element is most likely to be ionic.

(d) In any Group the atom's attraction for electrons (electronegativity) increases with increasing core charge.

Which of the following statements are correct?

(1) (a) and (b)

**(2) (c)*

(3) (b) and (d)

(4) (d)

Reasons:

(A) *Non-metallic character is shown by an atom's tendency to gain electrons; this tendency is controlled by the nuclear charge of the atom.*

*(B)** *The relatively high electronegativity of GroupVII (seven) elements can cause the transferenceof electrons from atoms of Group I (one) elements to those of Group VII (seven).*

(C) *An element's Atomic Number determines its electronic configuration and hence its atomic radius and chemical properties.*

(D) *The Coulombic effect of core charge decreases with increasing separation of charges.*

(E) *Ionic bonding occurs when atoms of high electronegativity transfer electrons to atoms of low electronegativity.*

Results: Number of choices (N=21)

Response	Reason A	B	C	D	E	Total responses
1	0	0	1	0	0	1 (5%)
2	0	11*	1	1	4	17 (81%)
3	0	0	1	0	0	1 (5%)
4	0	0	2	0	0	2 (9%)
Total reasons	0	11	5	1	4	21

*Best choices: 52%

Comment

Here is a test of a range of understandings related to atomic structure, properties of atoms or groups of atoms and the Periodic Table. In addition, the stem of the first tier (in statement (c)) contains a generalisation about ionic bond formation in relation to the Periodic Table - the only true statement of the four statements put forward.

In view of the range and complexity of the concepts involved, one might expect a fairly low success rate with introductory students. However, 17 respondents (81%) selected the correct first tier response, and of these, 11 (52%) chose the correct reason. In so doing they had to sift through those which were irrelevant (D), entirely wrong (E) or in contexts other than structure and bonding (C). This is quite a creditable achievement.

Confusion, careless reading or a lack of clear thinking is indicated in the choice of E (4 respondents, 19%), which stated a direction of electron-transfer which is the exact opposite of what is known to occur.

5.3.3 The Post-Instruction Test Question Part B

The melting point of MgO is 2800^{0}C. The radius of the metal species in MgO is 65pm (picometres).
Please tick a box to indicate the most likely value of each of these properties for BaO.

Melting point (^{0}C)	*100*	*4000*	*2000**
Results:	☐	☐	☐
Number of responses:	1(5%)	9 (43%)	11 (52%)

Radius of Ba species (pm)	*59*	*135**	*65*
Results:	☐	☐	☐
Number of responses:	5 (24%)	15 (71%)	1 (5%)

Both melting point and radius correct: 7 (33%)

Comments

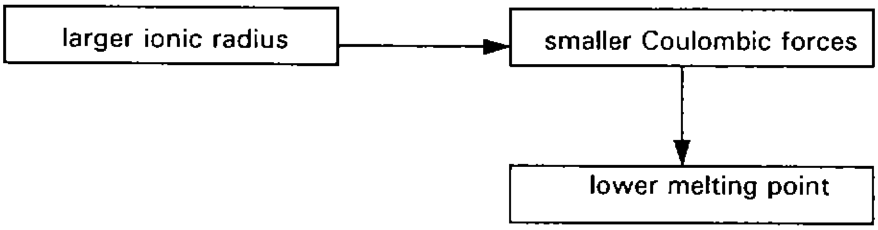
1. Background

The item calls for integration of knowledge of the Periodic Table and atomic structure with notions of ionic bonding and Coulomb's Law. This integration then can be applied to knowledge that the magnitude of the melting point is indicative of the magnitude of the bonding forces. The knowledge, concepts and reasoning which could have led to a correct response are as follows.

- Ba is below Mg in Group II on the Periodic Table.
    - Hence Ba is larger than Mg (either as atoms or as cations).
    - Thus the most likely radius of the Ba species in BaO must be 135pm.
- BaO and MgO are ionic - as Ba^{2+} O^{2-}, Mg^{2+} O^{2-} .
    - Hence electrostatic (bonding) attractions are present, and Coulombic notions apply - the Inverse Square Law relating force of attraction and square of the distance between (centres of) ions holds. The magnitudes, r, of the respective ions determines this distance.
    - Accordingly, since $r_{Ba} > r_{Mg}$, electrostatic attractions (bonding forces) for Ba^{2+} / O^{2-} are less than for Mg^{2+} /O^{2-} .
- The melting point (T_m) is lower for smaller bonding forces. Thus, since T_m = 100^{0}C is typical of molecular species, and T_m (BaO) < T_m (MgO), then T_m (BaO) = 2000^{0}C is the most likely.

2. Discussion of results

That 15 responses (71%) concerning r_{Ba} were correct indicates that knowledge of the Periodic Table with regard to size trends in the Group was adequate. Attempts to apply this size property to making a prediction of melting point were less successful. Respondents were almost equally divided between 2000^{0}C and 4000^{0}C for T_m (BaO), and of the 15 responses giving the correct radius, only 7 (33%) offered the correct value for the melting point. It seems that the reasoning sequence



provided too many pitfalls, especially the first step. No other hard data is available here, but there is anecdotal evidence that novices find difficulties with inverse relationships (such as the inverse square law).

5.3.4 Summary for the concept-cluster ***structure/bonding***

Success rates for the Concept Learning Test Sequence were (as percentages):

Pre inst		2TMC1	2TMC2	2TMC3	2TMC4	Post-Inst Part A		Post-Inst Part B		
bond'g	mp					bond'g	mp	mp	radius	both
48	24	48	57	57	52	100	86	52	71	33

The Pre-Instruction Question and the Post-instruction Question Part A jointly reveal a significant improvement in concept-learning with respect to a single compound, sodium chloride. However, apart from the Post-Instruction Test Question Part B item which involves radius (and is not strictly relevant to the concept-cluster structure/bonding), the success rates for the remaining five items are remarkably consistent, although low, averaging about 52%. Since the concepts of structure and bonding are well known to be at the Piagetian level of Late Formal, the items are clearly difficult. Nevertheless the Bridging students compare satisfactorily with the Year 12 (Matriculation) chemistry students studied by Peterson, Treagust and Garnett (1989) as discussed in Section 5.3.2.

Section 5.4 follows→

5.4 Concept-cluster - *Base/salt*

5.4.1 The Pre-Instruction Question and the Post-instruction Question Part A

The word base has a number of meanings in daily life.
Do you think that you understand the meaning of the term base as it is used in chemistry?
Please tick one of the boxes Y (yes), N (no) or U (uncertain).

	Y	*N*	*U*	
Results	☐	☐	☐	nr
Pre:	43	24	33	0
Post:	76	0	14	9

Please tick the substances below which you believe to be bases or have the properties of bases.

	limestone*	vinegar	table salt	bicarb soda*	ammonia*	table sugar	alcohol	
Results	☐	☐	☐	☐	☐	☐	☐	nr
Pre:	57	14	29	33	52	0	5	29
Post:	95	14	38	71	71	5	3	0

Comment

The numbers of respondents claiming confidence in their understanding of the term *base*, both pre- and post-instruction, fairly closely correspond to the numbers correctly selecting the three bases actually presented. In other words the general increase in confidence post-instruction is borne out by improved selection of the correct bases.

The increased incorrect selection, post-instruction, of Table Salt as a base (from 6 to 8 respondents) may be a result of a practical activity - forming hydrogen chloride from solid sodium chloride and concentrated sulfuric acid. However, as the respondents were not those in the top half of the group, this selection may simply represent confusion or guessing, (even though chloride ion is a base in the more sophisticated Bronsted theory, not introduced in this work-unit).

A small increase in the selection of alcohol as a base probably arises from a knowledge of the presence of the —OH functional group in ethanol and a failure to distinguish it from the ionic species OH^-.

The selection of vinegar (14%) seems to be without recognisable foundation (baseless!) in each case; only one student was consistent.

In the view of the student who is the subject of the Case Study (Chapter 7), acids and bases comprise a difficult topic.She thought that this was so because the unit was a large one and perhaps because bases were a less clear-cut group than acids.

5.4.2 The Two-Tier Multiple-Choice item

Barium salts in solution are poisonous to human beings if swallowed.

A suspension of $BaSO_4$ is swallowed by patients about to undergo X-ray examination of their stomach/intestines. ($BaSO_4$ is opaque to X-rays). There are no ill effects; $BaSO_4$ is insoluble in stomach acids.

If $BaSO_4$ were in short supply, could $BaCO_3$ be safely used in its place?

(1) yes

**(2) no*

(3) more information needed

Reason:

(A) Like $BaSO_4$, $BaCO_3$ passes through the digestive system unchanged and is excreted.

**(B) Unlike $BaSO_4$, $BaCO_3$ neutralises digestive acids to produce soluble barium salts.*

(C) $BaCO_3$ is poisonous whether in solution or in solid form.

(D) $BaCl_2$ formed from $BaCO_3$ in the digestive tract is insoluble in water solution and is harmless to human beings.

(E) The solubility of $BaCO_3$ in acid needs to be known.

Results:

Number of choices (N=21)

	Reason					
Response	A	B	C	D	E	Total responses
1	7	0	0	1	0	8 (38%)
2	1	5*	1	1	0	7 (33%)
3	0	0	0	0	5	5 (24%)
Total reasons	8	5	0	2	5	21

*Best choices: 24%

Comment

In order successfully to answer this item, respondents needed to realise that

- stomach acids are largely hydrochloric acid
- carbonates (including $BaCO_3$) are bases
- solid $BaCO_3$ can react with stomach acids forming barium salts (mainly $BaCl_2$) and carbon dioxide and water
- the $BaCl_2$ is soluble (from table of solubilities in *Introducing Chemistry)*

Respondent(s) who chose the combinations

- [1 + A] (33%) were apparently unaware of the basic (neutralising) property of the carbonate (to form the water-soluble $BaCl_2$)
- [1 + D] was unaware/forgot that $BaCl_2$ is water-soluble
- [2 + D] apparently did not realise the inconsistency of the choices
- [3 + E] (24%) may not have been aware that the term 'solubility' in Reason E can mean an ability to dissolve in (react with) acid. Alternatively they simply may not have realised the acid-base character of the possible reaction, but this seems unlikely if the clue in Reason B was at all thought-provoking or memory-jogging.

Overall, the success rate of 25% was disappointing. A higher success rate might have been recorded if the question had spelled out clearly that stomach acids could be thought of solely as hydrochloric acid. The medical context added another dimension which may have been a distractor.

5.4.3 The Post-Instruction Test Question Part B

(modified format)

State the formula of one of the bases in Part A:

Results:

appropriate base:	13 (62%) -	$CaCO_3$ (9), NH_3 (4)
other base:	3 (14%)	Na_2CO_3 (2), NaOH (1)

Include this formula in an equation representing a reaction in which a salt is formed:

Results:

equation, appropriate base, balanced:	8 (38%)
equation, other base, balanced:	1 (5%)
equation, wrong formula:	1 (5%)

Comment

As well as testing the base/salt concept, this item gave the first and only insight into the development (or otherwise) of symbol skills - the writing of formulae and equations. Opportunities to develop these skills were given during teaching/learning, but the skills themselves were not given the high priority accorded to the development of other chemical concepts. Those students with only Year 10 backgrounds (4,19%) were at a disadvantage because of lack of exposure and practice - less than a semester is not nearly enough time to become satisfactorily skilful from 'scratch'. Another seven students (33%) had only Year 11 Science or chemistry backgrounds and probably were not very developed in these symbol skills, pre-instruction.

Nevertheless the test was able to discern that, in terms of base/salt/acid concepts, there was some success, but not as much as was expected. Thus 13 respondents (62%) were actually able to give the correct formula of one of the three bases named in Part A. Another three respondents correctly quoted a formula of a base not in this group of three bases. Thus 16 respondents (76%) could write a correct formula of at least one base in their knowledge bank. Amongst the wrong formulae were those of salts and a generalised alcohol.

Attempts at equation-writing revealed further errors - in formula-writing, in the concept of a base and in writing fictitious or imagined reactions. However, eight respondents (38%) could write a relevant balanced equation and another two respondents wrote a balanced equation using an irrelevant base. In all, 10 respondents (48%) wrote an equation for the appropriate use of a base to form a salt. This was a disappointing outcome.

5.4.4 Summary for the concept-cluster ***base/salt***

Success rates for the Concept Learning Test Sequence are summarised as percentages on the table below.

Pre instruction (select 3 bases)	**2TMC**	**Post-Inst. Part A** (select 3 bases)	**Post-Inst. Part B** (two parts)
33, 52, 57	25	71, 52, 95	62, 38

Concept-learning of the base/salt concept-cluster was disappointing. One explanation for this may be that the unit of work in *Introducing Chemistry* was quite large and involved two weeks of contact. This is the view of the student, BR, who volunteered to take part in a Case Study, described in Chapter 7.

Section 5.5 follows→

5.5 Concept-cluster 5 - *Redox*

5.5.1 The Pre-Instruction Question and the Post-instruction Question Part A

The terms reduce and reduction have a number of meanings in daily life.

Do you think that you understand their ***chemical*** *meaning? Please tick a box Y (yes), N (no) or U (uncertain).*

	Y	*N*	*U*	
Results	☐	☐	☐	**nr**
Pre:	29	14	52	5
Post:	81	9	9	0

Consider the following chemical statement:

Hydrogen can reduce hot copper oxide to form steam and copper.

Please tick a box to show whether you think this is true (T), false (F) or that you are uncertain (U).

	*T**	*F*	*U*	
Results	☐	☐	☐	**nr**
Pre:	19	14	62	5
Post:	81	9	9	0

Comment

Before instruction, confidence in understanding the term *reduction* was very low - only 6 respondents (29%) claimed any understanding, and of these, only 2 (9%) chose correctly for the chemical statement.

Post-instruction confidence in the term *reduction* was much more firm, with 17 respondents (81%) claiming confidence. Of these 14 (67%) were able to choose the correct response to the chemical statement. This improvement may in part reflect participation in a laboratory activity which included calculating the ratio of atoms present in copper oxide using this very reaction.

5.5.2 The Two-Tier Multiple-Choice items

Five of these items were used during the semester. The first three items were administered soon after the initial teaching/learning had been completed. The other two items formed part of the final examination.

Item 1

In the reaction represented as

$$Fe_{(s)} + CuSO_{4\,(aq)} \rightarrow FeSO_{4\,(aq)} + Cu_{(s)}$$

The copper species is

(1) *oxidised*
**(2)* *reduced*
(3) *neither oxidised nor reduced*
(4) *a reducing agent*

Reason

**(A)* *electrons are transferred from the iron atoms to copper ions*
(B) *iron atoms act as an oxidising agent*
(C) *copper sulfate loses oxygen atoms*
(D) *Electron-transfer cannot occur*
(E) *the oxidation number of copper increases.*

Results: Number of choices (N=20)

	Reason					
Response	A	B	C	D	E	Total responses
1	1	0	0	0	1	2 (9%)
2	10*	1	4	0	1	16 (76%)
3	1	0	0	0	0	1 (5%)
4	1	0	0	0	0	1 (5%)
Total reasons	13	1	4	0	2	20

*Best choices: 50%

Comment

Of the 16 (75%) of the group who thought that the copper species was reduced, 10 (50%) only did so for the right reason. (During the 1995 trial of this item by the class of 33 Bridging Course students, the correct choice [2+A] was made by 12 respondents (35%)). Loss of oxygen by the sulfate (ignoring the loss, too, of sulfur) distracted most of their fellows. This error probably stems from the development of the concept historically through an early definition of reduction involving loss of oxygen by a compound.

The choices of Responses 1, 3 or 4 seem to reflect uncertainty about definition. *Reducing agent* was a concept which often gave rise to questions during teaching/learning. This difficulty forms part of the discussion of Item 2 of the present Two-tier Multiple-choice set.

Item 2

In the reaction

$$Cu_{(s)} + 2NO_3^- + 4H^+_{(aq)} \rightarrow Cu^{2+}_{(aq)} + 2NO_{2\,(aq)} + 4H_2O$$

the reducing agent is
(1) *nitrate ions*
**(2)* *copper atoms*
(3) *hydrogen ions*

Reason

(A) *nitrate ions have lost electrons*
(B) *nitrate ions have lost oxygen*
**(C)* *the oxidation number of nitrogen has decreased algebraically*
(D) *hydrogen ions have gained electrons*
(E) *hydrogen ions have gained oxygen*

Results: Number of choices (N=20)

	Reason					
Response	A	B	C	D	E	Total responses
1	1	2	2	0	0	5 (25%)
2	3	0	7*	1	0	11 (55%)
3	0	0	0	3	1	4 (20%)
Total reasons	4	2	9	4	1	20

*Best choices: 35%

Comment

Identifying a reducing agent proves difficult for introductory students, because, as well as observing and recognising where reduction occurs, the student needs to detect the species causing the reduction (the substance which is itself oxidised). In some cases the term *agent* appears to be incompletely understood - confusion exists as to whether the *agent* is the *cause* or the *effect* of the process of (in this case) reduction.

While an ability to use Oxidation Numbers to discern redox changes had been taught as the best approach, the residues of an historical approach to understanding the phenomenon appear to remain in the minds of many of the group - and the pitfalls forgotten. This is not unexpected, particularly as the time available for teaching/learning the topic concepts was circumscribed by the demands of other topics in the semester-unit. Garnett and Treagust (1992) found similar conceptual difficulties in secondary students.

In order to complete this question successfully, respondents needed to

- be aware of the range and limitations of the various descriptors available for redox reactions and/or

- realise that the system under consideration was best analysed in terms of the Oxidation Number system - and to use it skilfully.

The reasons A, B, D, and E contain redox descriptors (oxygen gain or loss, electron gain or loss) which are applicable in simpler systems but can become contradictory in more complex systems such as the copper/nitric acid mixture. The nitrate ions have apparently lost electrons (been oxidised) while at the same time appear to have been reduced (lost oxygen atoms). Altogether this makes the item a rigorous test of understanding as well as a test of Oxidation Number skills.

The correct response rate of 35%, though quite low, compares very favourably with that of 12% (N = 33) for the 1995 Bridging Course students.

Item 3

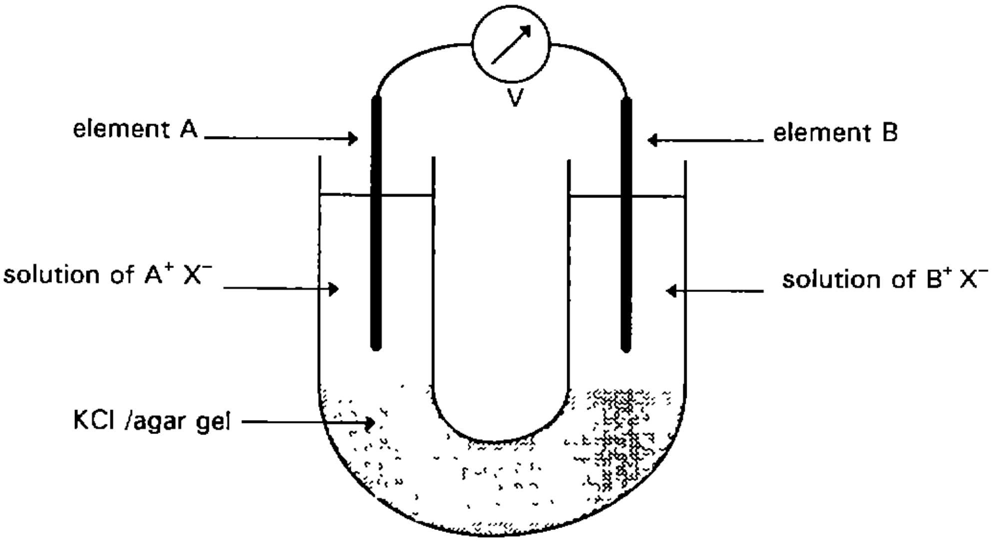


Figure 1

In Figure 1 the chemical change producing the current can be summarised as

*(1) $B + A^+ \rightarrow A + B^+$
(2) $B^+ + A \rightarrow A^+ + B$
(3) $A + B \rightarrow A^+ + B^+ + 2e^-$
(4) $A^+ + B^+ + 2e^- \rightarrow A + B$

Reason

The direction of the needle of the voltmeter shows that

(A) positive charges are lost by B^+
(B) electrons are moving in the external circuit from A to B
(C) X^- ions are moving through the KCl/agar from the B^+X^- arm to the A^+X^- arm.
**(D) A^+ is being reduced by electrons released by B atoms.*

Results:

Number of choices (N=20)

Response	Reason A	Reason B	Reason C	Reason D	Total responses
1	0	1	0	7*	8 (40%)
2	1	5	1	1	8 (40%)
3	0	1	1	0	2 (10%)
4	1	1	0	0	2 (10%)
Total reasons	2	8	2	8	20

*Best choices: 35%

Comment

The electrochemical U-cells were used during laboratory sessions to show that metal displacement reactions are actually electron-transfer processes. This is achieved by physically separating the more active metal from the relevant salt in separate arms of the U-cell. In this item, metal displacement, typified by the $Fe/CuSO_4$ reaction used in Item 1 above, is generalised as the $A/A^+//B/B^+$ system. For a complete understanding of the redox aspects of such a system, additional concepts were necessarily incorporated into the learning process.

One such concept was that of *conventional current,* an historically-based incorrect assumption that electricity flows from positive to negative terminals in an external circuit and that the needle of an analogue 2-0-2 voltmeter indicates the direction of flow.

A second such concept was the modern notion of current as the movement of electrons (negative charges) in the opposite direction to *conventional current.* This movement of electrons through the external circuit is from an electrode supplying electrons to an electrode receiving electrons.

A third and related notion in this particular electrochemical cell is that the source of the electrons is some of the atoms of the 'more active' metal. Such atoms enter the surrounding solution as cations, leaving their electrons to be conducted away from the metal atom matrix through the external circuit.

A fourth and complementary notion is that of capture of the freed electrons by cations of the less active metal in the other arm of the U-cell. This capture is accomplished at the surface of the less active metal (itself acting only in the role of electrical conductor) resulting in the deposition of atoms of that metal on the surface of the electrode.

A fifth notion (though less obviously important) is the maintenance of electrical neutrality in each arm of the U-cell. This is achieved through migration of K^+ or Cl^- ions from the 'salt bridge' into the respective arms of the U-cell which has lost or gained cations because of the two electrode processes comprising the outwardly simpler chemical change.

It is evident that the learner must grasp a number of abstract concepts before considering the relatively easy descriptors of redox reactions needed in this example - the loss or gain of electrons by atomic or cationic species respectively. To answer the item itself, a prime initial consideration is to decide upon the direction of the electronic current in the external circuit. Eight respondents (38%) chose the wrong direction, A to B (Reason B). Of these, five (24%) were internally consistent in choosing the chemical change represented by Response 2.

Those four respondents (19%) who chose Responses 3 or 4 seem to have realised that electron-transfer is somehow involved, but were confused as to how the electrons are generated or, indeed, that the system represents a simple displacement reaction. The two respondents choosing Reason A appear to still believe that electric current is a flow of positive charge. The two choices of Reason C suggest a belief in the migration of X^- ions in the internal circuit as generating a current, albeit in the same direction as 'conventional current' in the external circuit.

The proportion of those choosing the correct combination ([1 + D], 35%) is roughly comparable with that of the 30% success rate of the 1995 Bridging group of 33 students. Both groups fell short of success. Clearly the question is searchingly difficult.

Item 4

In the reaction

$$CO_3^{2-} + 2H^+_{(aq)} \rightarrow CO_2 + H_2O$$

the element carbon is

(1) *reduced*
(2) *oxidised*
**(3)* *neither oxidised nor reduced*

Reason

(A) *carbonate ion loses oxygen*
(B) *carbonate ion loses electrons*
**(C)* *the oxidation number of carbon does not change*
(D) *the oxidation number of carbon increases algebraically*
(E) *the oxidation number of carbon decreases algebraically*

Results:

	Number of choices (N = 21) Reason					
Response	A	B	C	D	E	Total responses
1	1	0	0	1	3	5 (24%)
2	0	0	0	1	0	1 (5%)
3	0	0	15*	0	0	15 (71%)
Total reasons	1	0	15	2	3	21

*Best choices: 71%

Comment

Appearing in the final examination, this item was attempted after a substantial period (about half of a semester) for maturation of the concepts of redox and acid-base reactions. As in Item 3, this item requires understanding of the limitations and range of the descriptors of redox and/or an ability to use oxidation numbers adequately. Initially, a recognition of the system as an acid-base reaction should give a realisation that here, oxidation numbers do not change. Accordingly the five (24%) respondents who chose Reasons D or E, probably did not realise the acid-base nature of the reaction or that acid-base reaction are not redox reactions. They certainly did not have satisfactory oxidation number skills. Guessing is a distinct possibility.

The success rate of 71% is not as large as was expected, given the relative ease of the item and the period for maturation of concepts. It compares favourably, however, with the success rate of 54% by the 1995 Bridging group (N = 33).

Item 5

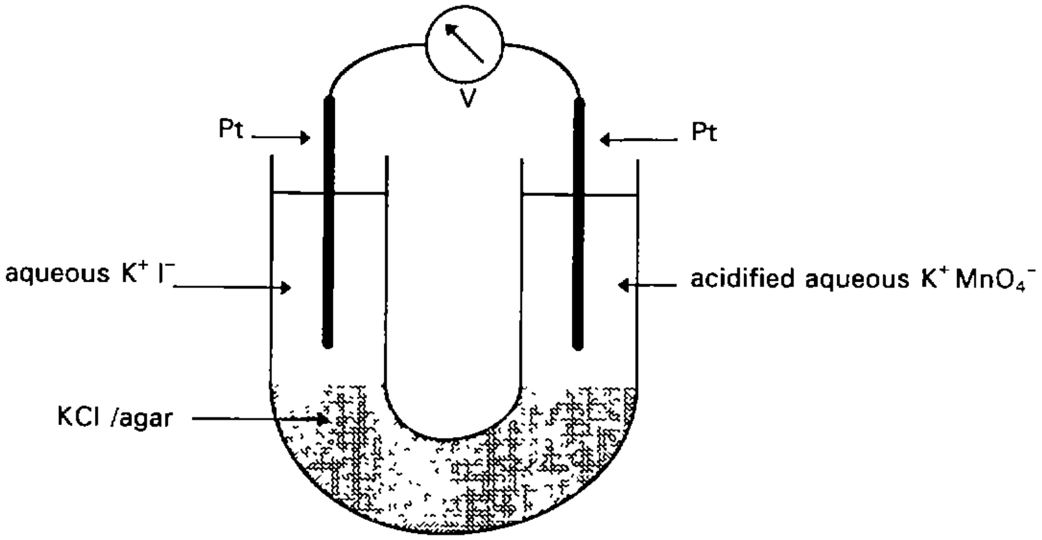


Figure 2

For the working cell (Figure 2), a student wrote four possible half-reactions:

(a) $2I^-_{(aq)} + 2e^- \rightarrow I_{2\,(s)}$

(b) $2I^-_{(aq)} \rightarrow I_{2\,(s)} + 2e^-$

(c) $MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 4H_2O + 5e^-$

(d) $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

The correct pair of half-reactions is

(1) *a + c*
(2) *b + c*
(3) *a + d*
**(4)* *b + d*

Reason: *In the external circuit*

(A) *positive charge is flowing from left to right*
(B) *electrons are flowing from right to left*
**(C)* *electrons are flowing from left to right*
(D) *positive charge is flowing from right to left*

Results: Number of choices (N=21)

	Reason				
Response	A	B	C	D	Total responses
1	0	3	0	0	3 (14%)
2	0	0	1	0	1 (5%)
3	0	1	1	2	4 (19%)
4	0	1	12*	0	13 (62%)
Total reasons	0	5	14	2	21

*Best choices: 57%

Comment

Set in the final examination, this item, like Item 3, tests redox concepts in the context of an electrochemical cell. It differs from Item 3 in that

- the reactants are specific, and known through laboratory experience of just such a cell.
- The electrodes take no chemical part in the cell reaction, serving only as electrical conductors. The reaction's electron-transfer takes place at each inert electrode by participation of ionic species in solution.

In the working cell, yellow-brown iodine solution appears in one arm of the cell while the pink-purple colour of permanganate disappears from the other arm. These characteristics may have helped students more easily to relate to and understand this cell than that in Item 3, the success rate of which was only 35%. Moreover, the period between the tests (about half of a semester) may have provided an 'incubation period' for the development of redox concepts. These factors may explain the better success rate of 57% in this item.

Consideration of the Responses and Reasons can give further insights.

Response 1, (a+c), represents electron-transfer in the opposite senses to the correct ones, chosen by 3 (14%) respondents, apparently because they believed that the voltmeter indicated elecron-flow right-to-left of the diagram. This response ignores the contradictory notion in half-reaction (a) of iodide ions *gaining* electrons to form molecular iodine. Response 2 implies belief that *each* half-reaction *released* electrons, denying the complementary nature of redox (electron-loss and -gain). The choice of Reason B by one student is difficult to understand. Response 3, the opposite of Response 2 and chosen by 4 respondents (19%) indicates belief that *each* half-reaction *accepted* electrons, the source of which is unclear, and for which no Reasons (B, C or D chosen) provide valid explanation, of course. The choice of Reason D by two respondents indicates a continuing belief in the actuality of 'conventional current'. The correct combination [4+C], chosen by 12 respondents (57%) represents a far superior success rate to the previous year, when only 21% chose this combination.

5.5.3 The Post-Instruction Test Question Part B

At high temperatures carbon reacts with copper oxide to form carbon monoxide and metallic copper.

Please tick a box T (true) or F (false) in response to the following statements about this reaction:

	*T**	*F*
• *Red hot carbon is a reducing agent*	☐	☐
Results	81	19
	*T**	*F*
• *Copper gains electrons*	☐	☐
Results	71	29
• *The oxidation number of* *oxygen changes from -2 to +2*	*T*	*F**
	☐	☐
Results	14	86

All three correct: 57%

Comment

The reaction was briefly studied in the laboratory. The questions represent a final simple test of the understanding of three redox descriptors. The success rate in individual questions is high, although guessing, clearly, is not to be discounted. The success rate in all three questions (57%) seems a more realistic measure of the group's handling of the descriptors.

5.5.4 Summary for the concept-cluster *redox*

Success rates for the Concept Learning Test Sequence are summarised below as percentages, with results of the 1995 trial for the Two-tier Multiple-choice items shown for comparison.

Year	Pre inst	2TMC					Post-Instruction				
		1	2	3	4	5	A	B			
'96	19	50	33	35	75	57	81	81	71	86	(all three: 57)
'95		36	12	30	54	21					

A simple comparison of success rates within the Sequence is not particularly instructive because the Two-tier Multiple-choice items were much more challenging than any single other item. Nevertheless the large improvement in a single aspect of the concept *redox* which can be inferred from the result of the Post-instruction Question Part A is signal of a degree of achievement in concept-learning.

Those students who were successful in each of the Two-tier Multiple-choice items and the three Post-Instruction Test items Part B could well be described as having achieved 'quality learning': the Two-tier Multiple-choice items as a group were as challenging as any in the ten Concept Learning Test Sequences. If a single test of redox concept-learning were needed for the Bridging group, that test might be to achieve success in all three items in the Post-Instruction Test Question Part B.

Comparisons with the 1995 group definitely favour the 1996 group, who had the advantage of an extra hour per week of instruction throughout the semester. The comparisons also give some consistent indication of the relative difficulty of each of the five Two-tier Multiple-choice items. Both groups, for example, found Number 2 to be the most difficult and Number 4 the least difficult. Analysis of these items could be fruitful for future administration of the tests.

5.6 Concept-cluster - *Mole*

5.6.1 The Pre-Instruction Question and the Post-instruction Question Part A

(modified format)

Do you feel confident about your skill in the use of indices (for example $5x10^{12}$) in arithmetic operations involving multiplication or division ?

Please tick Yes or No:

	Yes	*No*	
Results	☐	☐	**nr**
Pre:	81	19	0
Post:	81	5	14

Now attempt the following calculations:

At supermarkets one can buy a ***2kg*** *bag of table sugar. The bag itself has neglible volume and mass. If the sugar has a volume of* ***3 litres*** *and contains* ***$1x10^9$ granules****, answer the following questions. (You need not show your calculations unless you wish).*

Results and answers:

		Results	
	Answer	**Pre**	**Post**
1. How many bags are needed to have 12 kg of sugar?	6	95	95
2. How many bags are needed to provide $6x10^9$ granules?	6	86	100
3. How many granules are there in 7 bags of sugar?	$7x10^9$	90	100
4. How many granules occupy 1.5 litres?	$5x10^8$	81	86
5. What is the weight of $4x10^8$ granules?	0.8kg	67	76
6. Find the volume of $2x10^8$ granules.	0.6L	57	76
7. In 500 grams of sugar how many granules are there?	$2.5x10^8$	71	100
8. How much do 100 granules weigh?	$2x10^{-8}$ kg	43	76

Acknowledgement:
Gabel, D. & Sherwood, R.D. (1984). Journal of Research in Science Teaching 21(8) 843-851.

Comments

1. Confidence levels appear to be unchanged, post-instruction. The non-respondents were perhaps unwilling to admit to uncertainty in an examination context.

2. Gabel and Sherwood (1984) investigated skills and concepts that are pre-requisite for solving problems involving the mole concept. They used the quantitative properties of the contents of bags of oranges or packets of sugar as analogues for particulate aspects of the mole. Using multiple-choice questions they found that

- problems involving scientific notation were more difficult than those that do not
- problems involving the multiplication process are easier than those involving division
- problems involving two steps are harder than those requiring one step.

- problems involving multiples of a standard property (such as the weight, volume or number of granules in a bag of sugar) are easier to solve than those involving less than the whole.

In the present research, Gabel and Sherwood's questions were modified, adapted to SI units and converted to single-answer calculations. Eight items were developed to test whether the Bridging Course students had a similar range of difficulties to those students tested by Gabel and Sherwood. The sugar/granule analogue was used throughout for consistency. The table below presents the arithmetic characteristics of the eight calculations.

Arithmetic properties of the calculations

calcn. number	number of steps	number of terms with scientific notation	uses x or ÷ ?	answer has fraction of standard property?
1	1	nil	÷	no
2	1	2	÷	no
3	1	1	x	no
4	2	1	x ÷	yes
5	2	2	x ÷	yes
6	2	2	x ÷	yes
7	2	1	x ÷	yes
8	2	1	x ÷	yes

3. Used in conjunction with this table, the responses to the test items show that
    - in both Pre- and Post-Instruction Tests, the success rates tend to fall off after Calculation Number 3. This is likely to be because of the increased complexity of calculations after Number 3, thus concurring with the findings of Gabel & Sherwood (1984).
    - in the Pre-Instruction Test, Numbers 7 and 8, although 'structurally' the same as Number 4, appear to be more difficult. This is probably because their answers need to be expressed in scientific notation. Indeed, in Number 8 the need to express the answer with a negative index appears to have increased its difficulty.
    - in the Post-instruction Test, the 100% success rate in Calculation Number 7 may be a reflection of a rather easier question than Number 6, less manipulation of scientific notation being required.

The general improvement after instruction may be due, not only to experiences of the chemistry unit, but also to the concurrent Bridging Mathematics unit which all the Bridging Chemistry students attended.

5.6.2 The Two-Tier Multiple-Choice item

In Unit 6 of 'Introducing Chemistry' Joanna measured the temperature rise (ΔT^0C) in a series of 100mL mixtures of solutions of 1.0M Cu^{2+} and 2.0M OH^-. She called this Experiment 1. Here are her results.

mL Cu^{2+} (1.0M)	0	10	20	30	40	50	60	70	80	90	100
mL OH^- (2.0M)	100	90	80	70	60	50	40	30	20	10	0
$\Delta T(C^0)$	0	1.2	2.4	3.6	4.8	6.0	4.8	3.6	2.4	1.2	0

These results confirmed the formula $Cu(OH)_2$ for copper hydroxide and the reaction equation to be $Cu^{2+} + 2OH^- \rightarrow Cu(OH)_{2\ (s)}$.

Joanna plans to make a similar series of mixtures as Experiment 2, using 1.0M Cu^{2+} and 4.0M OH^- solutions. (She wants to find the maximum value of ΔT and the number of mLs (V) of 4.0M OH^- in the mixture when this maximum occurs).

Which of the following sets of results should she expect in Experiment 2?

	ΔT (C^0)	*V (mL)*
(1)	*3.0*	*50*
(2)	*12.0*	*50*
**(3)*	*6.0*	*25*
(4)	*12.0*	*25*

Reason:

In Experiment 2:

(A) At V=50 the number of moles of $Cu(OH)_2$ formed is twice as many as at V=50 in Experiment 1.

(B) At V=50 the number of moles of $Cu(OH)_2$ formed is the same as at V=50 in Experiment 1.

(C) The number of moles of $Cu(OH)_2$ formed is limited only by the number of moles of OH^-.

(D) At V=25 the number of moles of $Cu(OH)_2$ formed is twice as many as at V=50 in Experiment 1.

**(E) At V=25 the number of moles of $Cu(OH)_2$ formed is the same as at V=50 in Experiment 1.*

Results: Number of choices (N = 13, nr = 1)

	Reason					
Response	A	B	C	D	E	Total responses
1	1	0	0	0	0	1 (8%)
2	0	0	0	1	0	1 (8%)
3	0	0	0	0	8*	8.(62%)
4	0	0	0	0	3	3 (23%)
Total reasons	1	0	0	1	11	13

*Best choices: 61%

Comments

The original form of this item was presented in an assessment test with other Two-tier Multiple-choice items and conventional questions. However, an error was detected in the original item (Response choices were faulty) and it was withdrawn from the assessment after the students had attempted it. The following day the present version was attempted, albeit by six fewer students. With another student absent ill, and another unable to complete the question, the active respondents numbered only 13. It appears that the experience of doing the earlier version was of some help in attempting the second version. The success rate (61%) is quite high for such a difficult item. The basis of the item is a laboratory exercise performed by all the students. The table of experimental data given here resembles the data obtained in the laboratory exercise. The item is a test of the learner's understanding of the mole concept particularly in respect of calculations using mole relationships. The principal understandings needed are

- Cu^{2+} and OH^- react in the mole ratio 1:2 always
- n (number of moles) = V (volume as litres) x C (concentration as mol/litre) *or,* more conveniently,

  n (mmoles) = V (volume as mL) x C (concentration as mol/litre),

  ie, $n = VC$ (in consistent units)
- the temperature rise ΔT is proportional (under the conditions of the exercise) to the number of moles of $Cu(OH)_2$ which are formed.

  ie, $\Delta T \propto n$

  The data of Joanna's Experiment 1 permit quantification of this relationship.

The Reasons A, B, D and E in the Item imply that, to successfully answer it, a set of calculations needs to be made. The essence of the calculations is to work out the number of millimoles of $Cu(OH)_2$ formed at $V = 50$ and $V = 25$ and hence ΔT for each case. These calculations are set out below.

Calculations for Experiments 1 and 2

V (NaOH) (mL)	initial OH^- (mmoles)	initial Cu^{2+} (mmoles)	$Cu(OH)_2$ formed (mmoles)	ΔT (^0C)	comments
50	**Expt 1** n = VC = 50x2 = 100	n = 50x1 = 50	OH^- : Cu^{2+} = 2:1 50	6.0	establishes ΔT per mmole of $Cu(OH)_2$
	Expt 2: n = 50x4 = 200	n = 50x1 = 50	OH^- : Cu^{2+} = 2:1 50	6.0	excess NaOH. Same mmoles of $Cu(OH)_2$ as Expt 1
25	**Expt 2:** n = 25x4 = 100	n = 75x1 = 75	OH^- : Cu^{2+} = 2:1 50	6.0	excess Cu^{2+} Same mmoles of $Cu(OH)_2$ as Expt 1

These calculations provide some insight into the Response/Reason combinations which appear on the Results table:

- [1 + A] makes no sense, even if the calculations have not been made. Perhaps this is a guess.
- [2 + D] is internally consistent in the absence of correct calculations. Perhaps the respondent has erred in calculation or has failed to appreciate the notion that $\Delta T \propto n$.
- [3 + E] is the correct combination, reached by 8 respondents (61%). The intricacies of the above calculations and concepts have been negotiated.
- [4 + E]: ΔT cannot be doubled when the number of milli-moles of $Cu(OH)_2$ formed is the same in each case. There is the possibility of confusion between doubling the concentration of OH^- and doubling the possible number of moles formed.

It was a pity that six of the class were absent on the day of the reset test item. (It appears that they may have had urgent academic duties to complete for another unit). The extra number of respondents would have made insights into concept-learning a little more clear.

5.6.3 The Post-Instruction Test Question Part B

What is the weight (mass) in grams of 1.5 x 10^{21} molecules of SO_3 ?
(S = 32.0; O = 16.0)

Answer: 0.20g
Result: Correct answer: **57%**
Correct method only: **5%**

Comment

The successful respondents needed to know:

- how to calculate molar mass from the formula and Atomic Weights
- the relationships

$$m/M_r = n = N/N_A$$

- a value of N_A

The calculations are:

- $M_r\ (SO_3) = 32 + (3 \times 16) = 80$
- $m = M_r \times (N/N_A) = \{80 \times (1.5 \times 10^{21}) \div (6 \times 10^{23})\} = 0.20g$

The Item has the same arithmetic 'structure' as Number 5 in Part A of the Post-instruction Question, but the success rate is inferior (57% compared to 76%) and, indeed, some of the otherwise more successful students got this calculation wrong. One difference in content is that the molar mass had to be calculated from the sum of Atomic Weights. However, errors in this calculation seemed to be few (working was not required to be shown). The other difference from Number 5 was the use of the word *molecules* (Number 5 used *granules*). This led two students to equate *molecules* with *moles*, which in turn led them to astronomical masses for the sample quoted.

Some of the errors which generally arose were:

- the use of $m = N/M_r$ instead of $m = n\ M_r$
- answers with unrealistic values like 1.2×10^{-23}g were offered.

Overall, the success rate was not beyond expectations.

5.6.4 Summary for the concept-cluster *mole*

Success rates for the Concept Learning Test Sequence are summarised below as percentages.

Pre-instruction (range of 8 calculations)	2TMC	Post-Inst Part A (range of 8 calculations)	Post-Inst. Part B
43-95 mean:74	57	76-100 mean.89	62

For one of the most difficult of concept-clusters, the resulting learning is quite fair.

5.7 Concept-cluster - *Rate*

5.7.1 The Pre-Instruction Question and the Post-instruction Question Part A

In a chemical change the speed at which the reaction forms products is called the rate (R) of the reaction.
Often, when solids are involved, R is proportional to the surface area of the solid.
*Do you feel that you understand the phrase **is proportional to** ?*
Please tick a box.

	Yes	No	Unsure	
	☐	☐	☐	nr

Results

Pre:	81	5	9	0
Post:	91	5	0	5

In a study of a reaction in which R is proportional to the surface area (A) of a metallic reactant, a chemist did two experiments at the same temperature.The first had A = 100 units of area, and R was measured at 40 rate units.
In the second experiment, A was increased by 25 units of area.

What do you predict for the second value of R?
Please show your prediction in the box:

Results

R:	3	10	30	50*	65	"increase"
Pre:	0	9	0	71	5	0
Post:	5	0	5	71	9	1

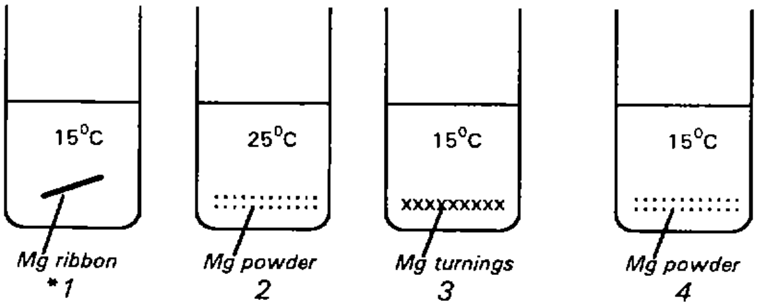
Comment

The notions of ratio and proportional reasoning were to be emphasised in the approach to Rate Law determinations in work-unit 7 of *Introducing Chemistry*. Accordingly it was necessary to check the confidence and skill of the class members prior to instruction. The initial confidence fo the class was quite high (81%), borne out by reasonable success in the above problem (71%). The actual success rate was unimproved and the diversity of wrong answers widened post-instruction for reasons which are unclear.

5.7.2 The Two-Tier Multiple-Choice items

Item 1

Masses of 1 gram of magnesium metal were reacted with hydrochloric acid (1.0 mol/L) under the conditions shown in the diagrams.



In which one of the beakers will the initial reaction rate be slowest?

Reason

A. *Reactant collision frequencies are increased by a rise in temperature and decreased by greater surface area of solids.*

B. *Increased surface areas of solid decrease the chance of collision between reactants.*

C. *Lower temperatures reduce inter-molecular distances thus increasing the number of reactant collisions.*

**D.* *Collision frequencies are increased by both increased surface area of solids and an increase in temperature of the reactants.*

Results: Number of choices (N = 21)

Response	Reason A	B	C	D	Total responses
1	3	0	0	17*	20 (95%)
2	1	0	0	0	1 (5%)
3	0	0	0	0	0
4	0	0	0	0	0
Total reasons	4	0	0	17	21

*Best choices: **81%**

Comment

The easiest of the Two-tier Multiple-choice items (with Item 4), this produced a very narrow range of selection of Responses and Reasons. Twenty students (95%) chose the correct beaker. Of them, three (14%) chose incorrect Reason A, apparently harbouring the misconception that increased surface area causes a slower rate of reaction. The single choice of beaker 2 probably arose from careless reading, expecting the question to ask for the *fastest* reaction.

Item 2

A chemist studied the effects of two catalysts, P and Q upon the initial rate of the reaction

$$X + Y \rightarrow Z.$$

The rate was measured in five experiments under conditions starting as shown in the table.

Experiment number	*[X] (mol/L)*	*[Y] (mol/L)*	*[P] (mol/L)*	*[Q] (mol/L)*	*Rate (mol/L/hr)*
1	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
2	*2.0*	*1.0*	*1.0*	*1.0*	*2.0*
3	*2.0*	*2.0*	*1.0*	*1.0*	*4.0*
4	*1.0*	*2.0*	*2.0*	*1.0*	*4.0*
5	*1.0*	*1.0*	*1.0*	*2.0*	*4.0*

The catalyst with the largest influence upon the rate was

(1) *P*
**(2)* *Q*
(3) *P and Q equally*
(4) *not able to be deduced*

Reason

A. *The different concentrations of X and Y in experiments 1,2,3,4 prevent valid conclusions from being made.*

B. *Doubling [X] or [Y] has the same effect as doubling [P] or [Q].*

**C.* *Doubling [Q] leads the quadrupling (four times) the rate of experiment 1.*

D. *Doubling either [P] or [Q] results in quadrupling (four times) the rate in experiment 1.*

E. *Doubling [P] leads the quadrupling (four times) the rate in experiment 1.*

Acknowledgement: *This item is based on Question 18, Application section of Beard, Fogliani, Owens & Wilson (1992). Multiple Choice Chemistry Questions. Senior Years 11 & 12 Vol 1. Australian National Chemistry Week.*

Results: Number of choices (N=21)

	Reason					
Response	A	B	C	D	E	Total responses
1	0	0	0	0	0	0
2	0	0	**15***	0	0	15 (71%)
3	0	2	0	1	0	3 (14%)
4	3	0	0	0	0	3 (14%)
Total reasons	3	2	15	1	0	21

*Best choices: **71%**

Comment

1. Implications of the experimental data

This item is essentially a test of proportional reasoning skills and controlling variables in a context of rates of reaction and tabulated data. Experiment No. 1 establishes a reference for concentrations and Rate. Experiments Nos. 2 and 3 collectively show the effect of changing the concentrations of X or Y without changing either of the catalysts P or Q. They establish that Rate is proportional to either [X] or [Y]. Experiment No. 4, when compared with the data of Experiment No. 3, establishes that halving [X] and doubling [P] at the same time, retains the same rate. Since halving [X] alone would halve the rate ($R \propto [X]$), it follows that Rate and [P] must be proportional ($R \propto [P]$). Comparison of Experiment Nos. 5 and 1 shows that doubling [Q] leads to a quadrupling of Rate, that is, $R \propto [Q]^2$. Thus Q has the larger effect of the two catalysts P and Q.

2. The responses

An examination of Responses reveals that

- the three students (14%) who chose the combination [4 + A] seem not to have the insights or skills to extract the relationships, and that
- this may also be true of the three respondents who chose Response 3. The quadrupling effect of Q, established by comparing Experiment Nos. 5 and 1 seems not to have been evident, although the inference that P has a simple proportional relationship with R is difficult to establish through a comparison of the results of Experiments 3 and 4.

That 15 (71%) students chose the correct combination of Response with Reason was taken as evidence of satisfactory skill in proportional reasoning in this context.

Item 3

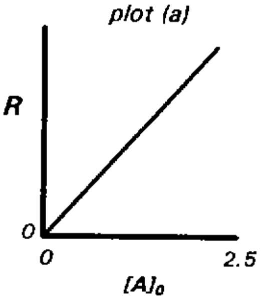
A chemist studied the decomposition of substance A in five experiments. The chemist was interested in the relationship between the initial rate (R), the rate coefficient (k) and the initial concentration, $[A]_0$. The following results were obtained, all other variables being kept constant.

Experiment number	*1*	*2*	*3*	*4*	*5*
$[A]_0$ (mmol/L)	*0.5*	*1.0*	*1.5*	*2.0*	*2.5*
R (mmol/L/h)	*0.48*	*1.92*	*4.30*	*7.60*	*12.0*

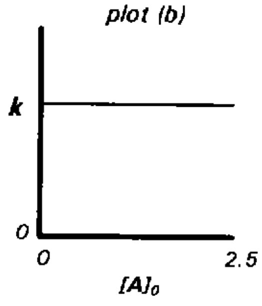
Which of the following plots (a), (b), (c), (d), (e) seem to be true statement(s) for the experiments?

(1) *(a) and (d)*
(2) *(c) and (e)*
(3) *(a)*
(4) *(d)*
**(5)* *(b)*

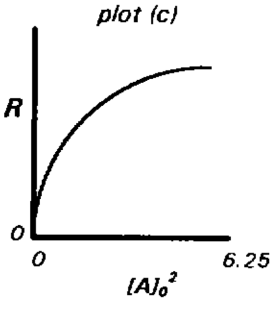
plot (a)

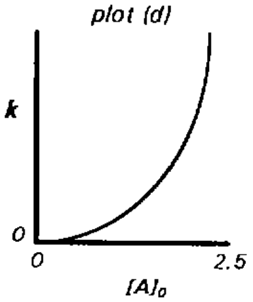


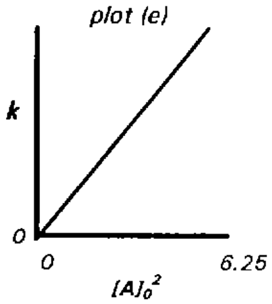
plot (b)



plot (c)







Reason

**A.* *k is independent of* $[A]_0$

B. *The reaction is first order in* $[A]_0$

C. *The reaction is not second order in* $[A]_0$

D. *k is proportional to the square of* $[A]_0$

E. *R is independent of the order in* $[A]_0$ *.*

Results: Number of choices (N=21)

	Reason					
Response	A	B	C	D	E	Total responses
1	0	0	0	2	0	2 (9%)
2	1	0	0	5	0	6 (29%)
3	2	3	0	0	0	5 (24%)
4	2	0	0	1	3	6 (29%)
5	2*	0	0	0	0	2 (9%)
Total reasons	7	3	0	8	3	21

*Best choices: 9%

Comments

1. An overview

This item was found to be the most challenging of all the Two-tier Multiple-choice items, having a success rate of only 9%. A particular challenge arose because a successful outcome could only be reached when there was concordance between *three* aspects of the question

- the implications of the experimental data
- the plot(s) chosen in response to the question (the Response)
- the Reason selected to justify the choice of plot(s).

To this extent the item was *three-tiered.* In many cases it appears that respondents failed to realise the need for this three-fold concordance.

The experimental data indicate the relationship Rate $\propto [A]_0^2$, that is, $R = k[A]_0^2$. This insight gives reason to reject plot (a) as untrue since this plot represents a linear relationship, $R = k[A]_0$. Plot (c) is a non-linear relationship between R and $[A]_0^2$ and so it, too, cannot be a true statement about the experimental data. The remaining plots (b), (d) and (e) display relationships between the *rate coefficient, k,* and concentration terms in $[A]_0$. Of these, plots (d) and (e) indicate dependence of k upon concentration. Since k is independent of concentration (a constant at a given temperature), neither plots (d) nor (e) can be true statements about the data. This leaves plot (b) which correctly represents k as unaffected by changes in $[A]_0$. The correct selection is therefore Response 5 with Reason A.

2. The respondents' choices

Both plots in Response 1 (plots (a) + (d)) fail to represent implications of the experimental data. The choice of Reason D ($k \propto [A]_0^2$) by two respondents (9%) has no relevance to plot (a). The selection of this Reason may in part be due to confusing the need to find plot(s) which represent a true statement about the experiments with giving a description of the relationship represented by a plot. Discounting or ignoring the constancy of k is evidence of additional confusion.

As described above, each of the plots selected by Response 2 ((c) and (e)) represents an incorrect statement about the experimental data. Of the six respondents (29%) with this choice, five selected Reason D ($k \propto [A]_0^2$) to support this Response, even though all their teaching/learning experiences emphasised the constancy of k at constant temperature. Testing this notion was an objective of the item. A possible clue to these respondents' thinking may be that Reason D correctly describes the relationship which plot (e) represents. This fact may have had some appeal. However, the general falsity of this relationship, or its relevance to plot (c), appears to have been overlooked.

Response 3 (plot (a)) is inappropriate for reasons described previously. Of the five respondents (24%) choosing it, two selected Reason A to support it. This Reason is a true statement in itself but irrelevant to the selection of Response 3. Reason B, selected by three respondents, is a true statement concerning plot (a) - again a fact perhaps having some appeal - but it does not justify the choice of plot (a) as a true statement about the experimental data.

In plot (d), Response 4 accepts an accelerating value of k with increasing $[A]_0$. As well as this comprehensive scientific incorrectness, the plot's relevance to the experimental data is non-existent. It may be that respondents were distracted by the shape of the plot, since a half-parabolic curve would be expected from the experimental data if R, not k, had been shown on the vertical axis. Of the six respondents (29%), two chose Reason A, which, being a generically true statement, completely contradicts the sense of their Response. Selection of Reason D by one respondent provides a correct description of the plot, *per se,* but without relation to the experimental data.

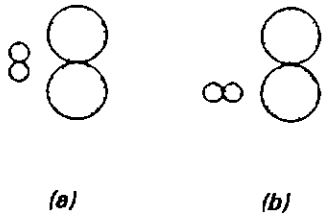
The three respondents (14%) who chose Reason E must have discounted or ignored the experimental data since the rate is demonstrably dependent upon the square of $[A]_0$.

Response 5 (plot (b)) correctly indicates the constancy of k with changing $[A]_0$. Reason A is then simply a restatement of this fact. The choice of Reason A here gives the correct combination for the item. Ultimately then, no plot directly represents the experimental data - rather, plot (b) represents the fact of rate studies, that the rate coefficient is constant at constant temperature and is independent of other factors.

Item 4

For the system $H_{2\,(g)} + I_{2\,(g)} \rightarrow 2HI_{(g)}$

- *Figure 1 shows two possible orientations of the reactant molecules*
- *Figure 2 shows plots representing the fractions of the total molecules which have particular energies at two temperatures.*



(a) *(b)*

Figure 1: Orientations of H_2 and I_2

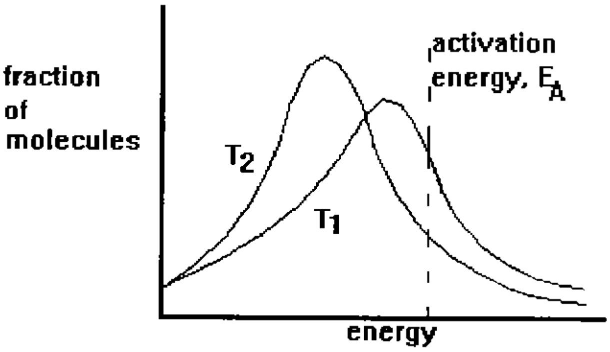


Figure 2: Energies of molecules at temperatures T_1 and T_2

Which combination of conditions is most likely to produce a reaction?

(1) *T2 plus (a)*

(2) *T1 plus (b)*

(3) *T2 plus (b)*

**(4)* *T1 plus (a)*

Reason:

A. *At T2, more molecular collisions exceed E_A ; (b) is a more favourable orientation for bond-breaking.*

B. *At T1, more molecular collision exceed E_A ; orientation (b) is more favourable for bond-making.*

C. *At T2, more molecular collisions exceed E_A ; orientation (a) is more favourable for bond-making and bond-breaking.*

**D.* *At T1, more molecular collisions exceed E_A ; orientation (a) is more favourable for bond-making and bond-breaking.*

Results: Number of choices (N = 21)

	Reason				
Response	A	B	C	D	Total responses
1	0	0	6	0	6 (29%)
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	15*	15 (71%)
Total reasons	0	0	6	15	21

*Best choices: 71%

Comment

As the easiest of the Two-tier Multiple-choice items (with Item 1) this produced only two Response-Reason combinations. This was not altogether unexpected in view of the relative simplicity of available choices and reasons. Every respondent chose orientation (a) for the molecule pair, either as Response 1 or Response 4,. This is the only occasion during the use of the Two-tier Multiple-choice items that there has been 100% agreement by respondents on a part of a test item.

The group divided 15:6 on their choice of plots. Critical steps in making a correct decision at this stage were

- understanding that the reaction is more likely to proceed when there is a higher proportion of molecules exceeding the Energy of Activation
- interpreting the plots in order to decide which indicates the higher proportion of more energetic molecules.

Experience suggests that the second step is more likely to be a source of error. It is relatively easy or tempting to interpret the higher and more conspicuous T_2 peak as having more molecules of the appropriate energy. As indicated above, however, the critical criterion is the number of molecules exceeding E_A (to the right of the dashed line): the T_1 plot clearly indicates more molecules than the T_2 plot in this region. Fifteen respondents (71%) chose this correct response with the appropriate reason.

5.7.3 The Post-Instruction Test Question Part B

In one kind of reaction, R is proportional to the concentration (C) of one of the reactants. In a second kind of reaction, R is proportional to the ***square*** *of the concentration (C^2) of one of the reactants.*

In two experiments with this latter kind of reaction, the first experiment had $C = 1$ unit of concentration, that is, $C_1 = 1$. The second had $C = 0.5$ units of concentration, that is, $C_2 = 0.5$. The respective rates R_1 and R_2 were measured at the same temperature.

Tick the correct relationship between the rates R_1 and R_2 :

	$R_2 = 2R_1$	$R_2 = 4R_1$	*$R_2 = R_1/4$	$R_2 = R_1/2$
	☐	☐	☐	☐
Results:	9	24	62	5

Comment
A reasoning sequence which could have been expected is

$$R \propto C^2,$$

therefore $R = k\,C^2$

and $R_1 / C_1^2 = R_2 / C_2^2$.

For $C_1 = 1.0$ and $C_2 = 0.5$

$R_1 / 1^2 = R_2 /(0.5)^2$

Hence $R_2 = R_1 /4$

This reasoning sequence seems straightforward enough, but 38% (8 students)could not get it right. An explanation for this result may lie in factors akin to those noted in Concept Learning Test Sequence Number 6, involving the mole and indices. Gabel and Sherwood (1984) found that early chemistry students had difficulties in mole calculations, not only with scientific notation, but also with problems involving two steps, the process of division and with fractions of a unit. It seems likely, in the context of rates of reaction, that similar students have had similar difficulties with the same kinds of arithmetical operations.

5.7.4 Summary for the concept-cluster *Rate*

Success rates for the Concept Learning Test Sequence are summarised below as percentages.

Pre inst	2TMC1	2TMC2	2TMC3	2TMC4	Post-Inst Part A	Post-Inst Part B
71	81	71	9	71	71	62

Apart from the exceptionally difficult Item 3, concept-learning was adequate.

5.8 Concept-cluster - *Metal*

5.8.1 The Pre-Instruction Question and the Post-instruction Question Part A

Here are some opinions from a discussion about metals and non-metals.

Arvo claims that coins are metallic. Darco insists that chlorine is a non-metal. Bruno thinks that copper is a metal, granite (rock) is non-metallic. Ivo believes that brass is a metal, sulfur is a non-metal. Mirko says that both Bruno and Ivo are half right. Eduardo states that each is half wrong; in a chemical context they should be discussing the matter in terms of elements

What is your opinion about the following statements? Please indicate true (T), false (F) or uncertain (U).

Results(% correct)

	T		F		U	
	pre	post	pre	post	pre	post
* *copper is a metal*	95	100	0	0	0	0
* *brass is a metal*	76	62	14	29	5	9
* *brass is an element*	19	19	67	81	5	95
* *pencils contain the metal lead*	38	19	57	81	9	0
* *granite is a non-metal*	48	52	29	33	19	9
* *silicon is a non-metal*	52	81	19	19	19	0
* *neon is a non-metal*	71	100	5	0	14	0
* *iron ore is metallic*	52	76	24	14	14	5

Note: nil responses are not reported here.

Comments

1. Overview

This question sought to discern the extent to which entrants to the course were aware of the chemical subtleties or had alternative conceptions relating to the terms *metal, metallic, non-metal* and *element*. During instruction the difficulty of defining a metal in physical or chemical terms was discussed. In *Introducing Chemistry* the *behaviour* of an element was defined as metallic when its atoms were donating electrons. Discussion of trends in Groups and Periods of the Periodic Table included trends in *metallic character* in terms of the tendency of atoms to lose (or donate) electrons.

2. The responses to the statements

*** *copper is a metal***

Not unexpectedly, this common element was strongly supported as a metal both in the Pre-Instruction Question (95%) and the Post-instruction Question Part A (100%).

*** *brass is a metal, brass is an element***

Being an alloy of two metallic elements, brass is excluded as a metal by the chemical definition. Its possession of metallic properties, nevertheless, is evidently appreciated in its pre-instructional endorsement as a metal (76%), notwithstanding its not being seen as an element by 14 respondents (67%).

Post-instruction, 17 respondents (81%) were confident that brass is not an element, although 13 (62%) were still prepared to call it a metal. Of this 13, ten (48%) believed that brass was not an element. This seems to indicate that the chemical notion of restricting the terms *metal* or *metallic behaviour* to elements was not well accepted. Review of the definition seems warranted. One respondent bypassed the T/F/U "tick boxes" (not presented in the version of the item presented above) to give the very satisfactory statement "brass is an alloy with metallic properties".

*** *pencils contain the metal lead***

Nowadays pencils contain graphite, but the notion that lead is used remains to an extent in everyday usage. This was evidently also the notion of 8 of the class (38%) pre-instruction. Of these, three retained their belief post-instruction.

*** *granite is a non-metal***

Although chemists restrict the terms *metal* and *non-metal* to elements, newcomers to chemistry often adopt the fallacy (pre-instruction) that if a substance is not a metal it must be a non-metal (or at least non-metallic), having no elemental basis for their classification. Thus 10 respondents (48%) classified granite pre-instruction as a non-metal, while another six (29%) were sure that it was not a non-metal, perhaps being more aware of the formal chemical nature of granite.

What is disappointing is that, post-instruction, the number of respondents classifying granite as a non-metal actually rose slightly. The study of the Periodic Table of Elements seems to have had no influence upon their response to the question.

***** *silicon../neon is a non-metal***

These elements, familiar to many in daily-life usage in electronics and signage, became markedly more recognisable as non-metals post-instruction (81% and 95% respectively).

***** *iron ore is metallic***

The increase, after instruction, in approval of the term *metallic* (from 52% to 76%) for iron ore may reflect a growth in appreciation of the components of the ore. However, the subtlety of usage of the term *metallic* as used in *metallic character*, for elements as described above has been lost on the majority. Only 3 (14%, being the more generally successful) were confident to indicate that the ore was not metallic.

The Post-Instruction Test Question Part B can reveal other insights.

5.8.2 The Two-Tier Multiple-Choice item

Consider the following statements about metals and the Periodic Table.

(a) In any Group the atom's attraction for electrons (electronegativity) decreases with increasing Atomic Number.

(b) The bonding between any Group II (two) element and a halogen is likely to be covalent.

(c) In any Period the metallic character decreases with increasing Atomic Number.

(d) The most powerful oxidisers are to be found nearer the bottom of Groups I and II.

(e) Sodium, potassium and mercury are exceptional metals in that they are good electrical conductors.

Which of the following statements (or pairs of statements) is true?

(1) d+e

(2) c

*(3) a+c

(4) b

(5) a

Reason:

**(A) An atom's attraction for electrons is partly controlled by the size of the atom - Coulomb's Law indicates that the larger the atom the smaller will be its attraction for outer shell electrons.*

(B) Across a Period the atoms' attraction for electrons decreases according to Coulomb's Law.

(C) In Periods and Groups electronegativity increases with increasing Atomic Number.

(D) Halogen atoms can achieve a stable octet by sharing electrons with metals to form covalent bonds.

(E) The most powerful oxidisers are the largest atoms because they can lose their electrons most readily.

Results: Number of choices (N=21)

	Reason					
Response	A	B	C	D	E	Total responses
1	1	0	1	0	0	2 (9%)
2	3	1	0	0	0	4 (19%)
3	5*	1	0	0	1	7 (33%)
4	0	0	0	1	1	2 (9%)
5	6	0	0	0	0	6 (29%)
Total reasons	15	2	1	1	2	21

*Best choices:24%

Comment

This item pursues the notion of the metallic character of an atom, defined through its tendency to lose electrons. The context is the Periodic Table wherein metallic character and the factors affecting it or responding to it can be allocated trends within Periods or Groups. This context means that successful respondents to this item need to have a grasp of other concepts such as bonding, redox, Coulomb's Law and atomic structure - they are incorporated into the Reasons or Responses. The item thus constitutes a considerable challenge to the respondent. Furthermore, of the above item-statements about metals and the Periodic Table, both statements (a) and (c) are true; and an opportunity exists to choose either or both as Responses 5, 2 or 3. This arrangement makes the selection of the *best* response more difficult.

The presented Reasons contain only one correct statement (A). Fifteen respondents (71%) chose this. Although only five (24%) chose the 'correct-and-best' Response-Reason combination, another 9 (43%) chose either [2+A] or [5+A], both of which can be regarded as 'correct-but-not-the-best-answer' because the respondent missed one other correct response. This partial success by a significant number of respondents may suggest that they had an answering technique which was not anticipated by the researcher. There was anecdotal evidence in tutorial classes that some students, particularly those who found the Two-tier Multiple-choice items difficult, tended to search the *Reasons* section first, looking for familiar or plausible statements. They then tried to find a matching Response. This approach might explain why such a large number of respondents got the partially correct combination: Reason A tends to stand out as the only correct reason. Selection, then, of Responses 2 or 5 may have been enough to give the respondent a satisfying combination.

The complete success of only five respondents (24%) is disappointing, but the ability of 15 respondents (72%) to choose the only correct Reason statement gives the diagnostician some encouragement.

5.8.3 The Post-Instruction Test Question Part B

List five general physical properties of metals.

Results

No. of physical properties:	1	2	3	4	5
Percentage of respondents:	5	0	9	33	52

Name two metals which are exceptional in at least one of these properties.

Results

No. of exceptional metals:	0	1	2
Percentage of respondents:	29	43	29

Comment

The two parts of the question were related to the notion that a metal cannot be classified or defined precisely in terms of physical properties. Rather, a substance described as a metal can be expected to share *most* of a list of five or six generalised physical properties with other elements called metals, but nevertheless might differ from the others in one or two aspects of those physical properties.That 18 respondents (86%) could nominate either four of five such physical properties was an adequate result.

Since there are only a few commonly known metals which are exceptional in some respects (mercury, potassium and sodium for example), a higher rate of naming two of them than 29% might reasonably expected, especially as two (mercury, sodium) were met in the laboratory. That only 71% (15 respondents) were able to name at least one exceptional metal was disappointing. Nevertheless, since concept-learning was the primary aim, such disappointment can be moderated in the light of the results of the previous question.

5.8.4 Summary for the concept-cluster - *Metal*

Success rates for the Concept Learning Test Sequence are summarised below as percentages.

Pre-instruction/ Post- instruction Part A

(Correct responses are shown (T, F) with the percentage).

	Cu/metal	brass/metl	brass/elt	pencil/lead	granite/nm	Si/nm	Ne/nm	Fe ore/metallic
pre:	T95	F14	F67	F57	F29	T71	T71	F24
post:	T100	F29	F81	F81	F33	T81	T100	F14

2TMC

tier1	tier2	tiers1&2
33	71	24

Post- instruction Part B

five gen phys props of metals					
No. of props:	1	2	3	4	5
% respondents:	5	0	9	33	52

two exceptional metals:		
No. of metals	1	2
% respondents:	43	29

The preceding commentary on the individual test items has remarked that the concept *metal* has been tested, (especially in the Two-tier Multiple-choice item) in the context of a diverse range of abstract concepts including element, atom, atomic structure, Coulomb's Law, electronegativity, redox and the Periodic Table. It is not surprising, therefore, to find a low success rate in the Two-tier Multiple-choice item and an imperfect knowledge of specifics in the Post-instruction Questions Parts A and B. Nevertheless, those who successfully completed the items could be described as having excellent concept-learning in these contexts.

Section 5.9 follows→

5.9 Concept-cluster - *Halogen*

5.9.1 The Pre-Instruction Question and the Post-instruction Question Part A

(Note: The original answer boxes are not shown in this presentation)

You may have heard of 'household bleach' or 'pool chlorine'. Each contains the same kind of compound of chlorine. The element chlorine is a member of the chemical family called The Halogens.
The elements fluorine and iodine are also members of this family.

Are you aware of some daily life uses or commercial applications of substances containing a halogen? Please tick (Yes, No)

Results	Yes	No	nr	uncertain
Pre:	81	14	5	0
Post:	95	0	0	5

If you answered 'Yes', please indicate a use or application for the element or one of its compound(s) in the boxes below:

Results:

	Application or use					
	correct		incorrect		nr	
	pre	post	pre	post	pre	post
chlorine:	62	95	9	0	29	5
fluorine:	29	62	33	24	38	14
iodine:	71	81	5	9	24	9

Comments

1. Overview

The intention of this question was to sample the prior general awareness of students concerning the uses of members of the halogen family (and their compounds) and then to ascertain any improvement as a result of learning experiences.

2. Pre-instructional knowledge

Surprisingly, uses for iodine (71%) were more commonly recalled than uses for chlorine (62%) despite two uses for chlorine being quoted in the preamble to the question. Iodine's use in an antiseptic is apparently well known. It was also somewhat surprising that, in a society which uses large amounts of PVC and chlorinated hydrocarbons, a quarter or so of the respondents could not recall any application for either chlorine (24%) or iodine(29%).

A significantly low number of respondents (6, 29%) were able recall a *correct* use for fluorine. An equal number erroneously but perhaps understandably considered that fluorine is used in fluorescent lighting tubes. Eight (38%) made no response for fluorine, perhaps being unaware or forgetting, that community water supplies are fluoridated, as are some brands of toothpaste.

3. Knowledge, post-instruction

Marked improvements in knowledge occurred for chlorine (from 62% to 95%) and for fluorine (from 29% to 62%) although several (14%) still retained their erroneous belief in the fluorine content of fluorescent lighting tubes. The improvement for iodine (from 71% to 81%) was less marked. The change for chlorine could be expected because it was featured during teaching/learning as the commonest and typical halogen.

5.9.2 The Two-Tier Multiple-Choice item

Chlorine gas can be used to sterilise water. When chlorine is passed through the water it forms a mixture of hypochlorous acid and hydrochloric acid.

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$

The polar covalent compound iodine chloride (ICl, m.pt. 27°C) is well known. If it were used to sterilise water ***would the most likely reaction be***

(1) $ICl + H_2O \rightarrow HOCl + H^+ + I^-$ or

**(2)* $ICl + H_2O \rightarrow HOI + H^+ + Cl^-$?

Reason:

**(A) The bonds in both ICl and H_2O are polar. The δ+ charge on the I atom is attracted to the δ− charge on the O atom leading to the formation of an I—O bond and the breaking of O—H and I—Cl bonds.*

(B) Iodine is lower in Group VII than chlorine and the I^- ion is therefore more stable than the Cl^- ion. Accordingly I^- forms together with HOCl and H^+.

(C) HOCl is a more stable molecule than the HOI molecule because the O—Cl bond is more polar than the O—I bond.

(D) Reaction 2 involves oxidation of the iodine species.

Results: Number of choices (N = 20)

	Reason				
Response	A	B	C	D	Total responses
1	0	8	7	0	15
2	2*	0	0	3	5
Total reasons	2	8	7	3	20

*Best choices: 10%

Comments

1. The reactions

The students were of course, not familiar with ICl. However, a response can be chosen using the knowledge that Cl, a smaller atom than I, (Cl is higher in Group VII) has a stronger affinity for electrons (higher electronegativity) than iodine. This means that it will tend to form an anion Cl^- (with complete "control" over an outer-shell octet of electrons) in preference to HOCl where there is sharing of a pair of electrons with an oxygen atom. Reaction 2 is the better choice. Those with good skills in working with Oxidation Numbers might see that in Reaction 1, the Oxidation Number of iodine would decrease and that of chlorine would increase (it would be oxidised) - an unlikely event given chlorine's superior electronegativity.

2. The Reasons, *per se*

Reason A provides a feasible mechanism for Reaction 2 based on the polarity of bonds arising from the superior electronegativities of Cl and O in ICl and H_2O respectively. This Reason is the only feasible one of the four.

Each of the Reasons B, C and D contain at least one incorrect notion-

- In Reason B iodine is of course lower in Group II but it does not follow that the I^- ion is more stable than Cl^-: the higher electronegativity of Cl precludes this.
- In Reason C, the polarity of covalent bonds is not a pre-requisite for stability, rather it is a contributor to interaction with other polar species such as H_2O, as can occur in ionisation reactions in water. Furthermore, as Cl and O are similar in electronegativity values, the Cl—O bond is *less* polar than the I—O bond. (Iodine has a lower electronegativity than both O and Cl).
- In Reason D, those skilful with Oxidation Numbers would have been able to discern that the Oxidation Number of iodine in ICl (+ 1) does not change with the formation of HOI and that redox does not therefore occur.

Even if a respondent could not choose between Reaction 1 and Reaction 2, it was possible, by working knowledgeably through the Reasons, to come to the conclusion that Reaction 2 was the more likely of the reactions.

3. The results

The Response/Reason data show the effect of the (intended) linkage of two Reasons to each Response. Response 1 generated Reasons A and D only, Response 2 stimulated Reasons B and C only. More importantly, the incorrect Response 1 was selected by 15 respondents (75%). Yet more importantly, 18 respondents (86%) chose one of the Reasons B, C, or D - all of which embrace wrong notions - either about stability, redox or polarity of covalent bonds and, by implication, electronegativity.

Certainly it must be concluded that the item was challenging (two successful respondents, 10%). At the same time, it is clear that the class lacked sufficient understanding and/or integration of the abstract concepts involved to successfully complete a question involving some comparative chemistry of the Halogen family.

5.9.3 The Post-Instruction Test Question Part B

Note: answer "boxes" in the original item have been deleted in this presentation.

Write down the formula of hypochlorous acid showing the oxidation number of the chlorine:

Results

correct formula (HOCl):	52%	nr: 19%
correct Oxidation Number (+1):	29%	nr: 5%

Write a balanced chemical equation for any reaction involving hypochlorous acid or the hypochlorite ion:

Results:	a correct equation:	19%
	an incorrect equation:	24%
	an irrelevant equation	19%
	no response	38%

Comments

1. The formula and the oxidation number

Of the eleven respondents (52%) who could write the formula of hypochlorous acid, only six (29%) could successfully perform the relatively simple task of calculating the oxidation mumber of chlorine in the molecule HOCl. The array of erroneous answers, either of formula or of Oxidation Number, or both, included:

$$\mathrm{HCl^-}\ \text{(three)};\ \mathrm{H\overset{-1}{Cl}O}\ \text{(two)};\ \mathrm{H\overset{+5}{Cl}O_3}\ ;\ \mathrm{HOCl^-}\ ;\ \mathrm{H\overset{-2}{Cl}};\ \mathrm{HOCl^+}\ ;\ \text{and}\ \mathrm{HCl^+}\ .$$

This clearly indicates very poor or non-existent skills in the writing of Oxidation Numbers and considerable unfamiliarity with hypochlorous acid.

2. The equation

The teaching/learning context of hypochlorous acid was lecture and tutorial discussion of swimming pool chemistry together with laboratory studies which included the topic "chlorine water". After such exposure it was expected that more than four respondents (19%) could have provided an equation involving hypochlorous acid such as

$$\mathrm{Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-}\ .$$

As it eventuated, eight respondents (38%) made no attempt at writing an equation. Of the nine (43%) responses which were not correct, seven (33%) contained fabricated reactions or impossible reactions or products. A number were not "balanced". Examples included

$$NaNO_3 + HOCl \rightarrow NaCl + NO_2 + H_2O \qquad \text{and}$$
$$KClO_3 + H_2O \rightarrow HCO_3 + KOH.$$

It has been remarked in the discussion of Concept Learning Test Sequence Number 4 that opportunities to develop these symbol and equation-writing skills were presented at that time, but the skills themselves were intentionally not given the higher priority accorded the development of other chemical concepts. Those students with only Year 10 backgrounds (4,19%) began at a disadvantage because of lack of exposure and/or practice pre-instruction. Another seven students (33%) with only Year 11 science or chemistry backgrounds were probably not very well developed in these skills, prior to instruction. Probably this disadvantage and lack of skill continued throughout the semester as the teaching of the unit pressed on to develop and emphasise other concepts and concept-clusters. Another partial and likely explanation for the generally poor performance in this area is that, under the pressure of studying this unit (along with Bridging Mathematics and Bridging Physics units) for the final examination, a number of students decided not to revise or study some sections of it. (The whole unit needed intensive study of the comparative chemistry involved). In this way they may have gained more time for what they perceived as more "pressing" studies of aspects of the chemistry (or other units) in preparation for imminent examinations, when this question was attempted.

5.9.4 Summary for the concept-cluster - *Halogen*

Success rates for the Concept Learning Test Sequence were (as percentages):

Pre-inst/Post-inst Part A			
use for:	CI	F	I
pre-	62	29	71
post-	95	62	81

2TMC		
tier1	tier2	both
25	10	10

Post-Inst Part B	
formula/ox no	HOCl equation
52	19

Uses, formulae, equations and Oxidation Numbers may not be regarded as central to the concept-cluster halogen, but they can be taken as manifestations of concept-development. However, at its centre the concept *halogen* involves notions of the nature and relative vigour of the reactivity of the Halogen family. To this extent the Two-tier Multiple-choice item here is the most probing indicator of concept-learning. The indications are that with this concept, the Bridging class has not been at all successful.

5.10 Concept-cluster - *hydrocarbon*

5.10.1 The Pre-Instruction Question and the Post-instruction Question Part A

Here are some daily life substances. Try to complete the table.

Substance	*chemical name(s) of component(s)*
petrol	
"bottled gas"	
petroleum jelly ("Vaseline")	
kerosene	
lubricating oil	

Results: (N=21)

	Pre- instruction	Post- instruction
none right or no response	15 (71%)	9 (43%)
correctly named one hydrocarbon	4 (19%)	4 (19%)
correctly named two hydrocarbons	0	4 (19%)
correctly named 3 or 4 hydrocarbons	1 (5%)	1 (5%)
"all are hydrocarbons"	1 (5%)	4 (19%)

In the box write one property which these substances share:
Note: Answer "box" not included in this presentation.

Results:

shared property	Pre- instruction	Post- instruction
all flammable	4 (9%)	4 (19%)
all organic, all h/c or all carbon compds	3 (14%)	11 (52%)
other, correct	3 (14%)	2
inappropriate	2 (9%)	4 (19%)
no response	9 (43%)	0

Comments

Clearly, students entered 041143 *Introductory Chemistry* with little awareness of the chemical nature of hydrocarbon mixtures of daily life. Fourteen students (67%) made no response at all to the table completion task and nine (48%) gave no response in the property "box".

Presentation of organic chemistry commenced late in the semester (about Weeks 11/12) when the class received a brief introduction to the uses of natural and daily-life hydrocarbons. Then began a more extensive study of theoretical and laboratory aspects of the early members of the three homologous hydrocarbon series *alkanes, alkenes and alkynes.* In the post-instruction attempt at the item, nine respondents (43%) could not write a correct chemical name on the table. As before, only four respondents (19%) could correctly name one specific hydrocarbon, but five others (24%) could actually name two, three or four specific hydrocarbons from the list of substances. These low achievements can be largely attributed to the intentional brevity of the treatment of the uses and an under-emphasis of the names of the members of the daily-life mixtures of hydrocarbons.

As for **properties shared by the substances**, there was considerable improvement in the post-instruction test: there were no nil responses and 17 (81%) respondents submitted acceptable shared properties.

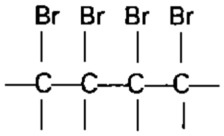
In terms of concept-learning, it is reasonable to report that, post-instruction, about nine (43%) of the class had a heightened awareness of the properties of the daily-life hydrocarbons, although they were not nearly so improved in awareness of names.

5.10.2 The Two-Tier Multiple-Choice item

A test tube contains 100mmole of a hydrocarbon X whose formula is C_4H_6. X does not react with ammoniacal cuprous chloride. When the tube of X is added to 100mmole of bromine (Br_2) as 'bromine water', the bromine is decolourised and a new substance Y is formed. Y, however, decolourises bromine water also. After addition of Y to another 100mmole of bromine water, the mixture is no longer able to decolourise it. A new substance, Z, is present.

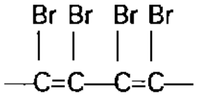
The more likely skeletonic structure of Z is

(1)



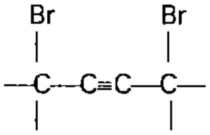
$$-\underset{|}{\overset{\overset{Br}{|}}{C}}-\underset{|}{\overset{\overset{Br}{|}}{C}}-\underset{|}{\overset{\overset{Br}{|}}{C}}-\underset{|}{\overset{\overset{Br}{|}}{C}}-$$

(2)



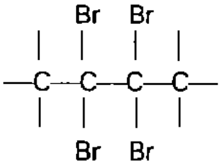
$$-\overset{Br}{\overset{|}{C}}=\overset{Br}{\overset{|}{C}}-\overset{Br}{\overset{|}{C}}=\overset{Br}{\overset{|}{C}}-$$

(3)



$$-\underset{|}{\overset{Br}{\overset{|}{C}}}-C\equiv C-\underset{|}{\overset{Br}{\overset{|}{C}}}-$$

(4)

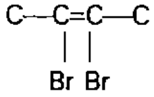


$$-\underset{|}{\overset{|}{C}}-\underset{\underset{Br}{|}}{\overset{Br}{\overset{|}{C}}}-\underset{\underset{Br}{|}}{\overset{Br}{\overset{|}{C}}}-\underset{|}{\overset{|}{C}}-$$

Reasons: (reasoning sequences)

(A)

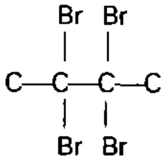
- *The formula* C_4H_6 *is consistent with the family formula* $C_nH_{(2n-2)}$ *of the alkynes, which have one triple covalent bond per molecule. A possible carbon skeleton of this molecule is* $C-C\equiv C-C$.
- *Substance Y can form by adding one molecule of* Br_2 *across the triple bond to form*



$$C-\underset{\underset{Br}{|}}{C}=\underset{\underset{Br}{|}}{C}-C$$

(skeletonic)

- *Mixing with another 100mmol of bromine adds* Br_2 *across the double bond to give*



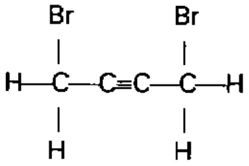
$$C-\underset{\underset{Br}{|}}{\overset{Br}{\overset{|}{C}}}-\underset{\underset{Br}{|}}{\overset{Br}{\overset{|}{C}}}-C$$

(skeletonic)

which is a likely structure of Z.

(B)

- *In the first reaction,* $C_4H_6 + Br_2 \rightarrow C_4H_5Br + HBr$, *Y forms by substitution.*
- *The second reaction,* $C_4H_5Br + Br_2 \rightarrow C_4H_4Br_2 + HBr$, *is also a substitution reaction where* $C_4H_4Br_2$ *is Z, which has the structure*



$$H-\underset{\underset{H}{|}}{\overset{Br}{\overset{|}{C}}}-C\equiv C-\underset{\underset{H}{|}}{\overset{Br}{\overset{|}{C}}}-H$$

consistent with $C-C\equiv C-C$ *(skeletonic) for X.*

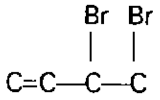
(C)

- *Bromine is a good oxidising agent, having a strong attraction for the electron-rich double bonds in a possible* $C=C-C=C$ *structure of X.*
- *Accordingly it forms four* C—Br *bonds by substituting one* Br *atom for an* H *atom on each atom of carbon, thus forming Z.*

(D)

- *The failure of X to react with ammoniacal cuprous chloride indicates that no triple bond is present. Perhaps there are two double bonds in each molecule of X. A possible carbon skeleton of X is* C=C—C=C .

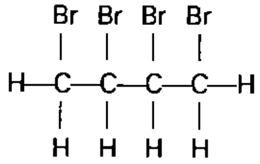
- *Addition to 100mmol of bromine permits bromination of only one of the double bonds to form*



$$C{=}C{-}\overset{Br}{\overset{|}{C}}{-}\overset{Br}{\overset{|}{C}}$$

(skeletonic).

- *Addition to a second portion of* Br_2 *brominates the other double bond forming*



$$H{-}\overset{Br}{\underset{H}{C}}{-}\overset{Br}{\underset{H}{C}}{-}\overset{Br}{\underset{H}{C}}{-}\overset{Br}{\underset{H}{C}}{-}H$$

Results: Number of choices (N=21)

	Reason				
Response	A	B	C	D	Total responses
1	1	0	0	7*	8 (38%)
2	0	0	0	3	3 (14%)
3	0	0	0	0	0
4	9*	0	1	0	10 (48%)
Total reasons	10	0	1	10	21

*Best choices: [1+D]: 33%
[4+A]: 43% See discussion below.

Comments

1. Background

During the teaching/learning sessions, acetylene (ethyne, C_2H_2), was studied as a typical example of an alkyne. Other specific alkynes were not studied. Accordingly, the ammoniacal cuprous (copper(I)) chloride test for ethyne was likely to be assumed by a majority of students as having general application to alkynes. What follows initially is a discussion which traces a logical use of this assumption to reach a satisfactory combinaton of Response and Reason. Thereafter the implications of not making the assumption (or knowing otherwise) are outlined.

2. Chemical logic following the assumption of a generic test for alkynes

The formula C_4H_6 for a molecule of Z is of the form $C_nH_{(2n-2)}$, the general formula familiar to students as that of the homologous series called alkynes. The molecule would thus be expected to contain a triple covalent bond between a pair of carbon atoms. However, Z fails to react with ammoniacal copper(I) chloride. Apparently there cannot be a triple bond in a Z molecule. At this stage the respondent may have had a *cognitive conflict - a triple bond is implied in the formula but the chemical test suggests otherwise.* Nevertheless, the evidence of bromine decolourisation indicates unsaturation (double or triple covalent bonds present) and the ability of Z to react with 2mmoles of bromine for every mmole of Z is consistent with the presence of a triple bond.

Notwithstanding this contribution to the cognitive conflict, a careful reading of the Reasoning Sequences provides the clue that *two double bonds* could be present in the Z molecule (as in Reasoning Sequences C and D). This would be consistent with the stoichiometry of the bromination reaction with the formation of an addition compound having a bromine atom bonded to each of the four carbon atoms (Response 1, Reason D). Seven respondents (33%) chose this satisfactory combination. An eighth respondent also chose Response 1, but in choosing Reason A introduced inconsistency between structures in Response and Reason.

The assumption of the general applicability of the ammoniacal copper(I) chloride test for alkynes is, in the context of the instruction, reasonable for introductory students, and was accepted during assessment.

3. Chemical correctness

Those students with prior knowledge or insight might have realised that a positive ammoniacal copper(I) chloride test is applicable only to alkyne molecules with the triple bond between the first and second carbon atoms, that is, the $H—C{\equiv}C—\cdots$ structure. In the context of the item this means that the non-reactivity of Z in the ammoniacal copper(I) chloride test could be consistent with the alkyne skeletonic structure $C—C{\equiv}C—C$. Bromination at the triple bond would then lead to a molecule with two atoms of bromine on each of the second and third carbon atoms (Response 4, Reason A). This is the chemically correct result. Nine respondents (43%) chose this combination. It appears that the more sophisticated understanding of chemistry implied in this choice had been acquired either through reading or discussion of the literature outside of the set text (or references) or during instruction received prior to commencing the Bridging course. The tenth student to choose Response 4 erred in choosing Reason C, which specified a substitution reaction (rather than the necessary addition reaction). The three respondents (14%) who chose [2 + D] seemed unaware that the tetrabromo compound of the Response was different in bonding from that in the Reason.

All told, 16 respondents (76%) chose an acceptable combination of Response and Reason. This suggests that, despite the very lengthy and involved question, the class was very acceptably able to deal with the concept of unsaturation in hydrocarbons and the addition of elemental bromine thereto.

5.10.3 The Post-Instruction Test Question Part B

> *Name and draw a structural formula of the fourth member of the homologous series which has the general formula* $C_nH_{(2n-2)}$.

Results

One student made no response to this question. Of the 20 respondents -

- 19 (91% of the whole class) used the correct suffix '-yne'
- 20 (95%) showed a structural formula with a triple covalent bond. Of these
    - 14 (67%) presented a structural formula with *only four* linearly linked carbon atoms, thus indicating that they had overlooked the fact that the alkyne homologous series begins with a molecule containing *two* carbon atoms, not one (a simple mistake). Of these respondents
        - 8 (38%) linked the name *butyne* with a corresponding structural formula, consistent with four carbon atoms and a triple covalent bond. Two more respondents gave the formula C_4H_6 instead of a name for a butyne structure. Another named it "alkyne".
        - Only one (5%) gave the correct name, pentyne, and an appropriate structural formula, although
        - two other respondents presented a structural formula with five correctly bonded carbon atoms. One student however, named this molecule 'hexyne', the other, perhaps unable to provide a name, wrote the correct molecular formula, C_5H_8 .

To summarise, the group were acceptably skilful in dealing with structure and bonding aspects of the question, but lacked knowledge in dealing with aspects of nomenclature relating to the naming of the carbon skeleton of the molecule.

10.4 Summary for the concept-cluster - *hydrocarbon*

Success rates for the Concept Learning Test Sequence were (as percentages):

Pre-inst/Post-Inst Part A			2TMC			Post-Inst Part B
	daily-life hydrocarbon mixts:					4th member of $C_nH_{(2n-2)}$:
	chem names	shared prop'ty	tier1	tier2	tiers1&2	name & struct'l formula
Pre:	various	various: 48				
Post:	various	various: 81	86^a	96^a	76^a	aspects: 0 - 95

a: two combinations accepted

in this Concept Learning Test Sequence the results are diverse and various, reflecting in part the openness of the Pre-Instruction Question and the Post-instruction Question Part A. Trends are not evident. The results show, as much as anything, the effect of particular emphases during the teaching/learning sessions. The understanding of concepts had been emphasised (*Introducing Chemistry,* Introduction, pp 5-11) and factual recall for its own sake was discouraged (not least in the various tests which had been conducted prior to this unit of work). For example, the Two-tier Multiple-choice item was very well done: the handling of fairly sophisticated structure-bonding inferences indicated quite strong development of understanding of concepts in an addition reaction of an unsaturated hydrocarbon. On the other hand, in the Post-Instruction Test Question Part B, the name of the compound $C_nH_{(2n-2)}$ was poorly reported, yet its bonding, possible structures and the generic suffix of the name of the homologues was successfully recorded by more than 90% of the group.

Although factual recall is of secondary importance, some "facts" can give life to a concept-cluster. In the prevailing teaching/learning context it was possible to give the hydrocarbon concept-cluster a greater richness and breadth by exploring uses and daily-life examples as crosslinks to the more profound notions of structure, bonding and reactivity, aspects near the heart of the concept-cluster *hydrocarbon.* No doubt the de-emphasis upon factual recall combined with the pressures of end-of-semester study led to a lower student priority for aspects like nomenclature and uses when preparing for the final examination.

5.11 Summary

Results for the ten Concept Learning Test Sequences are summarised in Tables 5.3 and 5.4, thus separating the Two-tier Multiple-choice items from the Pre- and Post-instruction questions for convenience.

5.11.1 Comments on the Results

Pre-instruction/Post-instruction (Part A) Tests - Table 5.3

In general, the expected improvement occurred at acceptable final levels. By their very nature these tests were not very challenging, since they initially sought to establish the conceptual background of the respondents, particularly in respect of their prior experience or skills.

Post-instruction (Part B) Tests - Table 5.3

There were some poor levels of achievement here, in particular, compound formation in Concept 2 (*mixture-compound*) and equation-writing in a context of Concepts 4

Table 5.3 Results for the Concept-Learning Test Sequences:
Pre-/Post-instruction Tests
(Results as a percentage of the class achieving the correct answer)

Concept	Pre-/Post-Instruction Part A	Post-Instruction Part B
1.Density	*Density of water vapour is ~500g/litre?* T **F*** U pre- 19 **9** 67 post- 29 **62** 9	*vol of 100g of ice?* Ans:109mL **81**
2.Mixt/cmpd	*Compounds (C) or mixtures (M)?* glass sugar b/soda rubber curry wine pre- M 39 C 76 C 57 M 29 M 91 M 76 post- 62 95 81 48 95 76	*$Fe + S \rightarrow FeS$...8g Fe, 4g S. Residual mixture after heat?* Ans: Fe=1g, S=0g; FeS=11g **24**
3 Struct/bondg:	*NaCl?* I M U pre **48** 24 24 post **100** 0 0 *M.Pt of NaCl?* -80° 80° 300° 800° U pre- 0 29 24 **24** 19 post- 0 9 5 **86** 0	*$T_m(MgO)=2800^0$, $R(Mg^{2+})=65$* *$T_m(BaO)$, $R(Ba^{2+})$?* T_m 100 4000 2000 5 43 **52** $R(Ba^{2+})$ 59 135 65 24 **71** 5 **both correct:** **33**
4. Base/salt	*Which are bases?* lime/stn* vin'gar salt carb soda* pre- **57** 14 29 **33** post- **95** 14 38 **71** ammonia* sugar alcohol pre- **52** 0 5 post- **71** 5 14	*Formula of a base in Part A?* **62** *Equation for that base?* Balanced, correct **38** balanced, other base **10**
5. Redox:	*Hydrogen can reduce copper oxide.....?* T* F U nr pre- **19** 14 62 5 post- **81** 9 9 0	*In $C+CuO \rightarrow CO+Cu$,* *C is reducing agent:* T 81; F 19 *Cu gains electrons:* T 71; F 29 *Ox N of O: $-2 \rightarrow +2$:* T 14: **F 86** **all three correct:** **57**
6. Mole:	*Eight calculations–* no. 1 2 3 4 5 6 7 8 pre- 95 86 91 81 67 57 71 43 post- 95 100 100 86 76 76 100 76	*Weight (mass) of $1.5x10^{21}$ molecules of SO_3 ?* Ans: 0.2g (200mg) **62**
7. Rate:	*Predict R_2* if R_1 = 40 A_1 = 100, A_2 inc 25... R_2 = 50: pre-: **71** post-: **71**	*R_2/R_1 if $R \propto C^2$, $C_1=1$, $C_2=0.5$,*..Ans:$R_2/R_1=1/4$ **62**
8. Metal:	Cu/metal brass/metl brass/elt pencil/lead pre- T*95 F*14 F*67 F*57 post- 100 29 81 81 granite/nm Si/nm Ne/nm Fe ore/metallic F*29 T*52 T*71 F*24 33 81 100 14	*List 5 gen phys props of metals* No of props: 1 2 3 4 5 5 0 9 33 **52** *Name 2 exceptional metals:* No. of metals 1 2 43 **29**
9. Halogen:	*Use or application* Cl F I pre- 62 29 71 post- 95 62 81	*Formula, Ox No of Cl in HOCl* **52** *Equation with HOCl:* **19**
10. H/Carbon:	*chemical names:* various	4th member of $C_nH_{(2n-2)}$: *Name?* -yne **95**; *Struct. form?* C≡C **95**

(*base-salt*) and 9 (*halogen*). In the matter of equations, it has been pointed out that while equation-writing formed part of the unit, it was not especially emphasised, nor time given over to much practice. During the semester, few test items related to equation-writing.

Analysis of the responses for Concept 2 suggests that there is a fairly strongly retained alternative conception that elements combine in any proportion. One-third of the class seemed to hold this view. It is interesting that the Two-tier Multiple-choice item on the same concept-cluster also had a low success rate (14%), with a wide spread of choice of reasons. The lack of success in this very fundamental concept was unexpected.

The individual results to the Concept 5 (*redox*) part-items were quite high (despite the fact that redox is usually quite a difficult concept) but consistency was lacking. This may reflect the adoption of only one or other of the three possible descriptors of the process of oxidation-reduction (as represented by the three part-items) to the detriment of an overview of the process. The percentage achieving success in all three part-questions was rather low at 57%, but was a better indication of the quality of the total understanding than the 71-86% range for the part-items.

The hydrocarbon concept (No. 10) had noteworthy final success rates in particular aspects, although many students did not appreciate that the fourth member of the homologous series has five carbon atoms. There is anecdotal evidence that beginning students generally prefer or particularly like Organic Chemistry. This positive attitude may be a factor in the higher success rates.

The Two-tier Multiple-choice tests - Table 5.4

As was remarked in Chapter 1, some of the concept-clusters were more intensively tested than others, partly because some chemical topics are more suited than others to the development of suitable Two-tier Multiple-choice items. Nevertheless, general confidence in the Two-tier Multiple-choice items can be drawn from comparisons of the results for the more intensively tested concepts with the results from earlier work, reproduced on Table 5.4. As the table shows:

- the 1995 pilot group did rather better than the 1996 group in two of the three Structure/Bonding items. However, their performance was much poorer than the 1996 group in the five Redox items, the differences being in the range 5% to 36%. In this case, some of the differences may be partly attributable to an extra hour per week of contact time allocated to the 1996 course. Furthermore, in 1996, two of the redox items (numbers 4 and 5) were administered much nearer the end of the semester, perhaps allowing more time for maturation of the concepts.

- The results of the 1996 Bridging group for two of the above Structure/Bonding items (numbers 2 and 3) fall between the results of the Year 11 and Year 12 groups, published by Peterson, Treagust and Garnett (1989). That the differences between the Year 12 group and the 1996 Bridging group are only 4-5% suggests that achievements of these Bridging students approach the Matriculation standard which could be hoped for.

Table 5.4 Results for the Concept Learning Test Sequences: Two-tier multiple-choice tests

(Results as a percentage of the class achieving the correct answer)

			Bridging 1996 (N=21)			Bridging 1995 (N=31)			Peterson &c (1989)[a]	
									Yr11	Yr12
Concept	Item/ subject		Tier 1	Tier 2	Both	Tier 1	Tier 2	Both	Both	Both
1. Density	1	$d_{CO2\ (liquid)}$	76	67	52					
	2	box/T rise	71	71	67					
2. Mixt/cmpd	1	%comp	52	14	14					
3. Struc/bondg	1	B_4C struct.	76	48	48					
	2	HF e^- pair	71	57	57	77	71	65	43	61
	3	Vaseline	71	57	57	74	74	68	37	63
	4	Gps I&VII	81	52	52	66	61	47		
4. Base/salt	1	$BaCO_3$	33	25	25					
5. Redox	1	$Fe+CuSO_4$	76	62	50			36		
	2	Red. agent	52	43	33			12		
	3	cell $A/A^+//..$	38	38	35			30		
	4	$CO_3^{2-}+H^+$	75	75	75			54		
	5	cell I^-/MnO_4	62	67	57			21		
6. Mole[b]	1	Cu^{2+}/OH^-	57	79	57					
7. Rate	1	$Mg+H^+$	95	81	81					
	2	P/Q data	71	71	71					
	3	Plots/data	9	33	9					
	4	H_2/I_2config	71	71	71					
8. Metal	1	Metals/PTbl	33	71	24					
9. Halogen	1	ICl repl Cl_2	25	10	10					
10. H/Carbon	1	$C_4H_6+Br_2$	86[c]	96[c]	76[c]					

Notes a: for Year 11, N=159; Year 12, N=84. b: N=13.
c: either of two combinations accepted.

The Concept Learning Test Sequences

These sequences have proved to be very effective diagnostic tools, whether at testing recall aspects of concept-clusters (as in naming hydrocarbons, or relating to the Periodic Table), at skills relating to concept-clusters (as in Oxidation Numbers, particle calculations or weight relationships) or in abstract conceptual notions (as in structure/bonding, the mole or redox). Perhaps surprisingly, at least half of the Post-Instruction Test Questions Part B, have proved to be as penetrating and effectively diagnostic as the more obviously challenging Two-tier Multiple-choice items. These questions include those used for concept-clusters 2,3,5,6 and 7.

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Chapter Six

Results: Concept-learning by individuals

6.1 Introduction

Chapter 4 has shown that the raw data from the Concept Learning Test Sequences were arranged in two ways - on Forms A and Forms B. In Chapter 6 we consider the data as presented on the twenty-one Forms B, one sheet for each student, summarising her/his responses to each of the items of the Concept Learning Test Sequences. The completed Forms B are presented in this chapter as Tables 6.1.1 to 6.1.21. The following points facilitate the reading of these tables.

- An identifiable abbreviation of each question/item is placed as near as possible to, or in the same line as, the number and name of the relevant concept-cluster.
- The "tick" or "check" symbol (✓) is used to indicate **selection** by the respondent of one of a set of available choices. It is not used to indicate a correct choice.
- Wherever possible, the correct solution to a question/item is shown in bold font, supplemented, for clarity, by an asterisk in certain cases. Student responses, correct or not, are shown in the standard font.
- Lower case letters c and x are used to designate, respectively, correct and incorrect answers to calculations or problems where lack of space prevents a full recording of the student's answer. The letters nr indicate that no response has been offered. The letters mc are used to indicate that, after the test had been conducted, the student concerned (number 9) presented a medical certificate to explain absence through illness.
- In the Two-tier (Multiple-choice) column, the correct solution and the respondent's choice of Response and Reason are each shown as the sum of a numeral (the number of the Response in the first tier) and an upper case letter (corresponding to the Reason selected in the second tier). The correct solution and the student's choice are presented within brackets, adjacent to the item's number and abbreviation. Thus, for example, at Concept-cluster 7 (Rate), for Two-tier Multiple-choice Item 2 (involving interpretation of data for substances P and Q) we might see

  2 P/Q data [2+C] [4+A]

  indicating that the (correct) solution to this item is Response 2 from the first tier and Reason C from the second tier, whereas the student has (incorrectly) chosen Response 4 with Reason A.
- Questions and items in the Concept Learning Test Sequences are presented in full in Appendices 4.1(b), 4.4.1.2 and 4.4.1.3.

Table 6.1.1 Concept Learning Test Sequences: Summary of results for student no. 1 - MAb

									Two tier tests			
Concept	Pre-/Post-Instruction Part A								item	solution	choice	Post-Instruction Part B
1 **Density** *Water vapour: density is 500g/litre?*									1 $d(CO_2)$	[2+D]	2+B	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	2+D	Answer: 109mL
pre-			✓									
post-		✓										
2 **Mixture/cmp'd** *Compound (C) or mixture (M)?*									1 % comp	[2+D]	2+B	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	C									[Fe = 1g, S = 0g; FeS = 11g]
post-	C	C	M									Answer: nr
	rubber [M]	curry [M)]	wine [M]									Fe = g, S = g; FeS = g nr
pre-	C	M	C									
post-	M	M	C									
3 **Structure/bonding** *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	1+A	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	[1+C]	1+D	$T_m(BaO)$? $R(Ba^{2+})$?
pre-	✓								3 Vaseline	[1+C]	1+C	
post-	✓								4 Gp I&VII	[2+B]	2+B	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 135 65
	-80^0	80^0	300^0	800^0	U							✓
pre-		✓										
post-				✓								
4 **Base/salt** *Which are bases?*									1 $BaCO_3$	[2+B]	1+D	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$NaSO_4$
pre-												*Equation for that base?*
post-	✓		✓	✓								balanced, correct:
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice: x
pre-			✓									
post-	✓											
5 **Redox**: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2+A]	2+B	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	3+D	*C is reducing agent:* T( ) F(✓)
pre-	✓								3 Cell $A/A^+//..$	[1+D]	2+C	*Cu gains electrons:* T( ) F(✓)
post-	✓								4 $CO_3^{2-} + H^+$	[3+C]	1+E	*Ox N of O: −2 → +2:* T(✓) F( )
									5 Cell I/MnO_4	[4+C]	2+C	
6 **Mole**: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3+E]	nr	*Weight (mass) of*
pre-	c	c	x	x	x	nr	x	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	nr	nr	c	x				[0.2g] answer: 5.3^{20}
7 **Rate**: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1+D]	1+D	R_2/R_1 *if* $R \propto C^2$, $C_1 = 1$,
[R_2 = 50]									2 P/Q data	[2+C]	2+C	$C_2 = 0.5$? [$R_2/R_1 = 1/4$]
pre:	50								3 Plots/data	[5+A]	3+B	ans: $R_2 = 2R_1$ (✓), $R_2 = 2R_1$ ( ),
post-:	65								4 H_2/I_2	[4+D]	4+D	$R_2 = R_1/4$ ( ), $R_2 = R_1/2$ ( )
8 **Metals** (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	4+D	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] F	[F] T								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] F	[T] F	[T] T	[F] T								*Name two exceptional metals*
post--	[F] T	[T] F	[T] T	[F] T								(1) mercury (2) magnesium
9 **Halogen**: *Use or application?*												*Hypochlorous acid*
	Cl	F	I									*formula:* nr
pre-	c	x	nr						1 ICl + H_2O	[2+A]	2+A	*ox no of Cl* : nr
post-	c	x	x									*equation with HOCl* : nr
10 **Hydrocarbon**: *Chemical names*									1 $C_4H_6 + Br_2$	[1+D]	2+D	*4th member of $C_nH_{(2n-2)}$: name?*
pre:	nr									or [4+A]		stem:[pent-]: nr -yne: nr
post	nr											*structural formula?* nr
one common property												C≡C: nr ; skeleton[5 carbons]: nr
pre:	x											
post	low cohesive forces											

Table 6.1.2 Concept Learning Test Sequences: Summary of results for student no. 2 - MAr

									Two tier tests			
Concept	Pre-/Post-Instruction Part A								item	solution choice		Post-Instruction Part B
1 Density *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2 + D]	1 + A	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4 + A]	3 + C	Answer: 109mL
pre-		✓										
post-			✓									
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	[2 + D]	2 + B	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	M	M									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	C	C	NR									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 0g, S = 0g; FeS = 23.6g
pre-	C	M	M									
post-	C	M	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	[3 + C]	3 + C	*T_m(MgO) = 2800^0, R(Mg^{2+}) = 65*
	I	M	U						2 HF e^-	[1 + C]	2 + B	*T_m(BaO)? R(Ba^{2+})?*
pre-	✓								3 Vaseline	[1 + C]	1 + C	
post-	✓								4 Gp I&VII	[2 + B]	2 + C	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 135 65
	-80^0	80^0	300^0	800^0	U							✓
pre-				✓								
post-				✓								
4 Base/salt *Which are bases?*									1 $BaCO_3$	[2 + B]	3 + E	*Formula of a base in Part A?* c
	limestone	vinegar	salt	**carb soda**								
pre-	✓		✓									*Equation for that base?*
post-	✓		✓									balanced, correct:
												balanced, other base:
	ammonia	sugar	alcohol									incorrect: x
pre-	✓											
post-	✓	✓										
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2 + A]	2 + A	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2 + C]	1 + B	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell A/A^+//..	[1 + D]	4 + A	*Cu gains electrons:* T ( ) F (✓)
post-			✓						4 CO_3^{2-} + H^+	[3 + C]	1 + E	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4 + C]	4 + C	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3 + E]	2 + D	*Weight (mass) of*
pre-	c	x	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	x				[0.2g] answer: 0.2g
7 Rate: *R_2 if R_1 = 40, A_1 = 100, A_2 inc 25 ?*									1 Mg + H^+	[1 + D]	2 + A	*R_2/R_1, if R ∝ C^2, C_1 = 1,*
[R_2 = 50]									2 P/Q data	[2 + C]	4 + A	*C_2 = 0.5?* [R_2/R_1 = 1/4]
pre:	50								3 Plots/data	[5 + A]	1 + D	ans: R_2 = 2R_1 ( ), R_2 = 4R_1 (✓),
post-:	50								4 H_2/I_2	[4 + D]	4 + D	R_2 = R_1/4 ( ), R_2 = R_1/2 ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3 + A]	3 + A	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] T	[F] T								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] T	[F] T								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] F	[T]T	[T] T	[F] T								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] T								(1) sodium (2) potassium
9 Halogen: *Use or application?*									1 ICl + H_2O	[2 + A]	1 + B	*Hypochlorous acid:*
	Cl	F	I									*formula:* HOCl
pre-	x	nr	nr									*ox no of Cl:* nr
post-	nr	nr	nr									*equation with HOCl* : x
10 Hydrocarbon: *Chemical names:*									1 C_4H_6 + Br_2	[1 + D]		*4th member of $C_nH_{(2n-2)}$:Name?*
Pre: nr nr nr nr nr									also	[4 + A]	4 + A	stem[pent-]: nr **-yne** nr →
post: x nr nr nr nr												formula C_2H_2 quoted
one common property: nr												*structural formula?*
pre: nr												**C≡C**:✓ ; skeleton **[5 carbons]**: 2
post: x												

Table 6.1.3 Concept Learning Test Sequences: Summary of results for student no. 3 - CB

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 Density *Water vapour: density is 500g/litre?*									1 $d(CO_2)$	**[2 + D]**	2 + B	*Vol of 100g of ice?* **[109mL]**
	T	F*	U						2 box, T↑	**[4 + A]**	4 + A	Answer: 109mL
pre-			✓									
post-		✓										
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	**[2 + D]**	2 + D	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	C									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	C	C	M									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 4g, S = 0g; FeS = 8g
pre-	C	M	M									
post-	C	C	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	**[3 + C]**	3 + C	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	**[1 + C]**	1 + C	$T_m(BaO)$? $R(Ba^{2+})$?
pre-	✓								3 Vaseline	**[1 + C]**	1 + C	
post-	✓								4 Gp I&VII	**[2 + B]**	2 + B	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 135 65
	-80^0	80^0	300^0	800^0	U							✓
pre-		✓										
post-				✓								
4 Base/salt		*Which are bases?*							1 $BaCO_3$	**[2 + B]**	2 + B	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre-	✓											*Equation for that base?*
post-	✓		✓	✓								balanced, correct: ✓
												balanced, other base:
	ammonia	sugar	alcohol									incorrect:
pre-	✓											
post-	✓											
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	**[2 + A]**	2 + C	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	**[2 + C]**	3 + D	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell A/A^+//..	**[1 + D]**	1 + D	*Cu gains electrons:* T (✓) F ( )
post-			✓						4 CO_3^{2-} + H^+	**[3 + C]**	1 + E	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	**[4 + C]**	4 + C	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	**[3 + E]**	4 + E	*Weight (mass) of*
pre-	c	c	c	c	x	nr	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				**[0.2g]** answer: $1.2x10^{23}$g
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	**[1 + D]**	1 + D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	**[2 + C]**	2 + C	*$C_2 = 0.5$?* **[$R_2/R_1 = 1/4$]**
pre:	10								3 Plots/data	**[5 + A]**	4 + E	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ (✓),
post-:	30								4 H_2/I_2	**[4 + D]**	4 + D	$R_2 = R_1/4$ ( ), $R_2 = R_1/2$ ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	**[3 + A]**	1 + C	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F]U	[T] T	[T] T	[F] F								*Name two exceptional metals:*
post--	[F] F	[T] T	[T] T	[F] T								(1) sodium (2) potassium
9 Halogen: *Use or application?*									1 ICl + H_2O	**[2 + A]**	2 + D	*Hypochlorous acid:*
	Cl	F	I									*formula* **[HOCl]***:* HCl
pre-	c	c	c									*ox no of Cl:* -1
post-	c	x	c									*equation with HOCl* : x
10 Hydrocarbon: *Chemical names:*									1 $C_4H_6 + Br_2$	**[1 + D]**	2 + D	*4th member of $C_nH_{(2n-2)}$:Name?*
Pre:	nr	nr	nr	nr	nr					also **[4 + A]**		stem **[pent-]**: but- **-yne**: ✓
post:	x	c	nr	nr	nr							
one common property:												*structural formula?*
pre: flammable												C≡C: ✓; skeleton**[5 carbons]**: 4
post: organic compounds												

Table 6.1.4 Concept Learning Test Sequences: Summary of results for student no. 4 - AC

Concept Pre-/Post-Instruction Part A	Two tier tests item	solution	choice	Post-Instruction Part B
1 Density *Water vapour: density is 500g/litre?*	1 d(CO_2)	[2+D]	2+D	*Vol of 100g of ice?* [**109mL**]
T F* U	2 box, T↑	[4+A]	4+C	Answer: 109 mL
pre- nr				
post- ✓				
2 Mixture/cmp'd *Compound (C) or mixture (M)?*	1 % comp	[2+D]	2+B	*Fe + S → FeS Fe = 8g, S = 4g*
glass [M] sugar [C] b/soda [C]				*Residual mixture after heat?*
pre- C C C				[**Fe = 1g, S = 0g; FeS = 11g**]
post- C C C				Answer:
rubber [M] curry [M)] wine [M]				Fe = 0g, S = 0g; FeS = 12g
pre- C M M				
post- M M M				
3 Structure/bonding *NaCl (ionic/molecular)?*	1 B_4C	[3+C]	3+A	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
I M U	2 HF e^-	[1+C]	1+C	$T_m(BaO)$? $R(Ba^{2+})$?
pre- ✓	3 Vaseline	[1+C]	2+C	
post- ✓	4 Gp I&VII	[2+B]	2+B	T_m (BaO) 100 4000 2000
				✓
Melting Pt of NaCl?				R(Ba^{2+}) 59 **135** 65
-80^0 80^0 300^0 **800^0** U				✓
pre- ✓				
post- ✓				
4 Base/salt *Which are bases?*	1 $BaCO_3$	[2+B]	3+E	*Formula of a base in Part A?*
limestone vinegar salt **carb soda**				$CaCO_3$
pre-				*Equation for that base?*
post- ✓				balanced, correct: ✓
				balanced, other base:
ammonia sugar alcohol				incorrect:
pre- nr				
post- ✓				
5 Redox: *Hydrogen can reduce copper oxide?*	1 Fe + $CuSO_4$	[2+A]	2+A	*In C + CuO → CO + Cu,*
T F U nr	2 Red. Agent	[2+C]	2+C	*Cu is reducing agent:* T ( ) F (✓)
pre- ✓	3 Cell $A/A^+//..$	[1+D]	1+D	*Cu gains electrons:* T (✓) F ( )
post- ✓	4 $CO_3^{2-} + H^+$	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) F (✓)
	5 Cell I/MnO_4	[4+C]	3+B	
6 Mole: *Eight calculations:*				
no. 1 2 3 4 5 6 7 8	1 Cu^{2+}/OH^-	[3+E]	absent	*Weight (mass) of*
pre- c c c c x x c nr				*$1.5x10^{21}$ molecules of SO_3?*
post- c c c c c c c c				[**0.2g**] answer: 0.2g
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*	1 Mg + H^+	[1+D]	1+D	*R_2/R_1, if $R \propto C^2$, $C_1 = 1$,*
[**R_2 = 50**]	2 P/Q data	[2+C]	3+B	*$C_2 = 0.5$?* [**$R_2/R_1 = 1/4$**]
pre: nr	3 Plots/data	[5+A]	1+D	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-: "increase"	4 H_2/I_2	[4+D]	1+C	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 Metals (statements):				
Cu/metal brass/metl brass/elt pencil/lead	1 Metals/PT	[3+A]	3+E	*List 5 gen phys props of metals*
pre- [T] nr [F] nr [F] nr [F] nr				No of props: 1 2 3 4 5
post-] [T] T [F] T [F] T [F] F				c x c c x
granite/nm Si/nm Ne/nm Fe ore/metallic				
pre- [F] nr [T] nr [T] nr [F] nr				*Name two exceptional metals:*
post-- [F] T [T] T [T] T [F] U				(1) sodium (2) copper
9 Halogen: *Use or application?*	1 ICl + H_2O	[2+A]	1+C	*Hypochlorous acid:*
Cl F I				*formula:* HClO
pre- c c c				*ox no of Cl:* +1
post- c c c				*equation with HOCl* : x
10 Hydrocarbon: *Chemical names:*	1 $C_4H_6 + Br_2$	[1+D]		*4th member of $C_nH_{(2n-2)}$:Name?*
pre: nr nr nr nr nr	also	[4+A]	4+A	stem[**pent-**]: alk -**yne**: c
post: nr nr nr nr nr				
one common property:				*structural formula?*
pre: flammable				C≡C:✓✓; skeleton[**5 carbons**]: 2
post: flammable				

Table 6.1.5 Concept Learning Test Sequences: Summary of results for student no. 5 - BE

										Two tier tests			
Concept	Pre-/Post-Instruction Part A									item	solution choice		Post-Instruction Part B
1 Density	*Water vapour: density is 500g/litre?*									1 d(CO_2)	[2 + D]	2 + D	*Vol of 100g of ice?* [109mL]
		T	F*	U						2 box, T↑	[4 + A]	4 + A	Answer: 109mL
pre-				✓									
post-			✓										
2 Mixture/cmp'd	*Compound (C) or mixture (M)?*									1 % comp	[2 + D]	3 + A	*Fe + S → FeS Fe = 8g, S = 4g*
		glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-		M	nr	nr									**[Fe = 1g, S = 0g; FeS = 11g]**
post-		M	C	C									Answer:
		rubber [M]	curry [M)]	wine [M]									Fe = 1mole, S = 0; FeS = 7moles
pre-		C	nr	nr									
post-		M	M	M									
3 Structure/bonding	*NaCl (ionic/molecular)?*									1 B_4C	[3 + C]	4 + B	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
		I	M	U						2 HF e^-	[1 + C]	1 + C	$T_m(BaO)$? $R(Ba^{2+})$?
pre-				✓						3 Vaseline	[1 + C]	1 + C	
post-		✓								4 Gp I&VII	[2 + B]	2 + B	T_m (BaO) 100 4000 **2000**
													✓
Melting Pt of NaCl?													R(Ba^{2+}) 59 **135** 65
		-80^0	80^0	300^0	800^0	U							✓
pre-			✓										
post-					✓								
4 Base/salt	*Which are bases?*									1 $BaCO_3$	[2 + B]	1 + A.	*Formula of a base in Part A?*
		limestone	vinegar	salt	**carb soda**								NH_3
pre-													*Equation for that base?*
post-		✓											balanced, appropriate:
													balanced, other base:
		ammonia	sugar	alcohol									inappropriate choice: yes
pre-					nr								
post-		✓											
5 Redox:	*Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2 + A].	2 + A	*In C + CuO → CO + Cu,*
		T	F	U	nr					2 Red. Agent	[2 + C]	2 + C	*Cu is reducing agent:* T (✓) F ( )
pre-		✓								3 Cell A/A^+//..	[1 + D]	2 + B	*Cu gains electrons:* **T** ( ) **F** (✓)
post-			✓							4 $CO_3^{2-} + H^+$	[3 + C]	3 + C	*Ox N of O: -2→+ 2:* T ( ) **F** (✓)
										5 Cell I/MnO_4	[4 + C]	4 + C	
6 Mole:	*Eight calculations:*												
no.		1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3 + E]	3 + E	*Weight (mass) of*
pre-		c	c	c	c	c	c	c	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post		c	c	c	x	c	c	c	c				**[0.2g]** answer: 0.2g
7 Rate:	*R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1 + D]	1 + D	R_2/R_1 if $R \propto C^2$, $C_1 = 1$,
	[R_2 = **50**]									2 P/Q data	[2 + C]	2 + C	$C_2 = 0.5$? **[$R_2/R_1 = 1/4$]**
pre:		50								3 Plots/data	[5 + A]	2 + D	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:		50								4 H_2/I_2	[4 + D]	4 + D	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 Metals	(statements):												
		Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3 + A]	3 + A	*List 5 gen phys props of metals*
pre-		[T] T	[F] T	[F] F	[F] T								No of props: 1 2 3 4 5
post-]		[T] T	[F] F	[F] F	[F] F								x c c c c
		granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-		[F] T	[T]U	[T] U	[F] T								*Name two exceptional metals:*
post--		[F] T	[T] F	[T] T	[F] F								(1) mercury (2) sodium
9 Halogen:	*Use or application?*									1 ICl + H_2O	[2 + A]	2 + D	*Hypochlorous acid:*
		Cl	F	I									*formula:* HClO
pre-		c	nr	c									*ox no of Cl:* + 1
post-		c	x	c									*equation with HOCl* : c
10 Hydrocarbon:	*Chemical names:*									1 $C_4H_6 + Br_2$	[1 + D]		*4th member of $C_nH_{(2n-2)}$:Name?*
pre:		nr	nr	nr	nr	nr				also	[4 + A]	4 + A	stem[pent-]: but- -yne: c
post:		x	x	x	x	x							
one common property:													*structural formula?*
pre: nr													C≡C: ✓; skeleton[5 carbons]: 4
post: all organic													

Table 6.1.6 Concept Learning Test Sequences: Summary of results for student no. 6 - PF

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 **Density**	*Water vapour: density is 500g/litre?*								1 d(CO_2)	[2+D]	2+D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	4+A	Answer: 109mL
pre-			✓									
post-		✓										
2 **Mixture/cmp'd**	*Compound (C) or mixture (M)?*								1 % comp	[2+D]	2+D	*Fe + S → FeS Fe=8g, S=4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	M	C	C									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 1g, S = 0g; FeS = 11g
pre-	M	M	M									
post-	M	M	M									
3 **Structure/bonding**	*NaCl (ionic/molecular)?*								1 B_4C	[3+C]	3+A	*$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$*
	I	M	U						2 HF e^-	[1+C]	1+C	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-		✓							3 Vaseline	[1+C]	1+C	
post-	✓								4 Gp I&VII	[2+B]	2+B	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 135 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-			✓									
post-				✓								
4 **Base/salt**	*Which are bases?*								1 $BaCO_3$	[2+B]	3+E	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre-	✓			✓								*Equation for that base?*
post-	✓			✓								balanced, appropriate: c
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-	✓											
post-	✓											
5 **Redox:**	*Hydrogen can reduce copper oxide?*								1 Fe+$CuSO_4$	[2+A].	2+A	*In C+CuO → CO+ Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	2+C	*Cu is reducing agent:* T (✓) F ( )
pre-	✓								3 Cell A/A^+//..	[1+D]	2+B	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 CO_3^{2-} + H^+	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) **F** (✓)
									5 Cell I/MnO_4	[4+C]	4+C	
6 **Mole**:	*Eight calculations:*											
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3+E]	3+E	*Weight (mass) of*
pre-	c	c	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	x	c	x				**[0.2g]** answer: 20.7g
7 **Rate**:	*R_2 if $R_1=40$, $A_1=100$, A_2 inc 25 ?*								1 Mg+H^+	[1+D]	1+D	*R_2/R_1 if $R \propto C^2$, $C_1=1$,*
	[R_2 = 50]								2 P/Q data	[2+C]	2+C	*$C_2=0.5$?* **[$R_2/R_1 = 1/4$]**
pre:	50								3 Plots/data	[5+A]	4+E	ans: $R_2=2R_1$ ( ), $R_2=4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	4+D	$R_2=R_1/4$ (✓), $R_2=R_1/2$ ( )
8 **Metals** (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	5+A	*List 5 gen phys props of metals*
pre-	[T] T	[F]T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c c x c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] T	[F] U								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] F								(1) x (2) x
9 **Halogen**:	*Use or application?*								1 ICl +H_2O	[2+A]	1+B	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: c
pre-	c	x	c									*ox no of Cl* [+1]: c
post-	c	x	c									*equation with HOCl* : c
10 **Hydrocarbon**: *Chemical names:*									1 $C_4H_6+Br_2$	[1+D]		*4th member of $C_nH_{(2n-2)}$:Name?*
pre: x c x x nr									also	[4+A]	4+A	stem [pent]: prop- -yne: c
post: c c c c nr												
one common property:												*structural formula?*
pre: flammable												C≡C: c skeleton [5 carbons]: 4
post: hydrocarbons												

Table 6.1.7 Concept Learning Test Sequences: Summary of results for student no. 7 - JG

	Two tier tests			
Concept **Pre-/Post-Instruction Part A**	**item**	**solution**	**choice**	**Post-Instruction Part B**
1 Density *Water vapour: density is 500g/litre?* T F* U pre- ✓ post- ✓	1 $d(CO_2)$ 2 box, T↑	[2 + D] [4 + A]	2 + D 4 + A	*Vol of 100g of ice?* [109mL] Answer: 109mL
2 Mixture/cmp'd *Compound (C) or mixture (M)?* glass [M] sugar [C] b/soda [C] pre- C C C post- C C C rubber [M] curry [M)] wine [M] pre- M M M post- C M M	1 % comp	[2 + D]	3 + C	*Fe + S → FeS Fe = 8g, S = 4g* *Residual mixture after heat?* [**Fe = 1g**, **S = 0g**; **FeS = 11g**] Answer: Fe = 0g, S = 0g; FeS = 12g
3 Structure/bonding *NaCl (ionic/molecular)?* I M U pre- ✓ post- ✓ *Melting Pt of NaCl?* -80^0 80^0 300^0 800^0 U pre- ✓ post- ✓	1 B_4C 2 HF e^- 3 Vaseline 4 Gp I&VII	[3 + C] [1 + C] [1 + C] [2 + B]	3 + C 1 + C 2 + B 2 + E	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$ $T_m(BaO)$? $R(Ba^{2+})$? T_m (BaO) 100 4000 2000 ✓ $R(Ba^{2+})$ 59 135 65 ✓
4 Base/salt *Which are bases?* **limestone** vinegar salt **carb soda** pre- ✓ ✓ post- ✓ ✓ ✓ **ammonia** sugar alcohol pre- ✓ post- ✓	1 $BaCO_3$	[2 + **B**]	1 + A	*Formula of a base in Part A?* $CaCO_3$ *Equation for that base?* balanced, appropriate: balanced, other base: inappropriate choice: yes
5 Redox: *Hydrogen can reduce copper oxide?* T* F U nr pre- ✓ post- ✓	1 Fe + $CuSO_4$ 2 Red. Agent 3 Cell $A/A^+//..$ 4 $CO_3^{2-} + H^+$ 5 Cell I/MnO_4	[**2 + A**]. [**2 + C**] [**1 + D**] [3 + C] [**4 + C**]	2 + A 2 + A 1 + D 3 + C 4 + C	*In C + CuO → CO + Cu,* *Cu is reducing agent:* **T** (✓) F ( ) *Cu gains electrons:* **T** (✓) F ( ) *Ox N of O: -2→+2:* T ( ) F (✓)
6 Mole: *Eight calculations:* no. 1 2 3 4 5 6 7 8 pre- c c c x nr nr x nr post- c c c c x c c c	1 Cu^{2+}/OH^-	[3 + **E**]	3 + E	*Weight (mass) of* *$1.5x10^{21}$ molecules of SO_3?* [**0.2g**] answer: $1.2x10^{23}$
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?* [R_2 = **50**] pre: 50 post-: 50	1 $Mg + H^+$ 2 P/Q data 3 Plots/data 4 H_2/I_2	[**1 + D**] [2 + C] [5 + A] [**4 + D**]	1 + D 3 + D 2 + D 4 + D	*R_2/R_1, if $R \propto C^2$, $C_1 = 1$,* *$C_2 = 0.5$?* [**$R_2/R_1 = 1/4$**] ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ), $R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 Metals (statements): Cu/metal brass/metl brass/elt pencil/lead pre- [T] T [F] U [F] F [F] T post-] [T] T [F] F [F] F [F] F granite/nm Si/nm Ne/nm Fe ore/metallic pre- [F] F [T] F [T] T [F] F post- [F] F [T] F [T] T [F] T	1 Metals/PT	[3 + A]	5 + A	*List 5 gen phys props of metals* No of props: 1 2 3 4 5 c c c x c *Name two exceptional metals:* (1) sodium (2) potassium
9 Halogen: *Use or application?* Cl F I pre- c x c post- c x c	1 ICl + H_2O	[**2 + A**]	1 + B	*Hypochlorous acid:* *formula* [**HOCl**]: HClO *ox no of Cl* [**+1**]: -1 *equation with HOCl* : c
10 Hydrocarbon: *Chemical names:* pre: nr nr nr nr nr post: hydrocarbons *one common property:* pre: nr post: flammability	1 $C_4H_6 + Br_2$	[**1 + D**] also [**4 + A**]	4 + C	*4th member of $C_nH_{(2n-2)}$:Name?* stem [**pent-**]: but- -yne: c *structural formula?* **C≡C**: ✓ skeleton [**5 carbons**]: 4

Table 6.1.8 Concept Learning Test Sequences: Summary of results for student no. 8 - VG

									Two tier tests			
Concept	Pre-/Post-Instruction Part A								item	solution	choice	Post-Instruction Part B
1 Density	*Water vapour: density is 500g/litre?*								1 $d(CO_2)$	[2+D]	2+D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	3+D	Answer: 104mL
pre-			✓									(took d = 0.96)
post-		✓										
2 Mixture/cmp'd	*Compound (C) or mixture (M)?*								1 % comp	[2+D]	2+B	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	M	M	M									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M]]	wine [M]									Fe = 0g, S = 0g; FeS = 12g
pre-	M	M	M									
post-	M	M	M									
3 Structure/bonding	*NaCl (ionic/molecular)?*								1 B_4C	[3+C]	2+A	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	[1+C]	1+A	$T_m(BaO)?$ $R(Ba^{2+})?$
pre-		✓							3 Vaseline	[1+C]	2+C	
post-	✓								4 Gp I&VII	[2+B]	2+B	T_m (BaO) 100 4000 **2000**
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 **135** 65
	−80⁰	80⁰	300⁰	**800⁰**	U							✓
pre-					✓							
post-				✓								
4 Base/salt		*Which are bases?*							1 $BaCO_3$	[2+B]	2+B	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								NH_3
pre-	✓			✓								*Equation for that base?* nr
post-	✓			✓								balanced, appropriate:
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-	✓		(nr)									
post-	✓		nr									
5 Redox:	*Hydrogen can reduce copper oxide?*								1 $Fe+CuSO_4$	[2+A].	1+E	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	3+E	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell $A/A^+//..$	[1+D]	2+A	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 $CO_3^{2-} + H^+$	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4+C]	4+B	
6 Mole:	*Eight calculations:*											
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3+E]	3+E	*Weight (mass) of*
pre-	c	c	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				**[0.2g]** answer: 0.2g
7 Rate:	*R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*								1 $Mg+H^+$	[1+D]	1+D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
	[R_2 = 50]								2 P/Q data	[2+C]	2+C	*$C_2 = 0.5$?* **[$R_2/R_1 = 1/4$]**
pre:	10								3 Plots/data	[5+A]	2+D	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	4+B	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 Metals	(statements):											
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	5+A	*List 5 gen phys props of metals*
pre-	[T] T	[F]T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c x c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] U	[T] U	[T] U	[F] T								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] T								(1) nr (2) nr
9 Halogen:	*Use or application?*								1 $ICl + H_2O$	[2+A]	1+B	*Hypochlorous acid:*
	Cl	F	I									*formula* **[HOCl]**: nr
pre-	c	c	c									*ox no of Cl* [+1]:nr
post-	c	c	c									*equation with HOCl* : nr
10 Hydrocarbon:	*Chemical names:*								1 $C_4H_6 + Br_2$	[1+D]	1+D	*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	nr c nr nr nr nr									also [4+A]		stem **[pent-]**: but- -yne: c
post:	nr nr nr nr nr nr											
one common property:												*structural formula?*
pre:	nr											C≡C: ✓ skeleton**[5 carbons]**: 4
post:	organic											

Table 6.1.9 Concept Learning Test Sequences: Summary of results for student no. 9 - CG

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 Density *Water vapour: density is 500g/litre?*									1 $d(CO_2)$	[2+D]	1+D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	4+A	Answer: 92mL
pre-	✓											
post-		✓										
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	[2+D]	2+A	*Fe + S → FeS Fe=8g, S=4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	M	C	C									**[Fe=1g, S=0g; FeS=11g]**
post-	M	C	C									Answer: nr - $FeSO_4$ [sic]
	rubber [M]	curry [M)]	wine [M]									Fe= g, S= g; FeS= g
pre-	C	M	M									
post-	C	M	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	4+B	*$T_m(MgO)=2800^0$, $R(Mg^{2+})=65$*
	I	M	U						2 HF e^-	[1+C]	1+C	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-	✓								3 Vaseline	[1+C]	2+B	
post-	✓								4 Gp I&VII	[2+B]	4+C	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 135 65
	-80^0	80^0	300^0	800^0	U							✓
pre-			✓									
post-		✓										
4 Base/salt *Which are bases?*									1 $BaCO_3$	[2+B]	mc	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								NaCl
pre-	✓	✓	✓									*Equation for that base?*
post-	✓	✓	✓	✓								balanced, appropriate:
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice: yes
pre-				(nr)								
post-				(nr)								
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2+A].	mc	*In C+CuO → CO+ Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	mc	*Cu is reducing agent:* T ( ) F (✓)
pre-			✓						3 Cell $A/A^+//..$	[1+D]	mc	*Cu gains electrons:* T ( ) F (✓)
post-	✓								4 $CO_3^{2-} + H^+$	[3+C]	1+A	*Ox N of O: -2→+2:* T (✓) F ( )
									5 Cell I/MnO_4	[4+C]	3+D	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3+E]	mc	*Weight (mass) of*
pre-	c	c	c	x	nr	x	nr	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	x	x	c	x				[0.2g] answer: 80g
7 Rate: *R_2 if $R_1=40$, $A_1=100$, A_2 inc 25 ?*									1 $Mg+H^+$	[1+D]	1+D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
	$[R_2 = 50]$								2 P/Q data	[2+C]	2+C	*$C_2 = 0.5$?* $[R_2/R_1 = 1/4]$
pre:	50								3 Plots/data	[5+A]	4+E	ans: $R_2=2R_1$ ( ), $R_2=4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	4+D	$R_2=R_1/4$ (✓), $R_2=R_1/2$ ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	4+E	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] F	[T]U	[T] T	[F] T								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] T								(1) mercury (2) lead
9 Halogen: *Use or application?*									1 ICl + H_2O	[2+A]	2+D	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: HCl
pre-	c	x	c									*ox no of Cl* [+1]: - (1)
post-	c	c	c									*equation with HOCl* : nr
10 Hydrocarbon: *Chemical names:*									1 $C_4H_6 + Br_2$	[1+D]	2+D	*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	x	c	x	nr	nr					also [4+A]		stem [pent-]: alk- -yne: c
post:	nr	nr	nr	nr	nr							
one common property:												*structural formula?*
pre:	contain hydrogen											C≡C: ✓ skeleton [5 carbons]: 2
post:	flammable											

Table 6.1.10 Concept Learning Test Sequences: Summary of results for student no. 10 - MG

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 Density *Water vapour: density is 500g/litre?*									1 $d(CO_2)$	[2 + D]	1 + D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4 + A]	4 + A	Answer: 1088mL
pre-			✓									took 1000g of ice
post-		✓										
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	[2 + D]	1 + C	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	M	C	C									[Fe = 1g, S = 0g; FeS = 11g]
post-	C	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 0g, S = 0g; FeS = 12g
pre-	M	M	M									
post-	M	M	C									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	[3 + C]	3 + C	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	[1 + C]	1 + C	$T_m(BaO)$? $R(Ba^{2+})$?
pre-			✓						3 Vaseline	[1 + C]	2 + B	
post-	✓								4 Gp I&VII	[2 + B]	2 + B	T_m (BaO) 100 4000 **2000**
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 **135** 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-				✓								
post-				✓								
4 Base/salt *Which are bases?*									1 $BaCO_3$	[2 + B]	2 + A	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre-												*Equation for that base?*
post-	✓			✓								balanced, appropriate: yes
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-				nr								
post-	✓											
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2 + A].	2 + A.	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2 + C]	2 + A	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell $A/A^+//..$	[1 + D]	2 + D	*Cu gains electrons:* T (✓) F ( )
post-		✓							4 $CO_3^{2-} + H^+$	[3 + C]	3 + C	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4 + C]	4 + C	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3 + E]	nr	*Weight (mass) of*
pre-	c	c	c	x	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3?*
post-	c	c	c	c	c	c	c	c				[0.2g] answer: 0.2g
7 Rate: R_2 *if* $R_1 = 40$, $A_1 = 100$, A_2 *inc 25 ?*									1 Mg + H^+	[1 + D]	1 + D	R_2/R_1 *if* $R \propto C^2$, $C_1 = 1$,
[R_2 = 50]									2 P/Q data	[2 + C]	4 + A	$C_2 = 0.5$? [$R_2/R_1 = 1/4$]
pre:	nr								3 Plots/data	[5 + A]	3 + B	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4 + D]	4 + D	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3 + A]	5 + A	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] T	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] T	[F] T								c c c x c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] T	[F] U								*Name two exceptional metals:*
post--	[F] F	[T] T	[T] T	[F] T								(1) nr (2) nr
9 Halogen: *Use or application?*									1 ICl + H_2O	[2 + A]	1 + C	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: nr
pre-	nr	nr	nr									*ox no of Cl* [+1]: nr
post-	c	nr	nr									*equation with HOCl* : nr
10 Hydrocarbon: *Chemical names:*									1 $C_4H_6 + Br_2$	[1 + D]		*4th member of* $C_nH_{(2n-2)}$ *:Name?*
pre: nr										also [4 + A]	4 + A	stem [pent-]: nept - -yne: c
post: nr x nr nr nr												
one common property:												*structural formula?*
pre: nr												C≡C: ✓ skeleton [5 carbons]: 4
post: contain C & H												

Table 6.1.11 Concept Learning Test Sequences: Summary of results for student no. 11 - NH

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 **Density** *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2+D]	2+B	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	4+A	Answer: 109mL
pre-			✓									
post-	✓											
2 **Mixture/cmp'd** *Compound (C) or mixture (M)?*									1 % comp	[2+D]	2+C	*$Fe + S \rightarrow FeS$ $Fe = 8g$, $S = 4g$*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	nr	C	M									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 0, S = 0; FeS = 0.14mol
pre-	NR	nr	C									
post-	M	M	C									
3 **Structure/bonding** *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	3+C	*$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$*
	I	M	U						2 HF e^-	[1+C]	2+B	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-	✓								3 Vaseline	[1+C]	1+C	
post-	✓								4 Gp I&VII	[2+B]	2+B	T_m (BaO) 100 4000 **2000**
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 135 65
	−80⁰	80⁰	300⁰	**800⁰**	U	nr						✓
pre-						✓						
post-		✓										
4 **Base/salt** *Which are bases?*									1 $BaCO_3$	[2+B]	1+A	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre		✓	✓									*Equation for that base?*
post-	✓		✓	✓								balanced, appropriate: yes
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-	✓											
post-	✓											
5 **Redox:** *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2+A].	2+A	*In $C + CuO \rightarrow CO + Cu$,*
	T	F	U	nr					2 Red. Agent	[2+C]	3+D	*Cu is reducing agent:* **T** (✓) **F** ( )
pre-				✓					3 Cell A/A⁺//..	[1+D]	1+D	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 CO_3^{2-} + H^+	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) **F** (✓)
									5 Cell I/MnO_4	[4+C]	4+C	
6 **Mole:** *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3+E]	absent	*Weight (mass) of*
pre-	x	x	x	c	nr	nr	nr	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				[0.2g] answer: 0.19g
7 **Rate:** *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1+D]	1+D	*R_2/R_1, if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	[2+C]	2+C	*$C_2 = 0.5$?* **[R_2/R_1 = 1/4]**
pre:	50								3 Plots/data	[5+A]	3+A	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	1+C	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 **Metals** (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	3+A	*List 5 gen phys props of metals*
pre-	[T] T	[F] F	[F] U	[F] F								No of props: 1 2 3 4 5
post-)	[T] T	[F] T	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] T	[F] T								*Name two exceptional metals:*
post--	[F] U	[T] T	[T] T	[F] T								(1) sodium (2) mercury
9 **Halogen:** *Use or application?*									1 ICl + H_2O	[2+A]	2+A	*Hypochlorous acid:*
	Cl	F	I									*formula* **[HOCl]**: $HClO_3$
pre-	c	x	c									*ox no of Cl* **[+1]**: +5
post-	c	c	c									*equation with HOCl* : x
10 **Hydrocarbon:** *Chemical names:*									1 C_4H_6 + Br_2	[1+D]		*4th member of $C_nH_{(2n-2)}$:Name?*
Pre: nr nr nr nr nr									also	[4+A]	4+A	stem **[pent-]**:but - **-yne**: c
post: nr nr nr nr nr												
one common property:												*structural formula?*
pre: carbon												**C≡C**: ✓ skeleton [**5 carbons**]: 4
post: all carbon												

Table 6.1.12 Concept Learning Test Sequences: Summary of results for student no. 12 - MNI

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 **Density** *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2+D]	3+A	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	2+D	Answer: 109mL
pre-			✓									
post-			✓									
2 **Mixture/cmp'd** *Compound (C) or mixture (M)?*									1 % comp	[2+D]	1+C	*Fe + S → FeS Fe=8g, S=4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	M									**[Fe=1g, S=0g; FeS=11g]**
post-	M	M	M									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe= g, S= g; FeS= g
pre-	C	M	M									meaningless answers
post-	M	M	M									
3 **Structure/bonding** *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	3+A	*$T_m(MgO)=2800^0$, $R(Mg^{2+})=65$*
	I	M	U						2 HF e^-	[1+C]	2+B	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-			✓						3 Vaseline	[1+C]	2+C	
post-	✓								4 Gp I&VII	[2+B]	2+D	T_m (BaO) 100 4000 **2000**
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 135 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-					✓							
post-				✓								
4 **Base/salt** *Which are bases?*									1 $BaCO_3$	[2+B]	2+D	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre-	✓		✓									*Equation for that base?*
post-	✓		✓									balanced, appropriate: yes
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-												
post-												
5 **Redox:** *Hydrogen can reduce copper oxide?*									1 Fe+$CuSO_4$	[2+A].	2+C	*In C+CuO → CO+ Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	2+C	*Cu is reducing agent:* **T** (✓) F ( )
pre-			✓						3 Cell A/A^+//..	[1+D]	3+C	*Cu gains electrons:* **T** (✓) F ( )
post-	✓								4 CO_3^{2-} + H^+	[3+C]	3+C	*Ox N of O: -2→+2:* T (✓) **F** ( )
									5 Cell I/MnO_4	[4+C]	3+B	
6 **Mole**: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3+E]	4+E	*Weight (mass) of*
pre-	c	x	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	x	c	x	c	x				[0.2g] answer: 1.8×10^{19}g
7 **Rate:** *R_2 if $R_1=40$, $A_1=100$, A_2 inc 25 ?*									1 Mg+H^+	[1+D]	1+A	*R_2/R_1 if $R \propto C^2$, $C_1=1$,*
[R_2 = 50]									2 P/Q data	[2+C]	3+B	*$C_2=0.5$?* [$R_2/R_1=1/4$]
pre:	50								3 Plots/data	[5+A]	3+A	ans: $R_2=2R_1$ ( ), $R_2=4R_1$ (✓),
post-:	3.125								4 H_2/I_2	[4+D]	4+D	$R_2=R_1/4$ ( ), $R_2=R_1/2$ ( )
8 **Metals** (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	2+A	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] T	[F] T								No of props: 1 2 3 4 5
post-]	[T] T	[F] U	[F] T	[F] T								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] T	[F] T								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] T								(1) chromium (2) silver
9 **Halogen:** *Use or application?*									1 ICl + H_2O	[2+A]	1+C	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: unclear
pre-				nr								*ox no of Cl* [+1]: - (1)
post-	c	c	c									*equation with HOCl* : c
10 **Hydrocarbon**: *Chemical names:*									1 C_4H_6+Br_2	[1+D]		*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	nr	nr	nr	nr	nr				also	[4+A]	4+A	stem [pent-]: but- -yne: c
post:	x	nr	nr	nr	nr							
one common property:												*structural formula?*
pre:	nr											**C≡C:** ✓ skeleton **[5 carbons]**: 4
post:	non-conductors of electricity											

Table 6.1.13 Concept Learning Test Sequences: Summary of results for student no. 13 - EK

									Two tier tests			
Concept	Pre-/Post-Instruction Part A								item	solution	choice	Post-Instruction Part B
1 Density *Water vapour: density is 500g/litre?*									1 d(CO_2)	**[2+D]**	2+B	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	**[4+A]**	2+A	Answer: 109mL
pre-			✓									
post-		✓										
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	**[2+D]**	1+A	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	M									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 0.48g, S = 0g; FeS = 11.5g
pre-	C	M	M									
post-	C	M	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	**[3+C]**	3+C	*$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$*
	I	M	U						2 HF e^-	**[1+C]**	2+B	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-	✓								3 Vaseline	**[1+C]**	1+C	
post-	✓								4 Gp I&VII	**[2+B]**	2+E	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 **135** 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-		✓										
post-				✓								
4 Base/salt *Which are bases?*									1 $BaCO_3$	**[2+B]**	1+A	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								NaOH
pre-	✓		✓	✓								*Equation for that base?*
post-	✓		✓									balanced, appropriate: c
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-												
post-	✓											
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	**[2+A]**	2+C	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	**[2+C]**	2+C	*Cu is reducing agent:* **T** (✓) F ( )
pre-		✓							3 Cell A/A^+//..	**[1+D]**	1+B	*Cu gains electrons:* **T** (✓) F ( )
post-	✓								4 CO_3^{2-} + H^+	**[3+C]**	3+C	*Ox N of O: -2→+2:* T ( ) **F** (✓)
									5 Cell I/MnO_4	**[4+C]**	4+C	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	**[3+E]**	absent	*Weight (mass) of*
pre-	c	c	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				**[0.2g]** answer: 0.199g
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	**[1+D]**	1+D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	**[2+C]**	2+C	*$C_2 = 0.5$?* **[$R_2/R_1 = 1/4$]**
pre:	50								3 Plots/data	**[5+A]**	4+D	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ (✓),
post-:	50								4 H_2/I_2	**[4+D]**	4+D	$R_2 = R_1/4$ ( ), $R_2 = R_1/2$ ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	**[3+A]**	2+B	*List 5 gen phys props of metals*
pre-	[T] T	[F]T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] F	[F] F	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] F	[F] F								*Name two exceptional metals:*
post--	[F] F	[T] T	[T] T	[F] T								(1) sodium (2) potassium
9 Halogen: *Use or application?*									1 ICl + H_2O	**[2+A]**	3+A	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: OHCl
pre-	nr	nr	c									*ox no of Cl* [+1]: − 1
post-	c	nr	c									*equation with HOCl* : nr
10 Hydrocarbon: *Chemical names:*									1 C_4H_6 + Br_2	**[1+D]**	1+A	*4th member of $C_nH_{(2n-2)}$:Name?*
pre: nr nr nr nr nr										also **[4+A]**		stem **[pent-]**:nr **-yne**: nr..→
post: x c x x x												(formula C_5H_8 quoted instead)
one common property:												*structural formula?*
pre: won't mix with water												**C≡C**: ✓ skeleton **[5 carbons]**: 5
post: immiscible with water												

Table 6.1.14 Concept Learning Test Sequences: Summary of results for student no. 14 - TK

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 Density *Water vapour: density is 500g/litre?*									1 $d(CO_2)$	[2 + D]	2 + D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4 + A]	4 + A	Answer: 109mL
pre-			✓									
post-		✓										
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	[2 + D]	2 + D	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	M	C	C									[Fe = 1g, S = 0g; FeS = 11g]
post-	C	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 1g, S = 0g; FeS = 11g
pre-	M	M	M									
post-	M	M	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	[3 + C]	3 + C	*$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$*
	I	M	U						2 HF e^-	[1 + C]	2 + B	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-	✓								3 Vaseline	[1 + C]	1 + C	
post-	✓								4 Gp I&VII	[2 + B]	3 + C	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 **135** 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-			✓									
post-				✓								
4 Base/salt *Which are bases?*									1 $BaCO_3$	[2 + B]	2 + B	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre-	✓			✓								*Equation for that base?*
post-	✓			✓								balanced, appropriate: c
												balanced, other base:
	ammonia	sugar	alcohol									inappropriate choice:
pre-	✓											
post-												
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2 + A].	2 + A	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2 + C]	2 + D	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell $A/A^+//..$	[1 + D]	2 + B	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 $CO_3^{2-} + H^+$	[3 + C]	3 + C	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4 + C]	1 + B	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3 + E]	absent	*Weight (mass) of*
pre-	c	c	c	c	c	x	c	x				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				[0.2g] answer: 0.18g
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 $Mg + H^+$	[1 + D]	1 + A	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	[2 + C]	2 + C	*$C_2 = 0.5$?* [$R_2/R_1 = 1/4$]
pre:	50								3 Plots/data	[5 + A]	5 + A	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4 + D]	4 + D	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3 + A]	3 + A	*List 5 gen phys props of metals*
pre-	[T] T	[F]T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] T	[F] F								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] F								(1) mercury (2) nr
9 Halogen: *Use or application?*									1 ICl + H_2O	[2 + A]	1 + B	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: HClO
pre-	c	x	c									*ox no of Cl* [+1]: -1
post-	c	c	c									*equation with HOCl* : nr
10 Hydrocarbon: *Chemical names:*									1 $C_4H_6 + Br_2$	[1 + D]		*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	c	c	x	x	x				also	[4 + A]	4 + A	stem [pent-]:pro- -yne: ✓
post:	x	c	x	x	x							
one common property:												*structural formula*?
pre:	hydrogen											C≡C: ✓ skeleton (5 carbons): 4
post:	all hydrocarbons											

Table 6.1.15 Concept Learning Test Sequences: Summary of results for student no. 15 - SL

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 **Density** *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2+D]	2+D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	4+A	Answer: 92mL
pre-			✓									
post-		✓										
2 **Mixture/cmp'd** *Compound (C) or mixture (M)?*									1 % comp	[2+D]	1+A	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	M	M	C									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 1g, S = 0g; FeS = 7g
pre-	C	M	M									
post-	C	M	M									
3 **Structure/bonding** *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	3+C	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	[1+C]	1+C	$T_m(BaO)$? $R(Ba^{2+})$?
pre-			✓						3 Vaseline	[1+C]	1+D	
post-	✓								4 Gp I&VII	[2+B]	2+E	T_m (BaO) 100 4000 **2000**
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 **135** 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-		✓										
post-				✓								
4 **Base/salt** *Which are bases?*									1 $BaCO_3$	[2+B]	1+A	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								$CaCO_3$
pre-	✓			✓								*Equation for that base?*
post-	✓			✓								balanced, appropriate:
												unbalanced, appropriate: yes
	ammonia	sugar	alcohol									balanced, other base:
pre–	✓											inappropriate choice:
post-	✓		✓									
5 **Redox:** *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2+A].	2+E	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	2+C	*Cu is reducing agent:* **T** (✓) F ( )
pre-	✓								3 Cell $A/A^+//..$	[1+D]	1+D	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 $CO_3^{2-} + H^+$	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) **F** (✓)
									5 Cell I/MnO_4	[4+C]	4+C	
6 **Mole:** *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3+E]	3+E	*Weight (mass) of*
pre-	c	c	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				**[0.2g]** answer: 0.20g
7 **Rate**: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1+D]	1+D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	[2+C]	2+C	*$C_2 = 0.5$?* **[$R_2/R_1 = 1/4$]**
pre:	50								3 Plots/data	[5+A]	2+A	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	4+D	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 **Metals** (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	3+B	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] F	[F] F								No of props: 1 2 3 4 5
post-	[T] T	[F] T	[F] F	[F] F								c x nr nr nr
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] F	[T] T	[T] T	[F] T								*Name two exceptional metals:*
post–	[F] F	[T] T	[T] T	[F] T								(1) mercury (2) nr
9 **Halogen:** *Use or application?*									1 ICl + H_2O	[2+A]	1+C	*Hypochlorous acid:*
	Cl	F	I									*formula* **[HOCl]**: HClO
pre-	nr	nr	nr									*ox no of Cl* [+1]: +1
post-	c	c	c									*equation with HOCl* : x
10 **Hydrocarbon:** *Chemical names:*									1 $C_4H_6 + Br_2$	[1+D]	1+D	*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	n	nr	n	nr	nr					also [4+A]		stem **[pent-]**: hex- **-yne**: c
post:	x	x	x	x	x							
one common property:												*structural formula*?
pre: all have same source												**C≡C:** ✓ skeleton **[5 carbons]**:5
post: flammable, organic												

Table 6.1.16 Concept Learning Test Sequences: Summary of results for student no. 16 - GM

									Two tier tests			
Concept	Pre-/Post-Instruction Part A								item	solution	choice	Post-Instruction Part B
1 Density *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2+D]	1+D	*Vol of 100g of ice?* [109mL]
	T	**F***	U						2 box, T↑	[4+A]	2+D	Answer: 109mL
pre-		✓										
post-	✓											
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	[2+D]	1+C	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	M									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 3.8g, S = 2.8g; FeS = 5.4g
pre-	C	M	M									
post-	C	M	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	3+C	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	[1+C]	1+C	$T_m(BaO)$? $R(Ba^{2+})$?
pre-	✓								3 Vaseline	[1+C]	1+C	
post-	✓								4 Gp I&VII	[2+B]	4+C	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 135 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-		✓										
post-				✓								
4 Base/salt *Which are bases?*									1 $BaCO_3$	[2+B]	3+E	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								NaCl
pre-	✓			✓								*Equation for that base?*
post-	✓		✓	✓								balanced, appropriate:
												unbalanced, appropriate:
	ammonia	sugar	alcohol									balanced, other base:
pre-	✓											inappropriate choice: yes
post-												
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2+A].	4+A	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	2+C	*Cu is reducing agent:* T (✓) F ( )
pre-		✓							3 Cell A/A^+//..	[1+D]	4+B	*Cu gains electrons:* T ( ) F (✓)
post-	✓								4 CO_3^{2-} + H^+	[3+C]	1+D	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4+C]	4+C	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3+E]	3+E	*Weight (mass) of*
pre-	c	c	c	c	c	x	x	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	x	c	c	x	x	x	c	c				[0.2g] answer: $1.2x10^{23}$g
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1+D]	1+A	*R_2/R_1, if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	[2+C]	2+C	*$C_2 = 0.5$?* [$R_2/R_1 = 1/4$]
pre:	50								3 Plots/data	[5+A]	4+A	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	1+C	$R_2 = R_1/4$ ( ), $R_2 = R_1/2$ (✓)
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	1+A	*List 5 gen phys props of metals*
pre-	[T] T	[F] F	[F] F	[F] T								No of props: 1 2 3 4 5
post-	[T] T	[F] F	[F] F	[F] F								c c c c x
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] U	[T] T	[F] T								*Name two exceptional metals:*
post--	[F] T	[T] T	[T] T	[F] T								(1) sodium (2) copper
9 Halogen: *Use or application?*									1 ICl + H_2O	[2+A]	1+C	*Hypochlorous acid:*
	Cl	F	I									*formula* [**HOCl**]: HCl
pre-	x	x	c									*ox no of Cl* [+1]: -2
post-	c	x	c									*equation with HOCl* : nr
10 Hydrocarbon: *Chemical names:*									1 C_4H_6 + Br_2	[1+D]	1+D	*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	c	x	x	x	x					also [4+A]		stem [**pent-**]: propan- -yne: x
post:	c	c	nr	nr	nr							
one common property:												*structural formula?*
pre:	flammable											C≡C: x ; skeleton [**5 carbons**]: 3
post:	x											

Table 6.1.17 Concept Learning Test Sequences: Summary of results for student no. 17 - LN

Concept	Pre-/Post-Instruction Part A								Two tier tests			Post-Instruction Part B
									item	solution	choice	
1 Density	*Water vapour: density is 500g/litre?*								1 $d(CO_2)$	[2+D]	2+D	*Vol of 100g of ice?* **[109mL]**
	T	F*	U						2 box, T↑	[4+A]	4+A	Answer: 109mL
pre-			✓									
post-	✓											
2 Mixture/cmp'd	*Compound (C) or mixture (M)?*								1 % comp	[2+D]	2+C	*Fe + S → FeS Fe=8g, S=4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	M									**[Fe=1g, S=0g; FeS=11g]**
post-	C	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe= 0g, S= 0g; FeS= 12g
pre-	M	M	M									
post-	C	M	C									
3 Structure/bonding	*NaCl (ionic/molecular)?*								1 B_4C	[3+C]	3+A	*$T_m(MgO)=2800^0$, $R(Mg^{2+})=65$*
	I	M	U						2 HF e^-	[1+C]	2+B	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-		✓							3 Vaseline	[1+C]	1+C	
post-	✓								4 Gp I&VII	[2+B]	2+E	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												$R(Ba^{2+})$ 59 **135** 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-					✓							
post-				✓								
4 Base/salt	*Which are bases?*								1 $BaCO_3$	[2+B]	1+A	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								Na_2CO_3
pre-												*Equation for that base?*
post-	✓			✓								balanced, appropriate:
												unbalanced, appropriate:
	ammonia	sugar	alcohol	nr								balanced, other base:
pre-				✓								inappropriate choice: yes
post-	✓											
5 Redox:	*Hydrogen can reduce copper oxide?*								1 Fe+$CuSO_4$	[2+A]	2+A	*In C+CuO → CO+ Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	1+C	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell A/A^+//..	[1+D]	2+B	*Cu gains electrons:* T ( ) F (✓)
post-	✓								4 $CO_3^{2-}+H^+$	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4+C]	3+C	
6 Mole:	*Eight calculations:*											
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3+E]	1+A	*Weight (mass) of*
pre-	c	c	c	c	c	nr	nr	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				**[0.2g]** answer: 0.2g
7 Rate:	*R_2 if $R_1=40$, $A_1=100$, A_2 inc 25 ?*								1 Mg+H^+	[1+D]	1+D	*R_2/R_1 if $R \propto C^2$, $C_1=1$,*
	[R_2 = 50]								2 P/Q data	[2+C]	2+C	*$C_2=0.5$?* **[R_2/R_1 = 1/4]**
pre:	nr								3 Plots/data	[5+A]	4+A	ans: $R_2=2R_1$ ( ), $R_2=4R_1$ (✓),
post-:	50								4 H_2/I_2	[4+D]	4+D	$R_2=R_1/4$ ( ), $R_2=R_1/2$ ( )
8 Metals	(statements):											
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	2+A	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] T	[F] F								No of props: 1 2 3 4 5
post-	[T] T	[F] F	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] T	[T] T	[F] T								*Name two exceptional metals:*
post-	[F] F	[T] F	[T] T	[F] T								(1) sodium (2) mercury
9 Halogen:	*Use or application?*								1 ICl +H_2O	[2+A]	2+A	*Hypochlorous acid:*
	Cl	F	I									*formula* **[HOCl]**: HCl
pre-	c	nr	c									*ox no of Cl* [+1]: -2
post-	c	c	c									*equation with HOCl* : nr
10 Hydrocarbon:	*Chemical names:*								1 $C_4H_6+Br_2$	[1+D]	1+A	*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	nr.nr.nr.nr.nr.									also [4+A]		stem **[pent-]**: - **-yne**: →
post:	x	c	x	x	nr							no name - C_4H_6 quoted
one common property:												*structural formula?*
pre:	nr											**C≡C**: ✓; skeleton [5 carbons]: 4
post:	hydrocarbons											

Table 6.1.18 Concept Learning Test Sequences: Summary of results for student no. 18 - BR

<table>
<tr><th rowspan="2">Concept</th><th rowspan="2">Pre-/Post-Instruction Part A</th><th colspan="3">Two tier tests</th><th rowspan="2">Post-Instruction Part B</th></tr>
<tr><th>item</th><th>solution</th><th>choice</th></tr>
<tr><td>1 Density</td><td><i>Water vapour: density is 500g/litre?</i><table><tr><td></td><td>T</td><td>F*</td><td>U</td></tr><tr><td>pre-</td><td></td><td></td><td>✓</td></tr><tr><td>post-</td><td></td><td>✓</td><td></td></tr></table></td><td>1 d(CO_2)
2 box, T↑</td><td>[2 + D]
[4 + A]</td><td>2 + D
4 + A</td><td><i>Vol of 100g of ice?</i> [109mL]
Answer: 109mL</td></tr>
<tr><td>2 Mixture/cmp'd</td><td><i>Compound (C) or mixture (M)?</i><table><tr><td></td><td>glass [M]</td><td>sugar [C]</td><td>b/soda [C]</td></tr><tr><td>pre-</td><td>C</td><td>C</td><td>C</td></tr><tr><td>post-</td><td>M</td><td>C</td><td>C</td></tr><tr><td></td><td>rubber [M]</td><td>curry [M)]</td><td>wine [M]</td></tr><tr><td>pre-</td><td>C</td><td>M</td><td>M</td></tr><tr><td>post-</td><td>C</td><td>M</td><td>M</td></tr></table></td><td>1 % comp</td><td>[2 + D]</td><td>2 + B</td><td><i>Fe + S → FeS Fe = 8g, S = 4g</i>
<i>Residual mixture after heat?</i>
[Fe = 1g, S = 0g; FeS = 11g]
Answer:
Fe = 1g, S = g; FeS = 11g</td></tr>
<tr><td>3 Structure/bonding</td><td><i>NaCl (ionic/molecular)?</i><table><tr><td></td><td>I</td><td>M</td><td>U</td></tr><tr><td>pre-</td><td></td><td></td><td>✓</td></tr><tr><td>post-</td><td>✓</td><td></td><td></td></tr></table><i>Melting Pt of NaCl?</i><table><tr><td></td><td>-80^0</td><td>80^0</td><td>300^0</td><td>800^0</td><td>U</td></tr><tr><td>pre-</td><td></td><td></td><td>✓</td><td></td><td></td></tr><tr><td>post-</td><td></td><td></td><td></td><td>✓</td><td></td></tr></table></td><td>1 B_4C
2 HF e^-
3 Vaseline
4 Gp I&VII</td><td>[3 + C]
[1 + C]
[1 + C]
[2 + B]</td><td>3 + A
1 + C
1 + C
2 + B</td><td>$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
$T_m(BaO)$? $R(Ba^{2+})$?<table><tr><td>T_m (BaO)</td><td>100</td><td>4000</td><td>2000</td></tr><tr><td></td><td></td><td></td><td>✓</td></tr><tr><td>$R(Ba^{2+})$</td><td>59</td><td>135</td><td>65</td></tr><tr><td></td><td></td><td>✓</td><td></td></tr></table></td></tr>
<tr><td>4 Base/salt</td><td><i>Which are bases?</i><table><tr><td></td><td>limestone</td><td>vinegar</td><td>salt</td><td>carb soda</td></tr><tr><td>pre-</td><td>✓</td><td>✓</td><td></td><td></td></tr><tr><td>post-</td><td>✓</td><td></td><td></td><td></td></tr><tr><td></td><td>ammonia</td><td>sugar</td><td>alcohol</td><td></td></tr><tr><td>pre-</td><td>✓</td><td></td><td></td><td></td></tr><tr><td>post-</td><td>✓</td><td></td><td></td><td></td></tr></table></td><td>1 $BaCO_3$</td><td>[2 + B]</td><td>1 + A</td><td><i>Formula of a base in Part A?</i>
$NaCO_3$
<i>Equation for that base?</i>
balanced, appropriate:
unbalanced, appropriate: yes
balanced, other base:
inappropriate choice:</td></tr>
<tr><td>5 Redox:</td><td><i>Hydrogen can reduce copper oxide?</i><table><tr><td></td><td>T</td><td>F</td><td>U</td><td>nr</td></tr><tr><td>pre-</td><td></td><td></td><td>✓</td><td></td></tr><tr><td>post-</td><td>✓</td><td></td><td></td><td></td></tr></table></td><td>1 Fe + $CuSO_4$
2 Red. Agent
3 Cell $A/A^+//..$
4 $CO_3^{2-} + H^+$
5 Cell I/MnO_4</td><td>[2 + A]
[2 + C]
[1 + D]
[3 + C]
[4 + C]</td><td>2 + A
2 + C
1 + D
3 + C
4 + C</td><td><i>In C + CuO → CO + Cu,</i>
<i>Cu is reducing agent:</i> T (✓) F ( )
<i>Cu gains electrons:</i> T (✓) F ( )
<i>Ox N of O: -2→+2:</i> T ( ) F (✓)</td></tr>
<tr><td>6 Mole:</td><td><i>Eight calculations:</i><table><tr><td>no.</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr><tr><td>pre-</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td></tr><tr><td>post-</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td></tr></table></td><td>1 Cu^{2+}/OH^-</td><td>[3 + E]</td><td>3 + E</td><td><i>Weight (mass) of</i>
<i>$1.5x10^{21}$ molecules of SO_3 ?</i>
[0.2g] answer: nr</td></tr>
<tr><td>7 Rate:</td><td><i>R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?</i>
[R_2 = 50]
pre: 50
post-: 50</td><td>1 Mg + H^+
2 P/Q data
3 Plots/data
4 H_2/I_2</td><td>[1 + D]
[2 + C]
[5 + A]
[4 + D]</td><td>1 + D
2 + C
2 + D
4 + C</td><td><i>R_2/R_1, if $R \propto C^2$, $C_1 = 1$, $C_2 = 0.5$?</i> [$R_2/R_1 = 1/4$]
ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )</td></tr>
<tr><td>8 Metals</td><td>(statements):<table><tr><td></td><td>Cu/metal</td><td>brass/metl</td><td>brass/elt</td><td>pencil/lead</td></tr><tr><td>pre-</td><td>[T] T</td><td>[F] T</td><td>[F] U</td><td>[F] T</td></tr><tr><td>post-</td><td>[T] T</td><td>[F] T</td><td>[F] F</td><td>[F] F</td></tr><tr><td></td><td>granite/nm</td><td>Si/nm</td><td>Ne/nm</td><td>Fe ore/metallic</td></tr><tr><td>pre-</td><td>[F] U</td><td>[T] T</td><td>[T] T</td><td>[F] T</td></tr><tr><td>post--</td><td>[F] T</td><td>[T] T</td><td>[T] T</td><td>[F] T</td></tr></table></td><td>1 Metals/PT</td><td>[3 + A]</td><td>2 + A</td><td><i>List 5 gen phys props of metals</i><table><tr><td>No of props:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr><tr><td></td><td>c</td><td>c</td><td>c</td><td>c</td><td>x</td></tr></table><i>Name two exceptional metals:</i>
(1) sodium (2) nr</td></tr>
<tr><td>9 Halogen:</td><td><i>Use or application?</i><table><tr><td></td><td>Cl</td><td>F</td><td>I</td></tr><tr><td>pre-</td><td>c</td><td>c</td><td>c</td></tr><tr><td>post-</td><td>c</td><td>c</td><td>c</td></tr></table></td><td>1 ICl + H_2O</td><td>[2 + A]</td><td>1 + C</td><td><i>Hypochlorous acid:</i>
<i>formula</i> [HOCl]: HClO
<i>ox no of Cl</i> [+1]: +1
<i>equation with HOCl</i> : x</td></tr>
<tr><td>10 Hydrocarbon:</td><td><i>Chemical names:</i>
pre: nr nr nr nr nr
post: x nr x nr nr
<i>one common property:</i>
pre: nr
post: hydrocarbons</td><td>1 $C_4H_6 + Br_2$</td><td>[1 + D]
also [4 + A]</td><td>1 + D</td><td><i>4th member of $C_nH_{(2n-2)}$:Name?</i>
stem [pent-]:but - -yne: ✓
<i>structural formula?</i>
C≡C: ✓; skeleton [5 carbons]: 4</td></tr>
</table>

Table 6.1.19 Concept Learning Test Sequences: Summary of results for student no. 19 - AR

<table>
<tr><th></th><th></th><th colspan="3">Two tier tests</th><th></th></tr>
<tr><th>Concept</th><th>Pre-/Post-Instruction Part A</th><th>item</th><th>solution</th><th>choice</th><th>Post-Instruction Part B</th></tr>
<tr><td>1 Density</td><td><i>Water vapour: density is 500g/litre?</i>
<table><tr><td></td><td>T</td><td>F*</td><td>U</td></tr><tr><td>pre-</td><td></td><td></td><td>✓</td></tr><tr><td>post-</td><td></td><td>✓</td><td></td></tr></table></td><td>1 d(CO_2)
2 box, T↑</td><td>[2+D]
[4+A]</td><td>2+B
4+A</td><td><i>Vol of 100g of ice?</i> [109mL]
Answer: 109mL</td></tr>
<tr><td>2 Mixture/cmp'd</td><td><i>Compound (C) or mixture (M)?</i>
<table><tr><td></td><td>glass [M]</td><td>sugar [C]</td><td>b/soda [C]</td></tr><tr><td>pre-</td><td>M</td><td>C</td><td>C</td></tr><tr><td>post-</td><td>M</td><td>C</td><td>C</td></tr><tr><td></td><td>rubber [M]</td><td>curry [M)]</td><td>wine [M]</td></tr><tr><td>pre-</td><td>M</td><td>M</td><td>C</td></tr><tr><td>post-</td><td>M</td><td>M</td><td>C</td></tr></table></td><td>1 % comp</td><td>[2+D]</td><td>1+C</td><td><i>Fe + S → FeS Fe = 8g, S = 4g</i>
<i>Residual mixture after heat?</i>
[Fe = 1g, S = 0g; FeS = 11g]
Answer:
Fe = 0g, S = 0g;
FeS = 0.136mole</td></tr>
<tr><td>3 Structure/bonding</td><td><i>NaCl (ionic/molecular)?</i>
<table><tr><td></td><td>I</td><td>M</td><td>U</td></tr><tr><td>pre-</td><td>✓</td><td></td><td></td></tr><tr><td>post-</td><td>✓</td><td></td><td></td></tr></table>
<i>Melting Pt of NaCl?</i>
<table><tr><td></td><td>−80⁰</td><td>80⁰</td><td>300⁰</td><td>800⁰</td><td>U</td></tr><tr><td>pre-</td><td></td><td></td><td></td><td></td><td>✓</td></tr><tr><td>post-</td><td></td><td></td><td></td><td>✓</td><td></td></tr></table></td><td>1 B_4C
2 HF e^-
3 Vaseline
4 Gp I&VII</td><td>[3+C]
[1+C]
[1+C]
[2+B]</td><td>4+B
1+C
1+D
2+B</td><td><i>$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$</i>
<i>$T_m(BaO)$? $R(Ba^{2+})$?</i>
<table><tr><td>T_m (BaO)</td><td>100</td><td>4000</td><td>2000</td></tr><tr><td></td><td></td><td></td><td>✓</td></tr><tr><td>R(Ba^{2+})</td><td>59</td><td>135</td><td>65</td></tr><tr><td></td><td>✓</td><td></td><td></td></tr></table></td></tr>
<tr><td>4 Base/salt</td><td><i>Which are bases?</i>
<table><tr><td></td><td>limestone</td><td>vinegar</td><td>salt</td><td>carb soda</td></tr><tr><td>pre-</td><td></td><td></td><td></td><td></td></tr><tr><td>post-</td><td></td><td>✓</td><td></td><td></td></tr><tr><td></td><td>ammonia</td><td>sugar</td><td>alcohol</td><td>nr</td></tr><tr><td>pre-</td><td></td><td></td><td></td><td>✓</td></tr><tr><td>post-</td><td></td><td></td><td>✓</td><td></td></tr></table></td><td>1 $BaCO_3$</td><td>[2+B]</td><td>3+E</td><td><i>Formula of a base in Part A?</i>
(an alcohol) x
<i>Equation for that base?</i>
balanced, appropriate:
unbalanced, appropriate:
balanced, other base:
inappropriate choice: yes</td></tr>
<tr><td>5 Redox:</td><td><i>Hydrogen can reduce copper oxide?</i>
<table><tr><td></td><td>T</td><td>F</td><td>U</td><td>nr</td></tr><tr><td>pre-</td><td></td><td></td><td>✓</td><td></td></tr><tr><td>post-</td><td>✓</td><td></td><td></td><td></td></tr></table></td><td>1 Fe + $CuSO_4$
2 Red. Agent
3 Cell A/A^+//..
4 CO_3^{2-} + H^+
5 Cell I/MnO_4</td><td>[2+A]
[2+C]
[1+D]
[3+C]
[4+C]</td><td>2+C
1+B
3+B
2+D
1+B</td><td><i>In $C + CuO \rightarrow CO + Cu$,</i>
<i>Cu is reducing agent:</i> T ( ) F (✓)
<i>Cu gains electrons:</i> T (✓) F ( )
<i>Ox N of O: -2→+2:</i> T ( ) F (✓)</td></tr>
<tr><td>6 Mole:</td><td><i>Eight calculations:</i>
<table><tr><td>no.</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr><tr><td>pre-</td><td>c</td><td>c</td><td>c</td><td>c</td><td>x</td><td>c</td><td>c</td><td>x</td></tr><tr><td>post-</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td></tr></table></td><td>1 Cu^{2+} /OH^-</td><td>[3+E]</td><td>absent</td><td><i>Weight (mass) of</i>
<i>$1.5x10^{21}$ molecules of SO_3 ?</i>
[0.2g] answer: 0.20g</td></tr>
<tr><td>7 Rate:</td><td><i>R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?</i>
[R_2 = 50]
pre: 65
post-: 65</td><td>1 Mg + H^+
2 P/Q data
3 Plots/data
4 H_2/I_2</td><td>[1+D]
[2+C]
[5+A]
[4+D]</td><td>1+A
4+A
3+B
1+C</td><td><i>R_2/R_1 if $R \propto C^2$, $C_1 = 1$,</i>
<i>$C_2 = 0.5$?</i> [$R_2/R_1 = 1/4$]
ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )</td></tr>
<tr><td>8 Metals</td><td>(statements):
<table><tr><td></td><td>Cu/metal</td><td>brass/metl</td><td>brass/elt</td><td>pencil/lead</td></tr><tr><td>pre-</td><td>[T] T</td><td>[F] T</td><td>[F] F</td><td>[F] T</td></tr><tr><td>post-</td><td>[T] T</td><td>[F] T</td><td>[F] F</td><td>[F] T</td></tr><tr><td></td><td>granite/nm</td><td>Si/nm</td><td>Ne/nm</td><td>Fe ore/metallic</td></tr><tr><td>pre-</td><td>[F] U</td><td>[T] T</td><td>[T] U</td><td>[F] U</td></tr><tr><td>post-</td><td>[F] U</td><td>[T] T</td><td>[T] T</td><td>[F] T</td></tr></table></td><td>1 Metals/PT</td><td>[3+A]</td><td>5+A</td><td><i>List 5 gen phys props of metals</i>
<table><tr><td>No of props:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr><tr><td></td><td>c</td><td>c</td><td>c</td><td>c</td><td>c</td></tr></table>
<i>Name two exceptional metals:</i>
(1) mercury (2) hydrogen</td></tr>
<tr><td>9 Halogen:</td><td><i>Use or application?</i>
<table><tr><td></td><td>Cl</td><td>F</td><td>I</td></tr><tr><td>pre-</td><td>nr</td><td>nr</td><td>nr</td></tr><tr><td>post-</td><td>c</td><td>c</td><td>x</td></tr></table></td><td>1 ICl + H_2O</td><td>[2+A]</td><td>1+B</td><td><i>Hypochlorous acid:</i>
<i>formula</i> [HOCl]: HCl
<i>ox no of Cl</i> [+1]: -(1)
<i>equation with HOCl</i> : x</td></tr>
<tr><td>10 Hydrocarbon:</td><td><i>Chemical names:</i>
pre: x x nr nr nr
post: x x nr x x
<i>one common property:</i>
pre: carbon
post: all contain carbon</td><td>1 $C_4H_6 + Br_2$
also</td><td>[1+D]
[4+A]</td><td>
4+A</td><td><i>4th member of $C_nH_{(2n-2)}$:Name?</i>
stem [pent-]: but - ; -yne: ✓

<i>structural formula?</i>
C≡C: ✓ skeleton [5 carbons]: 4</td></tr>
</table>

Table 6.1.20 Concept Learning Test Sequences: Summary of results for student no. 20 - JV

Concept	Pre-/Post-Instruction Part A								Two tier tests			Post-Instruction Part B
									item	solution	choice	
1 **Density** *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2+D]	2+D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4+A]	4+A	Answer: 109mL
pre-	✓											
post-	✓											
2 **Mixture/cmp'd** *Compound (C) or mixture (M)?*									1 % comp	[2+D]	1+C	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	nr									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M)]	wine [M]									Fe = 1g, S = 0 g; FeS = 11g
pre-	nr	M	nr									
post-	M	M	M									
3 **Structure/bonding** *NaCl (ionic/molecular)?*									1 B_4C	[3+C]	3+A	*$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$*
	I	M	U						2 HF e^-	[1+C]	1+C	*$T_m(BaO)$? $R(Ba^{2+})$?*
pre-		✓							3 Vaseline	[1+C]	1+C	
post-	✓								4 Gp I&VII	[2+B]	2+B	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 135 65
	-80^0	80^0	300^0	800^0	U							✓
pre-				✓								
post-				✓								
4 **Base/salt** *Which are bases?*									1 $BaCO_3$	[2+B]	2+B	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								NH_3
pre-												*Equation for that base?* nr
post-	✓			✓								balanced, appropriate:
												unbalanced, appropriate:
	ammonia	sugar	alcohol	nr								balanced, other base:
pre-				✓								inappropriate choice:
post-	✓											
5 **Redox:** *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2+A]	3+A	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2+C]	2+C	*Cu is reducing agent:* T (✓) F ( )
pre-			✓						3 Cell A/A^+//..	[1+D]	1+D	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 CO_3^{2-} + H^+	[3+C]	3+C	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4+C]	4+C	
6 **Mole:** *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+} /OH^-	[3+E]	3+E	*Weight (mass) of*
pre-	c	c	c	c	c	c	c	nr				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	c	c	c	c				[0.2g] answer: 0.2g
7 **Rate:** *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1+D]	1+D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	[2+C]	2+C	*$C_2 = 0.5$?* **[R_2/R_1 = 1/4]**
pre:	50								3 Plots/data	[5+A]	5+A	ans: $R_2 = 2R_1$ ( ), $R_2 = 4R_1$ ( ),
post-:	50								4 H_2/I_2	[4+D]	1+C	$R_2 = R_1/4$ (✓), $R_2 = R_1/2$ ( )
8 **Metals** (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3+A]	3+A	*List 5 gen phys props of metals*
pre-	[T] T	[F] T	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] F	[F] F	[F] F								c c c c c
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] nr	[T] nr	[F] nr								*Name two exceptional metals:*
post--	[F] nr	[T] T	[T] T	[F] nr								(1) nr (2) nr
9 **Halogen:** *Use or application?*									1 ICl + H_2O	[2+A]	1+B	*Hypochlorous acid:*
	Cl	F	I									*formula* [HOCl]: HOCl
pre-	nr	c	c									*ox no of Cl* [+1]: +1
post-	c	c	c									*equation with HOCl* : x
10 **Hydrocarbon:** *Chemical names:*									1 $C_4H_6 + Br_2$	[1+D]	1+D	*4th member of $C_nH_{(2n-2)}$:Name?*
pre: nr nr nr nr nr										also [4+A]		stem [pent-]: pent- -yne: ✓
post: nr x nr nr nr												
one common property:												*structural formula?*
pre: nr												C≡C: ✓; skeleton [5 carbons]:5
post: all flammable												

Table 6.1.21 Concept Learning Test Sequences: Summary of results for student no. 21 - SW

									Two tier tests			
Concept	**Pre-/Post-Instruction Part A**								**item**	**solution**	**choice**	**Post-Instruction Part B**
1 Density *Water vapour: density is 500g/litre?*									1 d(CO_2)	[2 + D]	2 + D	*Vol of 100g of ice?* [109mL]
	T	F*	U						2 box, T↑	[4 + A]	4 + A	Answer: 109mL
pre-	✓											
post-	✓											
2 Mixture/cmp'd *Compound (C) or mixture (M)?*									1 % comp	[2 + D]	1 + A	*Fe + S → FeS Fe = 8g, S = 4g*
	glass [M]	sugar [C]	b/soda [C]									*Residual mixture after heat?*
pre-	C	C	C									**[Fe = 1g, S = 0g; FeS = 11g]**
post-	M	C	C									Answer:
	rubber [M]	curry [M]]	wine [M]									Fe = 1g, S = 0g; FeS = 11g
pre-	C	M	M									
post-	C	M	M									
3 Structure/bonding *NaCl (ionic/molecular)?*									1 B_4C	[3 + C]	3 + C	$T_m(MgO) = 2800^0$, $R(Mg^{2+}) = 65$
	I	M	U						2 HF e^-	[1 + C]	1 + C	$T_m(BaO)$? $R(Ba^{2+})$?
pre-	✓								3 Vaseline	[1 + C]	1 + B	
post-	✓								4 Gp I&VII	[2 + B]	2 + B	T_m (BaO) 100 4000 2000
												✓
Melting Pt of NaCl?												R(Ba^{2+}) 59 135 65
	-80^0	80^0	300^0	**800^0**	U							✓
pre-			✓									
post-				✓								
4 Base/salt *Which are bases?*									1 $BaCO_3$	[2 + B]	2 + B	*Formula of a base in Part A?*
	limestone	vinegar	salt	**carb soda**								Na_2CO_3
pre-				✓								*Equation for that base?*
post-	✓			✓								balanced, appropriate: c
												unbalanced, appropriate:
	ammonia	sugar	alcohol									balanced, other base:
pre-	✓											inappropriate choice:
post-	✓											
5 Redox: *Hydrogen can reduce copper oxide?*									1 Fe + $CuSO_4$	[2 + A].	1 + A	*In C + CuO → CO + Cu,*
	T	F	U	nr					2 Red. Agent	[2 + C]	1 + C	*Cu is reducing agent:* T (✓) F ( )
pre-		✓							3 Cell A/A^+//..	[1 + D]	2 + B	*Cu gains electrons:* T (✓) F ( )
post-	✓								4 CO_3^{2-} + H^+	[3 + C]	3 + C	*Ox N of O: -2→+2:* T ( ) F (✓)
									5 Cell I/MnO_4	[4 + C]	1 + B.	
6 Mole: *Eight calculations:*												
no.	1	2	3	4	5	6	7	8	1 Cu^{2+}/OH^-	[3 + E]	4 + E	*Weight (mass) of*
pre-	c	x	c	c	c	c	c	c				*$1.5x10^{21}$ molecules of SO_3 ?*
post-	c	c	c	c	x	c	c	c				**[0.2g]** answer: 0.199g
7 Rate: *R_2 if $R_1 = 40$, $A_1 = 100$, A_2 inc 25 ?*									1 Mg + H^+	[1 + D]	1 + D	*R_2/R_1 if $R \propto C^2$, $C_1 = 1$,*
[R_2 = 50]									2 P/Q data	[2 + C]	2 + C	*$C_2 = 0.5$?* **[$R_2/R_1 = 1/4$]**
pre:	50								3 Plots/data	[5 + A]	2 + D	ans: $R_2 = 2R_1$ (✓), $R_2 = 4R_1$ ( ),
post-:	1000								4 H_2/I_2	[4 + D]	1 + C	$R_2 = R_1/4$ ( ), $R_2 = R_1/2$ ( )
8 Metals (statements):												
	Cu/metal	brass/metl	brass/elt	pencil/lead					1 Metals/PT	[3 + A]	5 + A	*List 5 gen phys props of metals*
pre-	[T] T	[F] F	[F] F	[F] F								No of props: 1 2 3 4 5
post-]	[T] T	[F] T	[F] F	[F] F								c c c x x
	granite/nm	Si/nm	Ne/nm	Fe ore/metallic								
pre-	[F] T	[T] F	[T] T	[F] F								*Name two exceptional metals:*
post--	[F] F	[T] T	[T] T	[F] T								(1) copper (2) lead
9 Halogen: *Use or application?*									1 ICl + H_2O	[2 + A]	1 + B	*Hypochlorous acid:*
	Cl	F	I									*formula* **[HOCl]**: HCl
pre-	c	x	c									*ox no of Cl* **[+1]**: +1
post-	c	c	c									equation with HOCl: x
10 Hydrocarbon: *Chemical names:*									1 C_4H_6 + Br_2	[1 + D]	1 + D	*4th member of $C_nH_{(2n-2)}$:Name?*
pre:	c	c	c	nr	nr					also [4 + A]		stem **[pent-]**: - **-yne**: not given
post:	c	c	c	c	nr							C_4H_6 quoted
one common property:												*structural formula?*
pre:	hydrocarbons											**C≡C**: ✓ skeleton **[5 carbons]**: 4
post:	hydrocarbons											

Clearly, each table permits a detailed study of the relevant individual's concept-learning. However, in terms of Research Question Number 1 (To what extent did students develop an understanding of the chemical concepts in the course?), it may be more instructive to present or interpret the data in such a way as to indicate the extent of each student's *development* or *improvement* in learning of each of the concept-clusters.

6.2 Estimating individual improvement in concept-learning

6.2.1 The development of a Concept-learning Improvement Scale

The disparate academic backgrounds of the Bridging Course students have been discussed in Chapter 4. Some indication of initial "concept-learning status" has been achieved for the 10 concept-clusters under consideration by means of the corresponding 10 questions (or items) in the Pre-Instruction Questionnaire. One specific indication of improvement in understanding has been made possible through the resetting of those 10 questions in the final examination as the Post-instruction Questions Part A. Since many of the questions possessed several elements, extra detail with respect to learning improvement within each concept-cluster has been obtained through this provision. The Post-Instruction Test Question Part B was intended to assess whether any concept-learning had been extended to the context of that Part B question. There was thus a second possible indicator of improvement in concept-learning, assuming that the respondent was not able to answer that particular question at the commencement of the course. More detail about learning improvement was also available here, the majority of items having several elements.

Unlike the comparison of a Pre-Instruction Question with a Post-instruction Question Part A, the Two-tier Multiple-choice items had no referent for determining improvement in concept-learning. However, as the two-tier format of these items produced such probing tests of understanding, it seemed reasonable to assume that a respondent's selection of the correct combination of Response with Reason was good evidence for substantial growth in concept-learning. In cases where the Concept-learning Test Sequence contained several Two-tier Multiple-choice items, the proportion of successfully answered items was itself an indicator of the extent of concept-learning.

Thus, with some assumptions, it was possible, in principle, to detect improvement in concept-learning in each of the segments of the Concept Learning Test Sequences, and also, in most instances, in more detail. It was thus possible to create a scale of improvement in concept-learning for each of the segments of the Concept Learning Test Sequences. This *Concept Learning Improvement Scale* is presented in Table 6.2.

Table 6.2 A Concept-learning Improvement Scale

	Segments of a CLTS[a]		
Improvement[e]	**Pre-/post-inst'n A[b]**	**2TMC[d]**	**Post-inst'n B[c]**
Scale category: symbol & name	portion of improved elements[f]	proportion[g] of correct items	portion or number of correct elements
N: Nil	nil	nil	nil
S: Slight	a few	nil	a few within a multi-element item
M: Moderate	a large minority	1/2, 1/4, 1/5 or 2/5	a large minority in a multi-element item
I: Intermediate	a majority	1/1, 1/2, 2/4, 2/5 or 3/5	the single-element item or a majority of a multi-element item
L: Large	most	1/1, 2/2, 3/4, 3/5 or 4/5	the single-element item or most of a multi-element item
E: Excellent	all (minor exceptions)	1/1, 2/2, 4/4 or 5/5	the single-element item or all of a multi-element item

Notes:

a CLTS: a Concept Learning Test Sequence
b pre-/post inst'n A: a Pre-Instruction Question with Post-instruction Question Part A
c post-inst'n B: a Post-Instruction Test Question Part B
d 2TMC: a Two-tier Multiple-choice item
e improvement: improvement in concept-learning is considered to have occurred when either

- a correct response to an element in the Post-instruction Question Part A follows an incorrect or nil response to the same element in the Pre-Instruction Question, or
- a correct combination of Response and Reason is given in a 2TMC item, or
- a correct response is given to an element of a Post-Instruction Test Question Part B.

f element: a component of a test item requiring an individual response
g proportion: shown as a fraction. The numerator gives the number of correct 2TMC items, the denominator shows the number of 2TMC items in the CLTS.

6.2.2 A Concept-learning Improvement Scale for Concept-learning Test Sequences

The above scale has some value when applied to the individual segments of a Concept-learning Test Sequence, but more pedagogical value can be extracted from this evaluation when the Scale is applied to a whole Sequence. Using a degree of pedagogical judgement, this can be achieved: Each segment of a given Concept Learning Test Sequence can be awarded a category in the Concept Learning

Improvement Scale, followed by a moderating process in which the evaluator takes into account the degree of difficulty and numbers of each element or item in the Sequence. The result is a rating of the entire Sequence using a category of the Scale.

6.2.3 Awarding a category for Concept-learning Improvement in a Concept-learning Test Sequence

Example 1

The process of awarding a category for Concept-learning Improvement in a Concept-learning Test Sequence can be exemplified by considering results for Respondent Number 4 (Table 6.1.4) in Concept-learning Test Sequence Number 3 (Structure/Bonding). In both the Pre-Instruction Question and the Post-instruction Question Part A, this respondent consistently indicated a correct belief that NaCl has ionic bonding, confirmed by a correct choice of 800^oC as its melting point. This response receives a Nil (N) category of improvement since no improvement in concept-learning was made (nor was possible) for this segment of the Concept-learning Test Sequence.

Of the four items of the Two-tier Multiple-choice segment this respondent was only successful in Item 2 (position of bonding electrons in HF) and Item 4 (statements indicating ionic bonding between Groups I and VII and a knowlege of electronegativity). His Response to Item 1 (B_4C structure) indicates a correct belief in a continuous covalent lattice, but his chosen Reason (A) shows a seriously incorrect belief in the presence of molecules in this structure. Furthermore, in Item 3, the choice of Response 2 indicates an incorrect belief that a continuous covalent structure causes the 'soft' physical property of 'Vaseline'. There are thus two indications of an inability to distinguish molecular from continuous covalent structures within the class of covalently bonded substances. According to Table 6.2, improvement in this segment of the Concept Learning Test Sequence would be rated as Intermediate (I), but there are reservations because of the above inability. A category M (Moderate) is probably justified here.

The two elements of the Post-Instruction Test Question Part B are correctly answered, indicating a grasp of an inverse relationship between interionic distance and melting point. (Such an indication confirms the development of a sound understanding in the area of *ionic* bonding/structure,the beginning of which was indicated in the Pre-Instruction Question and the Post-instruction Question Part A). Clearly, improvement in this segment is in the Excellent (E) category.

The three segments of Concept Learning Test Sequence Number 3 are thus rated as N (with no improvement possible), M (or doubtful I), E. Overall, and on the balance of understandings and uncertainties of the Respondent, pedagogic judgement awarded a Concept-Learning Improvement Category of M for the Sequence.

Example 2

Another example of the categorising of Concept-learning Improvement can be considered with the awarding of a Moderate category to Respondent 3 (Table 6.1.3) in Concept Learning Test Sequence Number 5 (Redox). This Respondent showed no improvement in the Pre-Instruction Question and the Post-instruction Question Part A segment (Reduction of CuO by H_2 ?) with U (uncertain) responses for both questions. This segment undoubtedly receives an N category.

Looking ahead to the Post-Instruction Test Question Part B, the evaluator gains the impression of a significant improvement in understanding of redox concepts, because the Respondent has all three elements correct. This appears to illustrate that he has grasped the general principles of redox which evolved through the notions of oxygen loss/gain, electron gain/loss and Oxidation Number change. Considered alone, this segment would gain an E category for Concept-learning Improvement.

However, in the Two-tier Multiple-choice segment, the Respondent achieved the correct Response/Reason combination in only two of the five items (Numbers 3 and 5), earning a tentative M category, as indicated by Table 6.2. As discussed in Chapter 5, correct choices in Item Number 3 (cell $A/A^+//B/B^+$) are good evidence for a generalised understanding of electron-transfer at electrodes and in electrolyte solutions. Item Number 5 (cell $I^-//MnO_4^-$, inert electrodes) demands a somewhat similar but specific understanding. These two correct items would encourage the evaluator to presume a good grasp of redox in electrochemical cells. However, the incorrect Reason in Item 1 indicates that this presumption is not wholely justified. The choice of Reason C (copper sulfate loses oxygen atoms) implies a failure to appreciate the nature of the electron-transfer from an iron atom to a copper ion, a chemical system specifically studied in the laboratory as a cell and as a displacement reaction in a test tube. Further, incorrect choices of Response and Reason in Item 2 indicates a lack of appreciation of the nature of a reducing agent (copper atoms), while in Item 4, an inability to effectively use Oxidation Numbers led to incorrect choice of Response and Reason. In the face of the correct answers in the Post-Instruction Test Question Part B, the above incorrect answers create doubt for the evaluator. A Moderate (M) category was therefore awarded for Concept-learning Improvement in this Concept Learning Test Sequence.

6.2.2 Quantifying Concept-learning Improvement

The evaluation of improvement can be made semi-quantitative, if desired. Each category of the Concept-learning Improvement Scale can be assigned a somewhat arbitrary numerical value, as indicated below.

Improvement category:	N	S	M	I	L	E
Assigned value:	0	2	4	6	8	10

When this is done for all 10 concept-clusters, the number of awarded improvement categories can be summarised and the assigned values for each category can be totalled to give a final *Individual Concept-learning Improvement Index*, the maximum possible value of which is 100. The results of this quantification process are presented Table 6.3.

Table 6.3: Improvement Categories and Improvement Indices for individual's concept-learning in the Concept-Learning Test Sequences

	Categories of improvement																
	CLTS number										Category totals						Improvement
Student	1	2	3	4	5	6	7	8	9	10	N	S	M	I	L	E	Index
1 MAb	S	N	I	S	N	S	M	M	M	N	3	3	3	1	0	0	24
2 MAr	M	S	I	S	M	M	M	I	S	I	0	3	4	3	0	0	40
3 CB	I	M	I	L	M	S	I	M	N	M	1	1	4	3	1	0	44
4 AC	M	S	I	M	L	I	M	I	S	M	0	2	4	3	1	0	46
5 BE	E	M	L	S	I	L	L	L	M	I	0	1	2	2	4	1	64
6 PF	E	E	L	M	L	I	L	M	M	I	0	0	3	2	3	2	68
7 JG	E	N	M	S	L	M	I	M	S	M	1	2	4	1	1	1	44
8 VG	M	S	M	I	M	E	I	M	N	S	1	2	4	2	0	1	42
9 CG	M	N	M	S	S	S	L	M	S	S	1	5	3	0	1	0	30
10 MG	M	N	L	M	I	I	I	S	S	I	1	2	2	4	1	0	44
11 NH	I	S	I	M	L	I	I	L	I	I	0	1	1	6	2	0	58
12 M-NI	S	S	S	S	I	N	M	S	M	I	1	5	2	2	0	0	30
13 EK	M	S	I	S	L	I	I	I	M	I	0	2	2	5	1	0	50
14 TK	E	E	I	E	I	I	L	I	S	I	0	1	0	5	1	3	70
15 SL	I	S	I	S	L	E	L	S	M	M	0	3	2	2	2	1	52
16 GM	M	S	I	N	I	M	M	S	N	N	3	2	3	2	0	0	28
17 LN	E	N	M	S	M	I	I	M	I	I	1	1	3	4	0	1	48
18 BR	I	L	L	S	E	I	I	M	M	I	0	1	2	4	2	1	60
19 AR	I	N	I	N	S	M	M	M	S	M	2	2	4	2	0	0	32
20 JV	E	I	I	L	L	E	L	I	M	I	0	0	1	4	3	2	72
21 SW	E	M	L	E	M	I	M	M	S	S	0	2	4	1	1	2	56

Mean: 47.6

6.3 Using the Concept-learning Improvement Scale and the Individual Concept-learning Improvement Index

These indicators of improvement in concept-learning are clearly both quite subjective parameters; it must be emphasised that an evaluator must always be prepared to re-examine the raw data of a Concept Learning Test Sequence before making even tentative judgements in such a context.

6.3.1 Testing the Individual Concept-learning Improvement Index

One test of usefulness or effectiveness of the Concept-learning Improvement Index was to compare the degree of improvement indicated by this Index for the students of different initial academic backgrounds, namely, those with previous experience limited to Year 10, Year 11 or Year 12 science or chemistry. It was intuited that those with Year 12 backgrounds would show a smaller Improvement Index than those with only Year 10 science experiences, having been exposed at some length on previous occasions to most, if not all of the chemical concept-clusters of this research. It seemed likely that less improvement in concept-learning was possible for those with Year 12 prior experience. This intuition proved, on the average, to differ from the indications of the Index, as shown by the data presented in Table 6.4.

Table 6.4 Individual Concept-learning Improvement Indices: Values for respondents with differing backgrounds

Prior experience	Improvement Indices of respondents	Mean of Indices
Year 10	46, 44, 50, 48	47.0 (N=4)
Year 11	24, 64, 42, 30, 70, 60, 32	46.0 (N=7)
Year 12	40, 44, 68, 44, 58, 30, 52, 28, 72, 54	49.0 (N=10)

A comparison of the means for the Individual Concept-learning Improvement Indices for Years 10, 11 and 12 showed no statistically significant differences between the Years (F=0.099, p=0.906). However, there were five students (numbers 1, 9, 12, 16 and 19) who, as described in Section 6.3.3, had various medical or social reasons which may have contributed to their low Concept-learning Improvement Indices. Even when these students were eliminated from the analysis, there was still no statistically significant difference between the Years. (Full statistical details are presented in Appendix 6). This suggests that improvement in concept-learning was, in general, independent of the background of the learner. Such a conclusion is surprising, especially from a constructivist viewpoint. However, the values of the individual Concept-learning Improvement Indices did show statistically significant differences with the scores of the Logical Reasoning and Proportional Reasoning puzzles (Section 4.3,

Table 4.1). For all students, analysis of variance gave F = 13.54, p = 0.002 and for the student group excluding those with "outside difficulties", F = 4.95, p = 0.044. (Full statistical data is presented in Appendix 6). In other words, students differed in their Concept-learning Improvement Index values depending upon their ability at the Logical Reasoning and Proportional Reasoning tasks. The results raise questions for research elsewhere:

- what fundamentally constitutes improvement in concept-learning?
- how well does the Concept-learning Improvement Index measure improvement in concept-learning?
- the influence, if any, of the quality of the prior concept-learning of the respondents
- the influence, if any, of a constructivist approach to teaching/learning
- the quality of the learning experiences in this context
- whether a capacity to improve one's concept development is a satisfactory or superior indicator of future success at tertiary studies.

6.3.2 A Group Concept-learning Improvement Index for the Concept Learning Test Sequences

In the columns of Table 6.3, each of the awarded categories of improvement in each of the Concept Learning Test Sequences can be totalled, as presented on Table 6.5. Applying the assigned value for each category to these totals leads to a sum representing a quantification of the extent of improvement in concept-learning for the entire class. The result of this calculation, called *The Group Concept-learning Improvement Index* is also shown on Table 6.5 for each Concept Learning Test Sequence.

Table 6.5 Development of Group Concept-learning Improvement Indices from Individual Improvement Categories

	Total categories awarded										
	CLTS Number										
Improvement Category	1	2	3	4	5	6	7	8	9	10	Overall
Nil (N)	0	6	0	2	1	1	0	0	3	2	15
Slight (S)	2	8	1	10	2	3	0	4	8	3	41
Moderate (M)	7	3	4	4	5	4	7	10	8	5	57
Intermediate (I)	5	1	11	1	5	9	8	5	2	11	58
Large (L)	0	1	5	2	7	1	6	2	0	0	24
Excellent (E)	7	2	0	2	1	3	0	0	0	0	15
Group Concept-learning Improvement Index:	132	62	124	78	120	114	124	94	60	92	

Although not strictly comparable, the values of the Group Concept-learning Improvement Index can be considered in the context of the class averages of *results* for the Concept Learning Test Sequences, which are discussed in Chapter Five. The lowest Group Concept-learning Improvement Index values of 62 and 60 were achieved in Concept Learning Test Sequences 2 (Mixture/compound) and 9 (Halogen) respectively. They coincide, not unexpectedly, with generally low *success* rates in those Sequences, described respectively in Chapter Five as "inadequate" and "poor performance,...not at all successful". Likewise, the relatively low Group Concept-learning Improvement Index of 78 achieved in Concept Learning Test Sequence Number 4 (Base/salt) corresponds to overall average results described in Chapter Five as "disappointing". On the other hand, the comparatively high Group Concept-learning Improvement Index of 120, achieved in Concept Learning Test Sequence Number 5 (Redox), seems to reflect improvement achieved in individual elements of a segment or item, rather than in the overall segment or item. For example, in the Post-Instruction Test Question Part B for this concept-cluster, the percentage success rates for the individual elements were 81%, 71% and 86%, whereas the percentage of the class obtaining correct answers to *all three* elements of the item was only 57%. As is remarked in Chapter 5, "..guessing, clearly, is not to be discounted. The success rate in *all three* questions...seems a more realistic measure of the group's handling of the descriptors" [of redox]. In this case the Group Concept-learning Improvement Index may be a less satisfactory indicator of concept-learning of the class.

6.3.3 Considering the improvement of individuals within the class

Students identified as numbers 1 (MAb), 9 (CG), 12(M-NI), 16 (GM) and 19 (AR) were awarded the low Concept-learning Improvement Indices of 24, 30, 30, 28 and 32 respectively. In general, they were awarded 5 or 6 categories N or S, and few, if any, L or E categories. Separate anecdotal evidence concerning most of these students suggests that each had reasons or excuses for low improvement during the course. Student No. 1 was absent from a considerable fraction of the course for no other offered reason than that of lack of interest. Student No. 12 had great difficulty with both written and spoken English language. Student No. 16 claimed to be a sufferer from Chronic Fatigue Syndrome, and Student No. 19 expressed lack of motivation, as a revertee from Pharmacy I, offered in the first semester. The lack of substantial improvement, as indicated in their Concept-learning Improvement Indices was echoed in their final results (only Student No. 19 achieved a Pass grade, level 2).

Four students had Concept-learning Improvement Indices in excess of 60. They were students numbered 5 (BE, Index=64), 6 (PF, 68), 14 (TK, 70) and 20 (JV, 72). Two of these students (BE, TK) had only Year 11 chemistry as prior experience, TK some 7 or 8 years previously. Of the two students with Year 12 chemistry as prior experience, JV had last studied this subject approximately 16 years earlier. As Table 6.3 indicates, these four students achieved the higher Concept-learning Improvement Indices through achieving seven or more categories E, L or I. Interestingly, the eight E categories obtained by the four were all achieved in the first four weeks of the course; three of the quartet's total of four S categories were gained in the last two weeks. Anecdotally, for at least three of the four students, reasons for their higher Indices appeared to lie in their higher levels of commitment, industry and motivation.

The four students with only Year 10 science prior experience were a group of interest. They were students numbered 4 (AC), 10 (MG), 13 (EK) and 17 (LN). As Table 6.4 shows, their Concept-learning Improvement Indices were very similar and had a mean (47.0) which was very close to the mean of the whole class (47.4) and similar, indeed, to that of the group with two more years of prior experience (48.6). Their indices were gained with few N or S and no E categories. As has been remarked in Section 6.3.1, their achievements raise some interesting research questions. The Research Diary records the persistence of MG as a questionner who seems to have taken the researcher's introductory advice about asking questions. This trait may well explain his ultimate success in gaining Distinction status in the overall assessment of the course. In Chapter Seven, the Case Study of student No. 18 (BR, not in the group of four under discussion here) indicates that Student No. 17 (LN) found that working cooperatively with BR had a very significant influence upon her final academic results (Pass with credit) and her personal attitudes to the difficulties of the course. No insights into the achievements of Students Nos. 4 and 13 (AC and EK respectively) can be offered in the absence of other evidence.

6.4 Answering Research Question Number One

The preceding quantitative but subjective evaluations of improvement in concept-learning have provided some specific and some general answers to Research Question Number 1: *To what extent did students develop an understanding of the chemical concepts in the course?* Assuming that the extent of development of understanding can be measured by an improvement in concept-learning, then some of the answers to this question can be found in Table 6.3, which, for each student

- indicates a quantitative measure of Concept-learning Improvement for each concept-cluster (at the same time giving a generalised measure of the difficulties experienced in understanding each concept-cluster)

- shows the distribution of the 10 awarded Concept-learning Improvement Categories (under the heading 'Category totals'), giving some idea of the consistency and range of improvement in concept-learning
- provides, through the Concept-learning Improvement Indices, an estimation of general improvement in concept-learning for the ten concept-clusters.

In terms of Concept-learning Improvement demonstrated by the class as a whole, Table 6.5

- shows the distribution of the awarded Concept-learning Improvement Categories for each concept-cluster
- presents the overall distribution of Concept-learning Improvement Categories
- provides, for each concept-cluster, a Group Concept-learning Improvement Index, the value of which gives the reader an estimation of the extent of general improvement in learning.

From Table 6.3, the mean value of the Concept-learning Improvement Indices gives some indication, for the whole class, of the general improvement in concept-learning. The value of 47.6 signifies an average value of 4.76 per concept-cluster per student. In terms of the values assigned to the Concept-learning Improvement Scale (Section 6.2.2), this could be roughly interpreted as an average Improvement Category between Moderate and Intermediate.

As already indicated, an unexpected aspect of this study was that the improvement in concept-learning was, on the average, independent of prior experience in science learning. Accordingly, in answer to Research Question One, the extent of development of understanding of the chemical concepts under study was, on the average, apparently independent of the prior experience in science learning.

6.5 Correlations between rankings

In order to investigate further the usefulness of the notion of improvement in learning as a measure of success, the respondents have been ranked according to their Concept-learning Improvement Index and also according to their final assessment mark expressed as a percentage. The results of these rankings are presented in Table 6.6. When these data are used to calculate r_S, the Spearman Rank Correlation Coefficient (Siegel, 1956), the value $r_S = 0.759$ is obtained. This means that the correlation between these two parameters is high and significant beyond the 0.01 level. In turn, this indicates that the final assessment percentage and the Concept-learning Improvement Index are consistent. Accordingly, this chemistry experience. Some research questions are raised by this finding. Section 6.3.2 develops the notion of a Group Concept-learning Improvement Index for the Concept-learning Test Sequences as derived from the individual improvement categories. This Index gives an indication of the improvement in concept-learning of the class as a whole for each Concept-learning Test Sequence. The inferences drawn from the Indices are related to some of the findings of Chapter Five.

Section 6.3.3 continues the Chapter's consideration of improvement in concept-learning by examining the Concept-learning Improvement Indices of a number of individual students and considering possible reasons for achieving the values awarded to those indices.

Section 6.4 provides some answers to Research Question Number One, either for individual students through tabulations of Concept-learning Improvement Categories and Indices (Table 6.3), or for the whole class (as on Table 6.5), through the distributions of Concept-learning Improvement Categories or the values of the Group Concept-learning Improvement Index for each concept-cluster.

Section 6.5 concludes the chapter by showing that the high calculated value of the Spearman Ranking coefficient for the rankings of the respondents by Concept-learning Improvement Index and by final assessment mark establishes a strong correlation between these two parameters. The Concept-learning Improvement Index, as an indicator of successful learning, thus appears to be a satisfactory alternative to the final assessment mark.

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Chapter 7

Case Study: BR, the Competent Mature-age Student

7.1 General Introduction

On the basis of an extended interview and an examination of all the assessments of a particular student volunteer, this Case Study attempts to provide answers to singular versions of the two Research Questions of this thesis.

> **Research Question One:** *To what extent did this student develop an understanding of the chemical concepts of the course?*
>
> **Research Question Two:** *What factors of the course contributed to this student's learning?*

The research methodology which was used to generate answers to these questions is described in Chapter Four. In general, Research Question One is answered by the quantitative data obtained from the student's responses to the various assessment items described in that chapter; the extended interview elicited qualitative data relevant to Research Question Two. The subject of this Case Study, BR, is introduced in Section 7.2.

Section 7.3 examines general aspects of BR's learning. Section 7.3.1 reviews her general approach to study, learning and assessment. Her perceptions about her own learning are canvassed at some length in Section 7.3.2. A particular achievement in BR's learning is revealed in Section 7.3.3.

Section 7.4 considers the raw and derived data obtained from BR's assessments. Conservation and Reasoning skills are discussed in Section 7.4.1. The results of Concept-learning Test Sequences and Concept-learning Improvement categories are examined in some detail in Section 7.4.2, while Section 7.4.3 offers an overview of the quantitative assessments, including consideration of some assessment items outside the Concept-learning Test Sequences.

The chapter concludes in Section 7.5 with summaries of answers provided by this Case Study to the singular versions of the Research Questions.

7.2 An Introduction to BR

BR is an Englishwoman who migrated to Australia some years ago. In 1996, at the age of 42, when her son was studying at a senior secondary level, she decided to apply for entry into the Bridging Program. Her objective was to qualify for admission to a university for baccalaureate study in the fields of mathematical or computing sciences.

In 1995, she had successfully completed studies in mathematics and physics at a local TAFE College. Apparently, she had used the TAFE experience to gauge her capacity for intensive study in mid-life after a considerable period of time devoted to home-making and to raising a family. Her successes at TAFE in 1995 led, in 1996, to her acceptance into the University of South Australia's Bridging Program and to the granting of academic status for the mathematics course of that Program. At this point, BR had last studied chemistry 25 years previously, at about Year 11 level, and had always done well at it.

During the Bridging Course, BR became known as an unpretentious, personable and industrious student. She had a steady temperament and a personal confidence which enabled her to relate affably either with students who were half her age or with the teaching staff. She was not afraid to confess to a lack of understanding, and accordingly, became one of main posers of questions about intellectual or practical difficulties.

> "I put little notes by my stuff, ask Glen, ask Glen, ask Glen." [interview]

Indeed, during tutorials, some students tended to wait for her to ask questions which they themselves were less confident to ask, or had not yet considered. As will be seen later in this chapter, BR's steady and agreeable temperament had a steadying, helpful and encouraging influence upon some students who were less confident, or who had less knowledge than herself. BR was an articulate person, capable of making objective, frank, sensible judgements about her own learning and the contexts for learning and teaching which were available during the course. All these traits made her a very suitable subject for interview and a case study. The interview was conducted on 11/12/96, some 23 days after the final examination.

7.3 Aspects of BR's Learning

BR enjoyed, even delighted in, insightful learning experiences, and she found many of them in the course. In particular, Unit 10 - Hydrocarbons in *Introducing Chemistry*, was her favourite.

> BR:
> ...I liked hydrocarbons, I enjoyed hydrocarbons....it was a nice progression, it was...good....I'm a logical person and there was a logic to hydrocarbons. Nice formulas and they were progressive [systematic].

BR expressed a particular interest in The Halogens for the vigour of their reactions (especially fluorine); she particularly enjoyed the laboratory work on acids, bases and salts (despite finding difficulty in developing an overview of the extensive coverage); she liked drop-titrations (apparently for the surprising use of indicators) and she appreciated analogies for the insights which they could provide. BR confessed to having fun in a tutorial exercise involving the making of a model of a sulfur molecule - she and her learning partner frequently laughed good-naturedly at each other's temporarily unsuccessful attempts. Conversely, she was disappointed when, in the laboratory, she and her learning partner did not get what she called "good results". She usually managed, however, to resolve her disappointment by asking questions either during the laboratory session or in the subsequent tutorial class.

7.3.1 BR's general approach to study, learning and assessment

In dealing with a week's work (usually based on the study of a single unit from *Introducing Chemistry*), BR found that the scheduled weekly sequence of lectures (class-meetings), laboratory work and tutorial suited her systematic style of studying and learning. She revealed this when explaining her perceived need of a text supplementary to what was already available in *Meeting Chemistry* and *Introducing Chemistry*.

> **BR:**
> ...you read something [in a text] and you make your notes and some of it is absorbed and some of it you don't understand and then you go into a lecture and then you get a different aspect and a different learning and then you have your lab which may or may not clarify other points and then you went to the tute which you can then backtrack over the things you haven't understood. That was good that's a good progression. That was a good way, that's quite a good way for me to learn. It was [dependent upon] having sufficient reading matter in the first place.
>
> I didn't have a problem with [much of] it being on the same day, it was at times, "Oh gosh, we've got so much of it in one day", but the sequence works. It was a nice...there was a progression...it was logical.

Within the weekly sequence of contact times, BR found that the content of the lectures (class-meetings) was quite demanding. She felt that she learned much more in the less formal atmosphere of the tutorial sessions.

> **Interviewer:**
> So you felt the lectures a bit heavy....Highly intensive would you say?
> **Response:**
> Yes.
> **Interviewer:**
> And you found that pretty overwhelming.
> **Response:**
> Yes, more so at times than at others so...and I know that other students found it overwhelming, more so than me. I tended to be able to [be] accepting [of the lectures] as they were, more so than other students did.
> **Interviewer:**
> Right....do you think this is because... there was difficulty conceptually, or it was too much at one time, or both, or some other reason?
> **Response:**
> Partly difficult conceptually. Certainly it felt like there was too much. We just couldn't fit everything into your brain at once, sort of thing....on the other hand, the tutes on the Thursday which were more relaxed and followed the lab where you felt like you'd got over that hump, you know, were more relaxed and I got a lot out of the tutes. I really did. There were things where either clarifying something or somebody else's questions or whatever and examples. The examples were good...going through a number of examples of the same thing. That was very good, that clarified things. So the sequence worked all right for me. I just felt that the lectures...
> **Interviewer:**
> ...a bit overpowering
> **Response:**
> Yes.

In the laboratory, she and her learning partner worked very conscientiously, aiming for understanding.

> **BR:**
> Lea [LN] and I worked fairly constantly in the lab. We didn't sit back and watch things happen.... We worked. We didn't want to rush to just get through it all without understanding our results, so we frequently did not get through all the lab work.

While discussing thinking tasks, especially those set in the Pre-laboratory Reports, BR revealed a realistic attitude to life in general which appears to have helped her to deal with challenges which arose in her studies.

> **BR:**
> ...and they [the thinking tasks] did get you thinking and I probably found them easier as I went along. To start with, "Oh, what the heck do I do here?" But you learn the style, I guess, as you go along...and you learn ways of.... life is not all perfect and wonderful, so wherever you go you've got to learn the way of doing things. So that's fine to a degree...
> **Interviewer:**
> So [it's a] technique of dealing with the course, or techniques of learning that you've learnt?
> **Response:**
> Yes. And adapting to the person's teaching style and so on.

During formal assessment, BR's usual state of mind seemed typical of her steady temperament - she claimed not to get flustered when confronted with a problem which she was unable to solve.

> **Interviewer:**
> ...I was having a look at your final test and you didn't have a go at the number part of the mole... There was a little calculation, do you remember? ...calculate the number of molecules in so many grams of...sulphur dioxide...and you just didn't do anything. I just wondered whether you...
> **Response:**
> Yeah....I know I had a problem with that and I can't remember what it was....There was a query on it that I couldn't clarify in my brain and it wasn't worth sitting there, and you know, [it was] one of those things that went by the way on the day.
> **Interviewer:**
> It surprised me because you're obviously a fairly mathematical person and I thought that was a nice easy application.
> **Response:**
> Yeah, there must have been something in the question that threw me, and I couldn't get my mind focussed again but...that was a one off, that didn't worry me too much.

BR confirmed this attitude in the following context of the interview. However, early in the course, she came under pressure when attempting the Two-tier Multiple-choice items. This pressure seemed to diminish as she became more experienced in attempting more of these items. Her comments reveal the extent of the challenge which they posed, and a suggestion for establishing a test sequence with a degree of difficulty which increased as the course progressed.

> **BR:**
> ...they were two-tier multiple-choice and I remember in particular the last exam, the hydrocarbon question...there was a lot of reading....with even the first test, the amount of reading and the amount of time set for the test, there was a little bit of discrepancy. I felt under pressure. And I'm not a person that's easily put off....I don't go blank in exams, I don't die a thousand deaths or whatever. So I don't think I'm a person that is stressed out over much, but I still felt that the amount of reading in relation to the time, I felt...got to hurry, got to hurry....and maybe if you'd allowed more time....to start with, then the pressure off, more benefit.
> **Interviewer:**
> Right, okay...about the two-tier tests....I'm wondering... Did you find them fair? Did you find them...useful for finding out what you didn't know? Did you find them...easy?
> **Response:**
> ...I think I probably got better at...them as I went along. I didn't necessarily get higher results but I certainly felt I got better at them as I went along because you have an understanding of how to go about them. They felt as if they were tricky because there was such an infinitesimal, sometimes ...what seems to be [a] tiny difference between one answer and the next and at times it was like it wasn't quite clear...I did understand why the answers [were correct] but I still felt as if a couple of them...it was touch and go. So the closeness of the answers, that's okay as you get along. Maybe in the earlier ones they need to be more clearly defined about...

Interviewer:
Yes,...choice...more clearly defined...
Response:
Clearly, the wrong ones more clearly wrong, you know...
Interviewer:
....less similar.
Response:
Yes. Yes. Because you've got to differentiate which one is the correct answer and then the correct reason, so it would be nice in the earlier ones...a natural progression that they get more difficult. That's fine, but the earlier ones the reasons to be more...for one to stand out a little bit more maybe against the others...they seemed so close. It was one word was wrong maybe, but that threw it out.

7.3.2 BR's perceptions about her own learning

During the early stages of the interview for this case study, BR felt that her learning proceeded most effectively when it was either mathematical, logical, or embraced analogies, and took place in a social context.

BR:
...The Mole and Rate involved maths and equations, an area which I was strong at and I felt I was able to understand quite easily.
Interviewer:
How did you go on the particle aspect of the mole?
Response:
Took me a while to get it. I remember somebody explaining about an egg. Somebody in the class brought up the idea of an egg and that clarified it for me.
Interviewer:
Oh yes. Yes that was a nice...[analogy].
Response
That was a very good explanation. Up to then I'd had a lot of difficulty understanding that you could have this number of things. That just clarified it in one example...
Interviewer
The idea of an entity?
Response:
Yes...and that an entity can have that many other entities.
Interviewer:
Right, yes.
Response:
That was a good example. Um...yeah, I felt as if I mastered that fairly well. Um...I don't think everybody did.
Interviewer:
Indeed no. It's a very difficult concept. Everybody has difficulty with the mole concept...Teachers find it the most difficult thing to teach properly at this kind of level.
Response:
It just seemed mathematically all right and that was fine by me. You know I... had the equation the m over M equals N over N_A and that was easy.
Interviewer:
Did you find that had significance or was it just a mechanical form, a set of formulae that you could play with?
Response:
No, as I used it, it had significance.
Interviewer:
So you got more significance as you used it.
Response:
Yes. I accepted it because it was logical. It was mathematically sound, which worked well with me and then as I used it then the whole notion became clearer. So in our pre-lab we had exercises which used it and um...as we went through those it became clearer and I was able to help other people who were having trouble with it. Um...we worked together and clarified it together.

During the course of the interview, BR became more aware of the extensive role of visualisation in her learning. She was learning about her own learning processes. This new awareness apparently developed while BR was recounting her responses to three separate learning situations (each also illustrative of constructive learning):

- personal observation of the displacement of copper metal while solving the problem of the extent of the catalytic effect of copper sulfate solution on the displacement of hydrogen from sulfuric acid by magnesium metal
- devising a concept map for the concept-cluster salt in a pre-lab exercise
- studying and learning in the unit Hydrocarbons.

The following extracts from the transcript of the interview reveal the gradual development of this new awareness as well as the nature of BR's learning in each of these situations.

Situation 1 (copper displacement during problem-solving at the bench)

Interviewer:
... in your case it [the problem] was catalysis wasn't it? ..of the action of an acid on a metal?
Response:
Yes.
Interviewer:
I suppose the formation of the salt was really not obvious, or at least not important.
Response:
...no it wasn't the thing that I was looking for the most, although we had the copper forming didn't we?
Interviewer:
Yeah, there was a bit of copper
Response:
And that was very interesting...I liked watching that copper forming.
Interviewer:
Why was that?
Response:
It looked good. I just liked seeing those little strands forming and then dropping down [the test tube]...
Interviewer:
This was the magnesium displacing the copper that had been added as a catalyst to the acid?...
Response:
Yes. So...I was doing the one with the sulphuric acid...so that at least I could see that displacement and that was **wonderful** [voice emphasis]. That was...more interesting almost than the catalyst itself....I could see that displacement that we talked about and that stuck in my mind through the rest of the course...
Interviewer:
Terrific!
Response:
...I could see that,...so some of those reactions where we got very visible, very definite results were helpful.
Interviewer:
Yes. You're talking about acid-base now, or you're generalising about the whole course?
Response:
Basically, I'd say I'm generalising now about the whole course, about work. When we got a very obvious, very definite result it tended to cement what we'd learnt. If we had a result that was inconclusive, sometimes that was all right 'cause I could confirm the results in the tute afterwards and other times it was disappointing...

Situation 2 (concept mapping the concept-cluster *salt* for a Pre-laboratory Report)

Interviewer:
...anything else you wanted to talk about..? The salt concept was easy enough to grasp after all that...hard work?
Response:
Yes I did, and ultimately the pre-lab where we had to draw the diagrams...with salts we had to do our own one ...
Interviewer:
The concept map
Response:
...that concept thing. That did get some of those ideas locked in.
Interviewer:
Good...

Response:
I guess I did...make the effort to do that one well....that one I tried very hard to do well and that possibly locked some of that in.
Interviewer:
So... you're talking about the concept map?
Response:
Yes.
Interviewer:
...Could you tell me a little bit more about what it did for your learning, doing the concept map?
Response:
I tended to...to remember the picture...so you could perhaps think, oh, I remember drawing that line to that. It...didn't always work, but there were connections that I made by...just having that picture of the boxes and the arrows that something linked, that which way it went.
Interviewer:
Yes. And you found that doing two boxes...was the important part or was it drawing the arrow with the description of the relationship that made the difference?
Response:
It was the whole picture of the...box to box, the arrow and the...description. It was an overall picture and that did have a link. I don't know that it would have worked for every subject, I think that worked quite well for acids and bases. It did make you think about the connections....so I do think that was beneficial in that [con]text.

Situation 3 (studying and learning in the unit *Hydrocarbons*)

Interviewer:
...you found that little demonstration we had...of the precipitate...[cuprous acetylide]
Response:
Yes and I remembered that.
Interviewer:
...that helped?
Response:
Yes. And sometimes that's handy...it's very good to be able to visualise something. So if you get a result in the lab that has been very visual, like I did as I said before with the acids and bases where I got that displacement of the copper, I remembered it by visualising. I'd think, oh yes, I remember seeing that copper forming down those and so it's a good example, a good picture to lock away and the same with that one with the...where we got that red...it was a red layer wasn't it? Was that the one?
Interviewer:
In [the unit] Hydrocarbons?
Response:
No that was a different one wasn't it? ...But I do tend to...
Interviewer:
You're a visile, as they say? A person who learns....
Response:
To a degree. Not always but...I don't know that...I wouldn't have...I wouldn't have previously said I was, but yes, I do use...visual reminders. It's like in *Meeting Chemistry* some of those tables, particularly that one with that double bond and triple bond where you had nothing happened and then those three it happened and then nothing happened and it happened with that one. There was the three, there was methane, ethyne, ethene. Um...so that table, yes, I'd use the visuals there to remember that. So that...I guess I do use visuals without knowing I'm doing it. I sort of picture things.
Interviewer:
So you're learning about your learning.
Response:
Yes. And I didn't think I was that kind of learner, but yes, I am, aren't I?
Interviewer:
Well partly, perhaps.
Response:
But I've used that to show people when they're having difficulty because I remembered a couple of years ago, somebody using just like wedges in a pie to show people (how) quarters and halves.... So if somebody's having trouble and I can help them, it will sometimes be in a...
Interviewer:
A visual way
Response:
...visual,..showing them a visual form to use it. Um...I liked hydrocarbons...(laughs).

Later, BR also remembered with pleasure that she had also learned through the sense of touch.

> **Interviewer:**
> ....Did you learn something out of that [reaction in a] plastic bag, by the way?
> **Response:**
> Yes.
> **Interviewer:**
> That was acid-base again, wasn't it?
> **Response:**
> Yes, and we had a cold spot and a hot spot in ours...
> **Interviewer:**
> Yes, lovely!
> **Response:**
> ....so I remember that you can get reactions which take in heat or give off heat and I haven't come across that before. That was a new...
> **Interviewer:**
> So you're a tactile as....
> **Response:**
> Yeah, so that was good.
> **Interviewer:**
> You're a tactile as well as a visile!
> **Response:**
> Yeah, I guess so, yeah. There you go, learning, learning, learning!

BR was to confirm too, that her learning could and would become more effective in a social context - in particular, with a "learning partner". This person, LN, was her allocated laboratory partner, a woman of the same age, with a similar family background and outlook but with only a Year 10 background in science. Each member of this duo contributed to the other's rewarding, successful and constructive learning, both inside and outside of a laboratory context. LN also found moral support and encouragement in the face of academic difficulties. The following extended extract from the interview with BR illustrates these significant aspects of the learning partnership, a partnership which apparently began early in the course with the need to deal with shared intellectual challenges to satisfactorily complete the weekly Pre-laboratory Reports. The initial context of the following discussion is BR's evaluation of the Pre-laboratory Reports. The extract also reveals what BR considered were incompatible characteristics in another possible learning partner - a course-member with whom LN had briefly tried to study.

> **BR:**
> ...in general the pre-labs...did work through the stuff [course content] reasonably well. There were some problems...I felt they probably became more useful as I went along. At first they were a task, a daunting task. Then I partnered up with somebody that we could learn together quite well and we found a time that suited us and we did our pre-labs together....And that's when I started to get more out of pre-labs and get better at them.
> **Interviewer:**
> So you found an interchange with this other person, discussing the various thinking tasks, was an ideal or a very good learning...
> **Response:**
> Yes, because you bou...yes it worked very well for me and I think it worked very well for her as well. You bounce ideas back and forth - what do you think of this? Yes, ...'til you come down to what you think is a reasonable...sometimes you got there very quickly and other times we couldn't seem to get there and suddenly we'd pick up perhaps the [chemical] dictionary, look for the meaning and then go back and suddenly you've got it clarified and it might have taken you awhile to get there but you weren't doing it alone. You were looking at that book and I was looking at that book and then you get your ideas together and that...worked very well for me with this person.
> **Interviewer:**
> That's a lovely example of constructivism at work. I haven't talked too much about constructivism but you might recall the introductory chapter had something about constructivism in it and the way it works.

Response:
Yeah. I don't know that I understood exactly what constructivism is but perhaps used it without giving it a name.
Interviewer:
Mm....that's right. What you're talking about was a nice example whereby the two of you and your various references were able to make links to your existing knowledge and use each other's information, each other's understandings to make those links for your own understanding. So you construct your own learning out of the experiences of other people, your books, your practicals and...
Response:
That's right, and it's pulling those things together to get the result. It's working with the right person too. You can't do that with just anybody.
Interviewer:
Right. So your learning partner, you have to choose with care.
Response:
Yes, you have to choose your learning partner rather than having that person thrust upon you because that won't necessarily work. That person [LN] tried working with another person and found they couldn't. Ultimately they couldn't...
Interviewer:
Have you got any suggestions about how staff can help people to find the right learning partner?
Response:
Well to a degree your backgrounds do make a difference.
Interviewer:
Yes. You mean your academic backgrounds or personal backgrounds?
Response:
No I didn't think...our academic backgrounds were quite different. I had studied recently and I had studied maths and science. She hadn't studied for a long time, she'd only just left the workforce. But I guess we had similar home backgrounds which made our problems...study problems were similar. So you're able to sympathise. Our age, we're both mature students, so we had past history alike.
Interviewer:
Something in common, quite a lot in common.
Response:
Yes....but that only worked with this person. Another person the same age as me I couldn't...who was also in the course, I couldn't have worked with in a million years.
Interviewer
Mm. Without being personal about it, can you suggest why?
Response
She was very negative. It was always everybody else's fault. She wanted other people to help her with her study and why shouldn't they and so on. The campus was...
Interviewer:
So everything was wrong.
Response:
Yes. I couldn't, and so I suspect I wouldn't, work with a negative person. The person I worked with was prepared to give it a go. Even if they weren't succeeding, they kept trying....and she found my positive attitude - and her husband even said this - was helpful to her. I tended to keep looking on the bright side. So she found that helpful and so I perhaps pulled her along when she might have got bogged down...
Interviewer:
...dropped out, yes, or become despondent.
Response:
Yes.
Interviewer:
Well that's lovely...And it worked in the end for her too didn't it?...I was pleased to see her [final] result.
Response:
Yes I was...'cause when I looked up my results, I knew what Lea's number was, so I [checked her result]...you've done it! So that was good.

LN ultimately obtained a final course grade of Pass with Credit.

7.3.3 A particular achievement - holistic insights in the concept-cluster *redox*

For the purposes of this research and from the viewpoint of the teaching staff of the Bridging Course, it was of interest to obtain a sampling of what an able student perceived to be a personal achievement of "quality learning" or "rich understanding" of one of the concept-clusters. BR's choice of Redox, discussed in the excerpt below, indicates that she was able, intellectually, to navigate the historical development of the presented notions, with their apparently conflicting definitions, to reach a satisfying grasp of a concept-cluster commonly regarded, with the mole, as at least as difficult as any in the course.

> **Interviewer:**
> ...finally,...could I ask you is there a concept in the course that you would note as being one which became very much more rich in your understanding of it than any other? Or would you say most of the concepts you were familiar with and you just learned a little bit more about them?
> **Response:**
> I don't know that I was overly familiar with any of the concepts. Not that I remember. It has been a long time since I'd done chemistry. Something like twenty-five years....I know I haven't spoken about redox and redox was quite interesting, it became clearer. That became a lot clearer....but I've still some confusion between that and acid-base reactions, so er...no, I quite liked redox, it was ...quite good
> **Interviewer.**
> Yes. What was good about it? Was it the practical or ...
> **Response:**
> Balancing the equations....seeing that it had happened. Seeing and those with the sulfur [sulfate] you know with the ferrous and the...copper rods and knowing the electrons where they're going and...
> **Interviewer:**
> Yes, the half-cells....The two half-cells in the U-tubes
> **Response:**
> Yeah....that one I feel I got a lot out of....in different ways, different approaches.
> **Interviewer:**
> Mm, oh good. You didn't find the various ways of defining redox confusing?
> **Response:**
> To start with, yes, but in the end, no.
> **Interviewer:**
> Good. Can you see why?
> **Response:**
> ...because redox to me was oxidation and 'ox' means oxygen so...getting oxygen was fine but then we talk about losing electrons and we've got this oxidation and it's a bit of a conflict of terms there.
> **Interviewer:**
> So what did you do when you'd had a non-oxygen reaction like...[a reaction with] chlorine?
> **Response:**
> Well then I just was able to understand the idea of the gain or loss of electrons.
> **Interviewer:**
> So you didn't use oxidation number much?
> **Response:**
> Well you do, because of the gain or loss of electrons. They're negative so you've got some negative gain there or some negative loss there and it's a...it's actually a whole idea. You don't necessarily base it on any one single idea.
> **Interviewer:**
> Well that's interesting
> **Response:**
> You use...whichever's appropriate at the time, whichever one works.
> **Interviewer:**
> So how did you go on that short two-tier multiple-choice [item] that involved carbonate and acid? I think you got it right, if I remember rightly.
> **Response:**
> Carbonate...
> **Interviewer:**
> Carbonate ion and two H-plus gives carbon dioxide and water....And I think the question said, is this redox? Does redox happen? And...
> **Response:**
> Er...and what did it...?
> **Interviewer:**
> You had a set of choices....And reasons.
> **Response:**
> Um...
> **Interviewer:**
> Well that's a little tricky one because of course the carbonate ion becomes carbon dioxide. Now apparently it's a loss of oxygen...
> **Response:**
> Yeah, but the carbon doesn't change its oxidation [number] and the oxygen doesn't change its oxidation number.
> **Interviewer:**
> The oxygen doesn't but the carbon...

Response:
Doesn't...I can't remember. I need to do it on paper to see it.
Interviewer:
Yes, but you have obviously used the oxidation number method for that one. You didn't get trapped into using the oxygen method.
Response:
No, I didn't no. I became very comfortable with using oxidation number and/or loss or gain of electrons.
Interviewer:
Right, so you ...used those two ideas together even though you kept at the back of your mind 'ox' for oxygen?
Response:
No I didn't use that 'ox' for oxygen in the end. I got over that.
Interviewer:
Ah. That's interesting.
Response:
I did get over that but it took me quite some time because it just wasn't logical. The name did not ring true and that's where I had to just...you just bury it, you accept it.
Interviewer:
Bury the idea of oxygen, give it up, is what you're saying.
Response:
Yeah.
Interviewer:
You give it up and take on the new
Response:
And it becomes redox which is a whole word rather than oxidation...so yeah, I changed my way of looking at it.
Interviewer:
Well it's...that's a lovely revelation about learning to me...'cause you dropped the old idea and you took on the new one.
Response:
And Lea came up with a little thing, 'OILRIG', which is 'oil [oxidation] is loss, reduction is gain' and that was to do with electrons rather than oxidation. But then, when we got to the oxidation numbers then that sort of got more clear, so there were a few along the way that I used.
Interviewer:
Mm, that's a difficult...chapter, difficult section, almost as difficult as the mole.
Response:
Yes but redox was okay in the end, that came...that came fine.
Interviewer:
Progressive revelation you might say.
Response:
Yes.
Interviewer:
Lovely.
Response:
Yeah, so we slowly got there.
Interviewer:
Mm, well I'm delighted about that. I'm delighted at your results. I was glad to see you getting a distinction along with four others, that was good to see.
Response:
Yeah, I'm really pleased.

7.4 Assessment: raw and derived data

BR's various results as Respondent Number 18 are to be found in Table 4.1 (Conservation and Reasoning Skills), Table 6.1.18 (CLTS data for the ten concept-clusters), Table 6.3 (Concept-learning Improvement Categories and Index), Table 6.6 (Class Ranking by Final Percent and by Concept-learning Improvement Index) and Appendix 7 (Summary of Class Results). These data will be discussed in the context of BR's comments during the interview.

7.4.1 Conservation and reasoning skills

Table 4.1 reveals that, of the four test items on these skills in the Pre-instruction Questionnaire, BR was unsuccessful in the item on Conservation of Mass. During the interview, she confessed to having some difficulty with Dalton's Atomic Theory (and implicitly, with the principles of conservation of matter and of constant composition), but it appeared that this difficulty was more associated with linking the name of Dalton with the theory than eventually understanding these principles. Examination of Table 6.1.18 for Concept-learning Test Sequence Number 2 (Mixture/Compound) shows that BR was successful in all items except the Two-tier Multiple-choice item (in which she selected the correct Response but the wrong Reason). That she was able to successfully complete the Post-Instruction Test Question Part B in this sequence (heated Fe/S mixture) is good evidence that Mass Conservation has been developed.

7.4.2 Concept-learning Test Sequences and Concept-learning Improvement

For convenience, BR's Concept-learning Improvement Categories and Concept-learning Improvement Index for the ten Concept-Learning Test Sequences are reproduced from Table 6.3.

	Categories of improvement CLTS number										Category totals						Improvement
Student	1	2	3	4	5	6	7	8	9	10	N	S	M	I	L	E	Index
18 BR	I	L	L	S	E	I	I	M	M	I	0	1	2	4	2	1	60

As indicated in Chapter 6, the Index value of 60 gave BR fifth ranking in the class for Concept-learning Improvement. This compared satisfactorily with fourth ranking by final percentage of marks. She was therefore a leading member of the class, both in terms of general improvement in learning and in "absolute" understandings of concept-clusters. The totals of the Concept-learning Improvement Categories, shown above, indicate that BR was fairly consistent in the improvement in her concept-learning. However, her ultimate achievements are more accurately discussed when each of the Concept-learning Improvement Categories is considered in parallel with the detail of each of her responses to the items of the relevant Concept-learning Test Sequence, as recorded in Table 6.1.18. This parallel consideration is necessary because, as described in Section 6.2.3, the Concept-learning Improvement Category (CLIC) discounts pre-existing correct knowledge and its retention. Here follows such a discussion.

In the Concept-learning Test Sequences numbered 1 (Density, CLIC = I) and 5 (Redox, CLIC = E), the overall level of achievement cannot be faulted. In Concept-learning Test Sequence Number 2 (Mixture/Compound, CLIC = L), the Reason selected in the Two-tier

Multiple-choice item was not unreasonable, although not the best support for the correctly chosen Response. Success in the remainder of the Sequence assisted the awarding of the Category "Large".

BR's mathematical skills appeared to have helped in Concept-learning Test Sequence Number 6 (Mole, CLIC = I), but her failure to attempt the arithmetic of Post-Instruction Test Question Part B, as reported in Section 7.2.1, detracted from an excellent level of achievement to that point. With the exception of the third item of the Two-tier Multiple-choice segment, mathematical skills also helped in Concept-learning Test Sequence Number 7 (Rate, CLIC = I). In that item, BR failed to realise, chemically, that the rate coefficient is constant at constant temperature and, mathematically, that the shape of the plot she selected did not match the square relationship between Rate and $[A]_0$ as indicated by the given data.

Although BR had enjoyed some of the practical aspects of Unit 4 *Acids, Bases and Salts*, she had found the size of the unit demanding - almost overwhelming. At the interview, by her own estimation, she had developed an uneven grasp of the component concepts of the Unit: she had become very confident about her understanding of the concept 'salt', confident about 'acid', but less confident about 'base'. The Concept-learning Test Sequence Number 4 revealed that, in the case of 'base', her estimation was justified. In the Post-Instruction Test Question Part A, she had identified ammonia as a base but had failed to identify 'carb soda' as such. Likewise, in the Two-tier Multiple-choice item, she had not realised that $BaCO_3$ was a base which could dissolve or react in stomach acids. She had managed, in the Post-Instruction Test Question Part B, to offer a *nearly* correct formula and an unbalanced equation involving a base. Accordingly, with these inadequacies, the Slight category was awarded for the CLIC in Concept-learning Test Sequence Number 4.

In Concept-learning Test Sequence Number 8 (Metals, CLIC = M), the Two-tier Multiple-choice item required, *inter alia*, an understanding both of the general trend in electronegativity of elements down a Group of the Periodic Table and the general trend in metallic character across a Period. BR's choice of Response implied that she understood the latter only. This, with other inappropriate responses, meant that the CLIC could be awarded at only a Moderate level.

Consideration of Concept-learning Test Sequence Number 9 (Halogen, CLIC = M), reveals that BR was unable to meet the challenge posed in the Two-tier Multiple-choice item. She appeared not to have recalled or understood a recent tutorial exercise wherein the requisite understanding of bond polarity and of relative ion stability in a similar reaction were addressed.

BR's liking for Hydrocarbons (Concept-learning Test Sequence Number 10) may well have been intensified by a mastery of the addition reactions of unsaturated hydrocarbons, as exemplified by her successful completion of the very lengthy and involved Two-tier Multiple-choice item. However, her inadequate knowledge of nomenclature and general properties meant that her Concept-learning Improvement Category in this Sequence could be classified as no more than Intermediate.

During the interview, Concept-learning Test Sequence Number 3 (Structure/bonding, CLIC = L) was not discussed. However, there appeared to be only one weakness in understanding, apparent in the Reason selected for the first Two-tier Multiple-choice item. It expressed the incorrect notion that molecules exist in the continuous covalent structure of B_4C. That the Concept-learning Test Sequence was not sufficiently comprehensive to monitor all aspects of the concept-cluster is illustrated by one of BR's results in Section Two of the final Examination (discussed in Section 7.4.3). In this Section, BR chose an essay topic involving the classification of pure matter on the basis of structure and bonding. Her answer to the question was atypical. It consisted of a very disappointing and incorrect sketch of a "family tree" of bonding-types without reference to structures. She scored 2 marks out of a possible 16. Assuming that BR's "essay" was not subject to "examination nerves" or a "mental block", this result suggests that overall improvement in concept-learning in this topic could certainly not be considered to be "Large", as suggested by the Concept-learning Improvement Category.

7.4.3 Overview of assessment

Apart from the Pre-Instruction Question and the Post-instruction Question Part A, which were part of the Pre-instruction Questionnaire, the other segments of the Concept-learning Test Sequences were themselves parts of four formal assessments designated as Assessments 1, 2, 3 (also known as Short Assessments) and Assessment 4 (also known as the Final Examination), a longer assessment. Each of the Short Assessments contained a Section One, consisting of Two-tier Multiple-choice items, allocated according to Table 4.3. They also contained a Section Two, comprising test items of a more descriptive or conventional nature. Normally the Sections Two had allocations of marks and time about equal to the first Section, and generally, but not always, dealt with parts of the course not covered by the Two-tier Multiple-choice items (that is, material not generally of relevance to this research). The Final Examination contained three Sections. One section contained the ten Pre-Instruction Questions and Post-instruction Questions Parts A and B, another contained Two-tier Multiple-choice items only, and a third section contained three essay-type questions with wide choices of topics. In the overall total for assessment, laboratory-based activities and reports received significant credit. A summary of BR's results for all assessment elements is shown below, together with their weightings, as extracted from Appendix 7.

Summary of BR's Assessment Results

Short assessm't:	1	2	3	Total→	Scaled	Exam	Lab	Total	%	Grade
I.D. \	Max: 24	22	32	78 →	30	90	55	175		
18 BR	13	16	21	50	19.2	61.5	53.1	134	76	D

One essay-type question relevant to BR's understanding of Structure/bonding has already been addressed in Section 7.3.2 above. Several other more conventional questions also provide some triangulation for the evaluation of BR's concept-learning.

Assessment Number 2 contained a whole completion-type question on Acids, Bases and Salts, for which BR scored three marks out of a possible seven. This rather low score helps to corroborate the S category awarded in the Concept-learning Test Sequence. In the same Assessment, another question on calculations involving the mole received 6.5 marks out of a possible seven, confirming BR's claim to be successful in mathematics-based questions, and, at the same time, supporting, if not enhancing, the Concept-learning Improvement category of Intermediate.

Assessment Number 3 contained two short questions, one of which required a comparison of the properties of metals with those of the Halogens. The other question tested a knowledge of simple common reactions of metals and halogens. BR's scores for these questions (each with a maximum of 6) were five and four respectively. Such results are not entirely inconsistent with the Concept-learning Improvement Category of "Moderate" for each of Concept-learning Test Sequences Number 8 (Metals) and 9 (Halogen).

In the Final Examination (Assessment Number 4), BR chose to do another essay-type question on redox reactions. For this she received 14 out of a possible 16 marks, thus firmly supporting the Concept-learning Improvement Category of Excellent for Concept-learning Test Sequence Number 5.

In general, the assessment results for questions attempted outside the Concept-learning Test Sequences have generally supported the evaluation of concept-learning represented by each Concept-learning Improvement Index. However, the sole detected exception to such support serves as a reminder that the Concept-learning Test Sequences must not be assumed to be unfailingly comprehensive, and that other tests can be useful cross-references in evaluating concept-learning by individuals.

7.5 A summary - with answers to the Research Questions

A general answer to Research Question One is available in BR's Concept-learning Improvement Index of 60. This value ranked her fifth in the class for Concept-learning Improvement. It equates to an average assigned numerical value of 6 per Concept-learning Test Sequence, equivalent to an average Concept-learning Improvement Category of "Intermediate". Specific answers to Research Question One have been presented in terms of the Concept-learning Improvement Categories for each of the ten Concept-learning Test Sequences. These Categories are generally supported by the few relevant assessment items outside the Concept-learning Test Sequences, with the exception of Concept-learning Test Sequence Number 3 (Structure/bonding), for which the Category "Large" seems too high.

In regard to Research Question Two, the interview provided answers which seem to be dominated by BR's revealed personal qualities, all of which appeared to exert a beneficial influence upon learning from the opportunities offered by the course. These personal qualities include maturity, motivation, steadiness, industriousness, a sense of humour, a capacity for enjoying learning, a liking for systematic, logical, analogical or mathematical topics, a memory with a propensity for visualisation of previous practical experiences, and, quite significantly, a capacity to learn with and from other people.

Accordingly, some of the aspects of the course which contributed to BR's learning were the opportunity to form a valuable learning partnership; plentiful opportunities to observe chemical phenomena (such as displaced copper) through laboratory and other activities (such as concept mapping); the intrinsic properties of some chemical systems (such as those of the hydrocarbons); a schedule of contact times and types of contact (particularly "relaxed" tutorials) which suited her learning style; challenges (such as the thinking tasks in the Pre-laboratory Reports); and topics which could be best understood with a degree of mathematical knowledge or skill (such as Density, The Mole or Rate). BR sometimes experienced intellectual difficulties with some parts of the course, but in the main, these difficulties were overcome though the application of many of her personal qualities. She therefore could pass the course with Distinction status, a result with which she was justifiably pleased.

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Chapter 8

Student Responses to the Course

8.1 Introduction

This chapter responds particularly to Research Question Two: *What factors of the unit contributed to student learning?*, mainly from the of view-point of the students. None-the-less the student responses sometimes include information which also relates to the *extent* of understanding and thus to Research Question One. The sources of data are the students' responses to the eleven weekly Post-laboratory Reviews (summarised in Appendix 4.4.2.3), the responses of twelve students to the End-of-semester Questionnaire and a few relevant entries from the Research Diary. (Appendix 4.4.2.4 comprises the questionnaire *per se*). To this point, the present research has almost exclusively concerned itself with teaching/learning of the ten chosen concept-clusters, but any of the students' comments about their learning during the course are of interest and value, whether concerned with the ten focus concept-clusters or with others. Sections 8.2 and 8.3 will respectively consider the responses to the Post-laboratory Reviews and to the End-of-semester Questionnaire, with corroborating comments from the Research Diary, as pertinent.

The first week of the course involved many introductory activities which included those which led into a study of Unit 1, *Physical Change and the Kinetic Molecular Theory* in Week 2. The film *The States of Matter* was such an activity. Notes in the Research Diary show that student feedback about its contents was generally very positive. "Overwhelming" was an adjective used in a jargonistic mode by one student, and echoed by a number of others; it seemed to mean that the film was a powerful practical exposition (of the relation between the Kinetic Molecular Theory of Matter and physical properties). However, some of script's analogies for molecular motion, based on a Western (USA) culture, were not understood by some of the students who came from other, different cultures. Accordingly, during and after the class meeting, the researcher spent some considerable time explaining the meaning of the phrases "stately dance" and "free-style ballet" to puzzled questionners. It appeared, however, that visual analogies for the same movements, for example, the movements of honey bees across the surface of their honeycomb and in leaving it, were quite understandable, and were remarked upon by others as excellent for assisting their learning. No Post-laboratory Review was required in Week 1.

8.2 Responses to the Post-laboratory Reviews

The methodology of administering the Post-laboratory Reviews has been discussed in Section 4.4.2.3. This section indicated that each Post-laboratory Review had a prepared framework or a preamble which was intended to guide each respondent's thinking about her/his learning experiences, but, after Unit 3, the guidance was with greater openness, increasing with students' experience of the course. After Unit 3, some respondents tended to ignore the preamble and to write down whatever seemed most relevant to them at the time. Some tended to concentrate solely upon the laboratory activities, whereas an overview of the learning activity in the whole unit was often requested. Nevertheless, the reporting of the responses in the Reviews of each unit of work from *Introducing Chemistry* will be preceded here with an italicised indication of the thrust of the relevant Review Sheet provided in that book.

8.2.1 Unit 1 - Physical Properties and the Kinetic Molecular Theory

The Post-laboratory Review Sheet sought indications of, and reasons for

- *the formation of new links between practical tasks and learnings in Sections A and B of the Unit*
- *new learnings and improvements in learning*
- *help received from the observed chemical events*
- *other thoughts about learning in the unit.*

Responses:

The single-most mentioned activity was the observation of Brownian Movement (a microscope-enlarged view of Indian ink particles in water projected on a television screen). Five students indicated that this had improved their understanding of the Kinetic Molecular Theory by enabling them to visualise the movement of the water molecules surrounding the visible particles.

It should be recorded that the affective domain of behaviour was significant at least in the performance of three of the mature-age students. Two, BR and LN, who were laboratory partners, admitted to being initially nervous about doing laboratory work (having long ago left secondary school), but lost their nervousnessness after jointly and successfully participating in the practical activities. A third student, JV, was able to preserve his equanimity while making mistakes, showing his maturity and insight by explaining that the mistakes were useful because they provided opportunities for learning.

An activity to plot the cooling curve of molten naphthalene provided insights for at least three respondents. For two of them (BR and LN), the insight related to the constancy of the temperature and the concomitant emission of latent heat at the freezing point.

> It seemed that we weren't getting anywhere with the naphthalene, but then it became clear - the waiting was worth it! (BR).

For a third student (CB), an alternative conception was remedied. This conception was that the melting point and freezing point of a pure substance were different temperatures.

The measurements of the density of substances in the three different physical states was helpful to at least one respondent - and was unhelpful to another. The former (NH) reported gaining insights into the reasons why these states had relatively different densities. The latter (MAb), who, in his responses to the Pre-Instruction Questionnaire, had revealed an inability to conserve mass and volume, also unconsciously revealed that a series of measurements (of density) for several unidentified metals had not helped this lack when he reported positively that

> I am now able to tell the difference between different unknown materials by calculating their volume.

The absence of experience in elementary laboratory activity of one student was clearly evident when he remarked

> Everything (nearly) I did today was new, so I learned heaps. (AC).

In the tutorial sessions which followed the laboratory work and the Post-laboratory Review, students reported that the main benefit of their attempts at concept maps on Kinetic Molecular Theory and physical properties was to develop an overview of the relationships between the sub-concepts involved in the task of producing their particular map (Research Diary).

8.2.2 Unit 2 - Chemical Change, Dalton and Atoms

The Review Sheet was similar in form to that in Unit 1.

Most of the commentary related to the laboratory activities. At least seven comments in the Review Sheets referred to the efficacy of "hands on" experimentation in assisting understanding or visualising what was happening in test tubes. Some respondents appeared to have had little past opportunity to do practical work, and relished the new experiences of "seeing for themselves". Several particularly, as the Research Diary confirms, delighted in colour changes, collecting oxygen by displacement of water, the enflaming of wooden splints (with oxygen), and in making small, safe explosions with hydrogen.

Reviewing the whole unit, one respondent (CB) expressed appreciation of the historical developments described therein.

> It [the unit] helped my understandings a lot. Dalton's theory of atomic weights and their ratios. How chemistry started (atomic weights, original symbols for elements) and how it was first thought how compounds were formed.

After one class meeting, a request for help from one student (MG) revealed an inability (conceptually) to conserve mass (as had been signalled in his Pre-Instruction Questionnaire). This inability was affecting his understanding of the concept-cluster *compound/mixture* and of Dalton's Atomic Theory. An immediate half-hour instruction session with the researcher may have convinced MG that mass was conserved during the rusting of iron.

8.2.3 Unit 3 - Bonding, Structure and Properties

The format of the Post-Laboratory Review was similar to that of the first two units.

The main new learning or improvement to learning which was reported was that the general nature of the bonding and structure of a pure substance could be elicited from a knowledge of the melting point and other physical properties of that substance. Five respondents made reference to this. Three respondents learned that NaCl added to water renders the solution conductive; another two respondents discovered that some solid non-electrolytes become electrolytes upon melting. A more experienced student raised a problem of understanding in that a test of the electrical conductivity of a dilute solution of acetic acid produced evidence of chemical change at the electrodes (gas evolution) but failed to produce a glow in the light bulb used as a detector of conductivity. Clearly, his difficulty was more with understanding the physics of electrical heating than with the chemistry of the conductivity of the solution.

8.2.4 Unit 4 - Acids, Bases and Salts

The preamble to the Post-laboratory Review Sheet contained the following questions.

- *"What effect, if any, have the experiences of the laboratory (especially the chemical changes) had upon your learning of concepts or ideas in chemistry?*
- *How did these effects influence your learning (for better or worse)?*

A significant number of respondents were able to give strongly positive answers to the questions. The experience(s)

> "had a major effect...effect was positive as it drummed in the the concepts" (BR). "..reinforce and illustrate...good to get a good grasp..." (TK). "...it make my memory stronger." (MG, a second-language student). "Seems to bring home what you've read." (JV).

Four respondents were able to give a constructivistic flavour to their general description of the effects, summarised by LN, who remarked

> "seeing and doing helped to connect the concepts together."

A fifth student (with Year 12 experience in chemistry) was significantly metacognitive. His insights were clearly descriptive of his learning processes.

> "I find that when we do work in the lab, a lot of forgotten or suppressed chemistry experiences resurface. I then link what I have learned in previous years to what we are currently learning and everything that I already know arranges itself into a comprehensive order. Also, by doing these practicals and talking with my partner, we both understand what is happening in far more depth than before we entered the lab." (SW).

It was reported that some of the most meaningful experiences were those which also had interest generated by colour or colour changes (four references), or new or unexpected effects.

> "The use of indicators...was really interesting, since we found the indicator remains active if alkali is added again." (LN). "Interesting to see how two substances that appear simple & normal [magnesium metal and a mineral acid], react so vigorously when put together." (AR). "Seeing that different salts can be made in different ways". (GM).

Some of this new knowledge could be taken to the following week's work when acids, bases and salts were the context for the laboratory "Challenges".

8.2.5 Unit 11 - What's your problem? The art of problem-solving (Context: Acids, Bases and Salts)

Please discuss the part played by problem-solving at the bench in assisting your learning of concepts or other chemistry. What else might the unit have helped you to learn? How did this happen?

The responses in this Post-laboratory Review were generally very favourable towards several learning outcomes of the unit: learning about the process of problem-solving, becoming self-reliant, working with others, and learning chemistry enjoyably through that process. Three quotations summarise these responses.

> "...helped me to learn to analyse the problem, discuss it with others, make a plan, then follow it. Previously I have rarely done the above." (PF)
>
> "We tested the bright yellow precipitate with litmus and behold - it stayed blue!...It was really good to get the expected result after all our hard work...Our technique was correct... and this again makes me confident." (LN).
>
> "I found this problem-solving exercise one of the most useful so far in the course. There is more responsibility on the student to fully understand what is happening in the experiment and more thinking is required than if the experiment is already devised. I feel I have learned much more from this kind of practical by having had to figure it out for myself beforehand. The rest of the unit was helpful in developing good plans and strategies for problem-solving." (PM, who later withdrew from from the course).

A note in the Research Diary recorded the very positive feedback on the educational merits of Unit 11, received from the Friday tutor, AJD, who had been approached by students for help with the problem-solving Challenges during the preceding week.

8.2.6 Unit 5 - Introducing Redox Reactions

What effect, if any, have the experiences of the laboratory (especially the chemical changes) have upon your learning of concepts or ideas in chemistry? How did these effects influence your learning (for better or worse)?

As might be expected, the lack of a background beyond Year 10 proved to be a substantial disadvantage for such students, in readily understanding most aspects of this difficult concept-cluster.

> "...Did the experiments, but do not truly understand the processes/reactions...Neither my partner or I have a clue what is going on." (AC).
>
> "Some of the chmical reaction was really good specially Cu + $HgCl_2 \rightarrow CuCl_2$ + Hg which mean that the Cu become ionic and the liquid become blue, and black pice [pieces] form which is the Hg metal form. This I found really good, but most of the rest is not quit understant." (MG, a second language student).

An entry in the Research Diary reveals that the added linguistic difficulties for second language students such as MG were emphasised when, after the laboratory session, he asked for, and received, instruction on the difference between the words "oxidised" and "oxidiser".

The poverty of background of other students with only Year 10 background is exemplified by the belief of AC (as recorded in the Research Diary) who thought that sulfur is a metal. AC, along with his laboratory partner, revealed during the practical session that they did not know that the black end of a spent matchstick was essentially the element carbon. On the other hand, a number of students found the demonstration of electron-transfer in electrochemical cells to be quite illuminating.

> "...[the electrochemical cells] were a great illustration of electron-transfer." (TK and five similar comments.
>
> "You can see from the voltmeter that the current is flowing...you believe because you can see it." (JV).

Others would rather have been involved in an opportunity to be interactive with the cells.

> "...I would have preferred to have done the cells myself so we could adjust parts...to work out the effect different solutions had on the cell." (SL and similarly from TK).

A few other comments related to improvements in understanding the metal displacement series (MAb and CB), and the revelation of the magnitude of heat release during the reduction of metallic oxides on the tip of a burnt matchstick. There was a little frustration when some displacement reactions were slow or difficult to observe (LN). A sensible approach to perplexity came from AR.

> "I think I need to go away and read up on oxidation and reduction reactions. The practical was slightly helpful, but I am still pretty confused... I find it helpful getting help and discussing the experiments with my peers."

8.2.7 Unit 6 - Introducing the Mole

...Please review your learning in this unit. Indicate where possible

- *any new insights you developed, and how this happened*
- *what role, if any the practical work itself played in giving you new or improved understanding*
- *what aspects became or remain unclear.*

Despite this preamble, all respondents concentrated on aspects of the laboratory session. Given the nature of the topic, it was surprising that there were no expressions of difficulty, indeed, many were of enjoyment. This may have been because, in a number of cases, the activities emphasised the particle aspect of the mole with several "hands on" analogues. In other cases, the applications of the mole concept-cluster were in simplified situations, which did not require a well-developed practical technique.

> "I liked the experiment which involved the marbles and the nails because it helped my understanding about the atom and weight relative to other weights". (CB).
>
> "I thought today's practical was great. It was pretty straightforward and easy to understand...The titrations were good, as was counting the marbles. Part 5 was excellent in helping me to understand bonds and moles. It was interesting learning that the amount of heat generated depends upon the number of bonds made." (AR)
>
> "...interesting... that temperature [change] could be related to the chemical reactions and that from this the formula of a chemical could be calculated...Also, using the different-sized cardboard atoms helped me to understand how there can be a relationship between atoms even though they are different and not related." (SL).
>
> "Today's practicle [sic] was very thought-provocative, particularly in the calculations...You could get a relatively good result for the conc of the solution by using a drop to drop method and not having to do the titrations with a burette." (SW).

An incident which occurred during the laboratory session was a reminder that student ill-health can be an unsuspected problem. GM appeared unable to solve the simplest of algebraic equations and was confused by the negative sign in the solution to $x + 2 = 0$ He asked for instruction in substituting values into a formula. During subsequent discussion, he claimed to be suffering from Chronic Fatigue Syndrome and that he could not remember many of the events of the last two years. He said that he had difficulty in staying awake at night in order to study. His medical advice was to "battle on". Apparently he received similar advice at enrolment, and seemed to be acting on that advice (Research Diary).

8.2.8 Unit 7 - How fast?

Review your learning processes on this page. In particular, please address the questions, 'In what ways did the experimental work assist (or impede) my learning? Why was this so? Are any difficulties related mainly to mathematical ideas (logarithms, indices, graphs)?'

The principal focus of comment was graphing. It was a source of difficulty for some, and enlightenment for other respondents.

> "The idea of rate of reaction has become clearer. No problems with the maths." (BR).
>
> "The graphs played a large role in..understanding...I don't understand *why* the graph in Part 2 came out to be a straight line when graphed logarithmically." (SW).
>
> "I found some of the graphs used in the pre-lab difficult to understand...Determining the rate of reaction due to different variables was interesting, though at times difficult. Graphing the result helped me to understand the relationships between reactions and the variables." (SL).
>
> "The 'real' practice of recording the reaction rates and graphing them was great." (EK).

8.2.9 Unit 8 - Metals and compounds of Metals

In this review of your learning you may come to reflect upon the differing contributions of Parts A and B to learning the sum total of the topic. Which part was more useful? Why? What was the role of each part? Did Part B assist your understanding of Part A? Did Part B have effects upon your attitudes? ...What role did the actual experimentation have upon your understandings? Feel free to record any other aspects of your learning in this unit. **Note:** More correctly, the *Parts* referred in this preamble and the students' responses are designated *Sections* in other units of *Introducing Chemistry*. Section A contained the pre-laboratory reading and thinking tasks together with the related Pre-laboratory Report Sheets. Section B comprised the laboratory activities proper (and their thinking tasks) together with a separate sheet for the Post-laboratory Review.

As expected, there seemed to general agreement that the most colourful changes (involving transition metal compounds) or most vigorous reactions (Na/H_2O; heated Ca/S) were the most enjoyable, interesting or instructive. There was, however, a divergence of opinion as to the contributions of Parts A and B to effective learning.

> "I found Part B more useful than Part A, and Chapters 13 & 14 [of *Meeting Chemistry*] more useful than Part B. However, I always find the practicals useful in grouping material into smaller related chunks, which helps for recall during tests & exams...Overall the actual experimentation was enjoyable & educational , but not as educational as the pre-lab, or researching for the pre-lab". (EK).
>
> "Part A definitely more useful. This has been the case over the course of the semester. However, the pracs are certainly interesting and helpful and almost always provide a useful insight into the learning for the week. The most useful parts are the Pre-labs which provide a focus for every week's learning. Also provide instant and useful feedback. I wish Maths had something similar". (TK).

Perhaps the most insightful and balanced comment came from JV, who seemed to summarise the intentions of the writer for the whole unit.

> "I think both Parts A & B are very useful, each in different ways, but together they give you a very good understanding of the subject at hand. Part A sort of puts the concepts in your head & then Part B consolidates the concepts from Part A because it gives you hands on experience of those concepts. I think the colours of the transition metal compounds add to the experiment because it's better to work in colour than just clear or white substances. The actual experiments showed me how violent some substances can be in reaction".

8.2 10 Unit 9 - The Halogens

...What have the respective parts of the unit done for your learning? Has a pre-laboratory study of the text really helped your learning of experience in Part B? How or why? Can you summarise the main learning that you have achieved through doing this

unit? What could be done to improve the quality or the quantity of learning? Please comment of your role and the teaching role in such an improvement.

Almost every respondent ignored the questions above concerning the roles of the various components of the unit. Those who did address the questions, made comments similar to, but not as extensive as those presented in Section 8.2.9. A few referred to particular aspects of the reactions which were studied. Notes in the Research Diary showed that, during the laboratory session, a macro-scale demonstration of the extreme solubility of hydrogen chloride, known as the Fountain Experiment, received interested attention, but no comment in the Post-laboratory Reviews. Teaching staff got the impression that students were becoming jaded as the end of the semester approached.

> "I learned that chlorine smells much worse than I thought it would and that ammonia is even worse!" (GM)
>
> "...the experiments were good but a bit tedious, as occasionally they wouldn't work...I particularly found the phosphorus & chlorine experiment unexpected. The little flame [spark] was a surprise as I hadn't thought I would have enough chlorine gas to create the reaction." (SL).
>
> "...the prac was a great illustration of the Halogen's ability to oxidise especially." (TK).
>
> "I felt 3 hours was too long." (LN)

8.2.11 Unit 10 - Organic chemistry

van den Berg and Giddings (1992) have proposed that there are really three kinds of laboratory work:

- ***the concept lab:*** *where the focus is upon concept learning and development through laboratory experience*
- ***the skills lab:*** *where the focus is upon personal, physical and technical skills involved in studying scientific phenomena*
- ***the thinking lab:*** *in which problem-solving and critical thinking skills are developed in a practical context.*

How, if at all, does Part B of this unit fit into this classification? Has the total unit helped your learning in any of the above categories? If so, how; if not, why not? Or are there other ways of classifying lab work, and lab-learning? What has been the value (if any) of doing Parts B and A?

(The laboratory work of this unit was spread over two weeks. In the first week the preparation and properties of hydrocarbons were studied. In the second week the students prepared and purified ethyl acetate).

Respondents seemed generally agreed that Part B of the unit comprised aspects of both the concept lab and the skills lab. The second week's work was seen as having a particular role for skill as it involved the setting up of apparatus for reflux and distillation and performing those processes. A few acknowleged a role for thinking. A number of respondents reported that they had enjoyed participating in the laboratory activities, particularly the second week's work. Presumably this had an influence on their attitude to the topic and to its learning.

> "Second part [week] was great fun. More complex and more interesting than some of the test tube stuff we've been doing. Thanks." (TK)
>
> "...I enjoy organic chemistry more than the rest of it." (SW)
>
> "...I enjoyed the distillation...because it required me to think about the reaction taking place & it was fun to do, & required some degree of manual dexterity to set up! I found this unit better than some other units, both from a learning & enjoyment point of view." (EK).

JV had a holistic view for this unit and all the others, a view which incorporated a new aspect, in that the laboratory can also be seen, in effect, as a 'confidence lab'.

> "...the total unit helped in the concept lab category because it dealt directly with the subjects we had been studying in class. I also think that evey lab session helps in the skills lab category because each session helps you gain confidence in using the equipment necessary. In our relatively short course I have noticed a marked improvement in my own confidence in the lab & I think each lab session has helped in its own way even if it was when an experiment was not as successful as it should have been. Part B [in this lab] was perhaps more to do with the skills category because the set up & procedure of the experiment was a bit more technical than we have been used to .."

The reference to confidence by a student who eventually achieved the top Distinction in this unit, is a useful reminder that the affective domain should receive due consideration when studying concept-learning.

8.2.12 Summary of the Post-laboratory Reviews

Although it was not always intended, the students were inclined to focus their comments on aspects of the practical activities. Amongst a significant group of respondents there was a relishing of the opportunity to do things for themselves, "hands on", and to see the results. Experienced teachers know that chemistry students enjoy or relate to the colourful, the new, the noisy and the smells. It was not surprising therefore to find frequent reference to such things as Brownian Movement (Unit 1), hydrogen explosions (Unit 2), the conductivity of molten electrolytes (Unit 3), colour changes in acid-base indicators (Unit 4), coloured precipitates (Unit 11), evidence of electron-transfer in electrochemical cells (Unit 5), redox on the tip of a burnt match stick (unit 5), marbles and nails as analogies for the mole (Unit 6), startlingly vigorous reactions (Unit 8), strong odours (Unit 9) and new processes of reflux and distillation (Unit 10). If confirmation really was required, the stimulation of the senses was confirmed as an important aspect of the learning process in practical chemistry for these students. Notwithstanding this, the Reviews for Unit 11 showed that the various roles of Parts A and B of the teaching/learning units in *Introducing Chemistry* served the needs of different students in different ways. In other words, laboratory work was not necessarily regarded as a dominant factor in effective learning, rather, most students took it to be complementary. With the apparent failure of some of the micro-chemical reactions studied in Unit 9 - *The Halogens,* some students asked for more demonstrations. No mention was made in the Reviews of Unit 4 (Acids, Bases and Salts) of the lecture-room practical activity *Chemistry in a Zip-lok Bag*, which was a hybrid of a demonstration and a student macro-chemistry experiment. Its effectiveness was remarked upon by BR in Chapter 7. There is room for incorporating more of such participatory practical activities in the lecture theatre or tutorial room.

A useful aspect of some of the Reviews (in Unit 4, for example), was that some students were able to reveal an ability to be perceptively metacognitive and in so doing, could indicate the constructivistic nature of their learning. This appears to be an advantage of having a course with post-matriculation students in age, if not in academic level. Another revelation of quality learning was made in Unit 11 wherein a significant number of students were very positive about the problem-solving format for learning in the context of Acids, Bases and Salts. This, and the enthusiasm of the tutor (AJD), is robust encouragement for a similar approach in other units. Interestingly, little or no references were made to the thinking tasks (themselves often "mini-problems" incorporated into the laboratory procedures). It may well be that the demands of the practical tasks, together with a de-emphasis upon completion of each Section B *in toto*, diminished the significance of these aspects of the laboratory activities. Future editions of *Introducing Chemistry* could consider reversing this trend.

Early references to nervousness and to the gaining of confidence (through working with a partner), underline a perhaps neglected aspect of learning, namely that the affective domain of human behaviour. The forming and function of fruitful learning partnerships, linked to this domain and referred to here and in Chapter 7, appear to be important subjects for investigation.

8.3 The End-of-semester Questionnaire

The administration of this probe is discussed in Section 4.4.2.4. A copy of the Questionnaire is presented in Appendix 4.4.2.4. Unfortunately, the most suitable available time for responses was immediately after completion of the final examination. Because students were granted a half-hour extension to complete this nominally two-hour examination, they were probably tired and ready to leave rather than to spend more time in completing this rather extensive document. In such circumstances, and as completion was both voluntary and anonymous, it is not surprising that nearly half of the class submitted a blank Questionnaire. The twelve who provided responses were at times very brief in their comments. Sometimes they avoided questions or entire sections. Accordingly, this probe is less than adequate as a representation of the final opinion of the whole class on a broad range of aspects of the course. Fortunately, the Post-laboratory Reviews have already provided feedback on the learning occurring in the eleven units of *Introducing Chemistry*. Student evaluation of the course through the End-of-semester Questionnaire is presented in Appendix 8 as summaries of responses (where possible) to the respective items of the Questionnaire. The following discussion of those summaries uses the the format of the five main sections of that document, namely

- Section A - Context: the units in *Introducing Chemistry*
- Section B - Particular aspects of the course
- Section C - Learning and Teaching
- Section D - Assessment
- Section E - General

8.3.1 An overview of responses to the End-of-semester Questionnaire

That only 12 of the 21 students offered responses to this questionnaire and as far fewer answered individual items, the usefulness of this probe as evidence is reduced. In Section A, there were only a few comments or insights which were not already made or referred to in Section 8.2. Reconsidering the treatment of graphs and their interpretation in Unit 7-*How Fast?* is a useful suggestion (perhaps to be raised with the coordinator of the Bridging Mathematics course). Likewise a re-examination of some of the micro-scale reactions in Unit 9-*The Halogens* could be made to ensure that effectiveness is achieved. The problem of time allocations for practical work could be reviewed to ensure that the essential reactions are observed by all students while permitting enriching additional studies to be performed by more experienced class-members.

In Section B of the Questionnaire, the role of the Pre-laboratory Reports in focussing the students' studies is clearly appreciated. In contrast, the Post-laboratory Reviews were not seen by the respondents as particularly useful. It may be desirable for the course convener to place greater emphasis on the value to students of more intensive metacognition (and allowing more time for it) and indeed, of a greater appreciation of a constructivist attitude to learning. The general approval of the the books, especially *Introducing Chemistry*, suggests that they are performing their intended complementary roles.

The diversity of responses to Item 1 of Section C seems to reflect the diverse characteristics and needs of the individuals in respect of their learning. Item 2 contains possible hints for improvement in the teaching environment. Furthermore, the range of abilities, backgrounds and rates of learning which stimulated other comments about repetition of some aspects of the course will remain a challenge to the teacher - who may well be able to devise new ways of dealing with this continuing problem. In Item 3 of this Section, comments on the teaching in various modes of presentation were, on the whole, satisfactory, with some suggestions about personal characteristics of the presenter(s) which could bear reflection.

Commentary on Assessment, Section D, were surprisingly lacking in criticism. As expected the Two-tier Multiple-choice items were found difficult by some, and it was they, presumably, who asked for more time. The presence of a chance to display knowledge, as in the essay-type questions in the Final Examination (not the subject of study in this thesis), seemed to help to create a positive attitude to the whole of the Examination.

General comments in Section E seemed to reflect a broad-based satisfaction with the course as a whole. A mean mark of 7.0, calculated from the students' gradings on the assessment continuum provided in Item 4, was a quantitative indication of this satisfaction. The individual gradings are tabulated below.

Student gradings of the unit
End-of-semester Questionnaire, Section E, Item 4
(N=11)

(In the interests of clarity, the continuum line has been omitted for each respondent and the awarded X placed in a corresponding space between, or in place of, the numerals of the scale. Script C did not have a grading).

	of no use	very poor	poor	fair		very fair	OK	good		very good		excellent
A	0	1	2	3	4	5	6	7		X	9	10
B	0	1	2	3	4	5	6	X		8	9	10
D	0	1	2	3	4	5	6	7	· X	8	9	10
E	0	1	2	3	4	5	6	7 X		8	9	10
F	0	1	2	3	4	5	6	X		8	9	10
G	0	1	2	3	4	5	6	7 X		8	9	10
H	0	1	2	3	4	5	X	7		8	9	10
I	0	1	2	3	X	5	6	7		8	9	10
J	0	1	2	3	4	5	6	7	X	8	9	10
K	0	1	2	3	4	5	6	7		X8	9	10
L	0	1	2	3	4	5	6	7	X	8	9	10

It is interesting to note that the writer of Questionnaire script "I", who awarded the mark of 4 on this scale, and made the comment of disappointment mentioned in Item 1 of Section E, was subsequently revealed to the author as BR, the subject of the Case Study in Chapter 7. It appears that BR scored the course low because, at the time (immediately after completing the final exam), she felt that she had done badly in the examination and accordingly was somewhat upset with her apparent lack of success. This disappointment must have evaporated when she discovered her final result. As is recorded in Chapter 7, BR received a course grade of Pass with Distinction, about which she was quite delighted. (It should be noted that, by volunteering to interviewed, there is a possibility that BR may have been seeking to make amends for grading the course so low, by saying mainly positive things about it at the interview). In any event, her self-assessment of her ability in chemistry has, no doubt, been restored.

* * *

Chapter 9

Summary, Overview, Recommendations and Reflections

Preamble

This thesis has its origins in the Research Problem which incorporated the question, *How can a bridging course in chemistry be designed, presented and evaluated in order to meet student and university needs?* The preceding eight chapters of this thesis have described aspects of approaches to this problem, as generated by two more specific questions

- Research Question Number One: *To what extent did students develop an understanding of the chemical concepts in the unit?*
- Research Question Number Two: *What aspects of the unit contributed to student learning?*

In this chapter, Section 9.1 reviews and summarises the data generated as answers to these two Research Questions. Answers to Research Question Number One relate to the ten Concept-learning Test Sequences developed to evaluate concept-learning in the ten concept-clusters selected for study. Answers to Research Question 2 include reviews of the students' evaluation of the course as well as the researcher's evaluation from the perspective of the course-as-designed. Section 9.2 presents recommendations for improving current responses to the Research Problem in terms of course structure, teaching and learning, assessment, and further research. Section 9.3 considers limitations of the study. The chapter concludes with Section 9.4, which reflects upon other aspects of the course.

9.1 Responses to the Research Questions

9.1.1 Research Question No1: *To what extent did students develop an understanding of chemical concepts presented in the course?*

For all ten Concept-learning Test Sequences, this question has been answered in two ways - either by considering the *understandings* of the class as a whole (N = 21), or by considering the individual *improvements* in the concept-learning of each member of the class.

The extent of understandings of concept-clusters as a class of learners is indicated in Chapter 5 by data and discussion for each item of each Concept-learning Test Sequence. Table 5.11 summarises results for the Pre- and Post-instruction items as percentage success rates for the class. Parts A of the Post-instruction Questions indicated generally improved levels of understanding following instruction, albeit in not very challenging contexts. By contrast, Parts B of the Post-Instruction Test Question indicated some poor levels of achievement. For example, in Concept-learning Test Sequence No 2 (Mixture/compound) the Fe/S/FeS item was successfully completed by only 24% of the class. Furthermore, in this Concept-learning Test Sequence, a fairly strongly held alternative conception was detected in about one third of the class, namely, that chemical elements combine in any proportion. In Concept-learning Test Sequence No 5 (Redox) a class success rate of only 57% was achieved in the Part B item, even though the success rates in the three individual components of the item were in the range 71-86%. The hydrocarbon concept-cluster (No 10) had noteworthy success rates (95%) in some specific fundamental aspects of the Part B item.

Table 5.12 summarises the results of the class for all the Two-tier Multiple-choice tests administered within the ten Concept-learning Test Sequences. In a context of various intensities of testing, the class achieved success rates ranging from 9% (for the very challenging Plots/data item in CLTS No 7, Rate) to 81% (for the Mg/H^+ item in the same CLTS). In Concept-learning Test Sequence No 5 (Redox) the range of success rates for the four items was from 33% to 75%. This range far exceeded that of the (pilot) class of 1995 (N=31) who achieved only 12 to 54%. In Concept-cluster No 3 (Structure/bonding), the class were rather less successful than the 1995 pilot group but approached the Year 12 results of the test groups of Peterson, Treagust and Garnett (1989) in the items available for comparison.

The extent of each individual's understanding of the ten concept-clusters is indicated in Chapter 6 in Tables 6.1.1 to 6.1.21. The extent of *improvement* in concept-learning by these individuals is displayed on Table 6.3 as Concept-learning Improvement Categories for each Concept-learning Test Sequence. This table also displays the Concept-learning Improvement Indices, derived for each student from a summation of numerical values assigned to each of their Concept-learning Improvement Categories. These indices give an overall or average indication of improvement in learning for the ten concept-clusters. The Concept-learning Improvement Indices range from 24 for the least successful student, to 72 for the student ranked first on the list. The mean for the class was 47.6. Such a value is equivalent to an average category (per concept) about half-way between Moderate and Intermediate. Given the range of academic and cultural backgrounds in the class, this modest achievement is acceptable. Table 6.4 provides evidence that three groups of students from within the class, each group with a different academic background, had similar mean Concept-learning Improvement Indices, namely 47.0, 46.0 and 49.0, each quite close to the above mean for the whole class. This result has the unexpected implication that concept-learning improvement in this course seems independent of initial academic background. In turn, this raises interesting new questions for subsequent research. To this extent at least, the development of Concept-learning Improvement Catrgories and Indices is a useful innovation.

In Table 6.5, the individual Concept-learning Improvement Categories are collated and summed to provide Group Concept-learning Improvement Indices for each concept-cluster, thus providing a quantitative indication of the improvement in the understanding by the class of each of the ten concept-clusters. The resulting Indices demonstrate a wide range of values, from 62 (for Concept-cluster No. 2, Mixture/compound) to 132 (for Concept-cluster No. 1, Density). These Indices thus provide an indication of the degree of difficulty of each concept-cluster, which is an interesting alternative to the corresponding class success rates. As might be expected, low values of Group Concept-learning Improvement Indices correspond fairly closely to low success rates. However, there is a lesser degree of correspondence at higher Index values and rates of success. Nevertheless, this points to a need for further investigation as to which is the more useful or reliable indicator of quality learning.

9.1.2 Research Question No 2: *What aspects of the course contributed to student understanding?*

Many positive aspects of the course have been discussed, as respondents' perceptions, in Chapter 8 (Student responses to the course) and in Chapter 7 (Case Study). These perceptions are summarised in Section 9.1.2.1, followed in Section 9.1.2.2 by the perceptions and general professional judgement of the researcher in relation to the attainment of the objectives which were set for the writing and using of *Introducing Chemistry*. Section 9.1.2.3 deals with factors which tended to work against understanding.

9.1.2.1 The main factors contributing to student learning, as reported by students

Chapter 8 reported the students' responses which were made through the Post-laboratory Reviews and the End-of-semester Questionnaire. A study of the former revealed that

- the available 'hands on' practical work was a major positive factor in three areas: in learning, in confirming understanding and in interest-generation.
- problem-solving at the bench, in the form presented, received strong endorsement - this activity clearly involved student-centred learning.
- Section A (development of theory, Prelaboratory Report) and Section B (practical activities, Post-laboratory Reviews) of *Introducing Chemistry* were

generally seen as complementary, necessary and useful parts of the book for the presentation of the course and the consequent learning.

- A few references by respondents to their attitudes or personal feelings suggest the important notion that, for the particular kinds of student found in this bridging course, the laboratory activities could be not only be viewed as 'concept/skills' labs, but also as 'confidence labs'. Such a notion is apparently new, and is well worth consideration in the future development and design of such activities.

Responses to the End-of-semester Questionnaires revealed that

- the Pre-laboratory Reports were clearly and generally appreciated as a focus and stimulus for the commencement of study of any of the units of work.
- there was general endorsement of the books *Introducing Chemistry* and *Meeting Chemistry* (especially *Introducing Chemistry*) as fulfilling their intended roles.
- in tutorials, a number of repondents found that the less formal approaches to teaching and learning were conducive to clarifying aspects of concept-clusters which were not clearly understood.

Chapter 7 (Case Study) recorded the observations and opinions of BR, the eponymous competent mature-age student. She indicated that

- enjoyment of insightful and noteworthy practical learning experiences in both laboratory and tutorials was, for her, an important part of the course.
- like a number of other students, the relaxed teaching and learning atmosphere in tutorials was very conducive to quality learning: her questions could be extensively pursued in order to clarify difficulties. Exercises consolidated her learning in these tutorials.
- visualisation was a very significant characteristic of her learning. Indeed, she also discovered that she was learning about her own learning, even during the interview.
- forming a learning partnership with another class-member was very significant for the learning improvement of both parties and for encouragement and "moral support" of the other person.

It was clear to the researcher that BR's personal qualities (including steadiness, industriousness, motivation, sense of humour, organisation) were very significant in contributing towards her successful learning.

- **Integration of theoretical studies with laboratory experiences**

The End-of-semester Questionnaire contained several commendatory remarks about this aspect of *Introducing Chemistry*. The writer was generally satisfied that the integration had been successfully achieved in the writing of the book. The Sections A, including the pre-labs, initially focussed upon the development of theoretical concepts, then drew attention to the illustrative and developmental practical work described in the Sections B. (In this, the pre-labs differed from those of Johnstone, Sleet and Vianna (1994) and of Mitchell and de Jong (1994) who apparently used them to focus solely upon the tasks and challenges of forthcoming laboratory activities). The thinking tasks incorporated into the Sections B directed practical attention to the concepts of the relevant Section A. The preambles to the Post-laboratory Reviews generally attempted, with limited success, to draw attention to aspects of both theory and practical work (especially the latter) which had influenced the learning of concepts.

- **Compulsory, effortful Pre-laboratory Reports**

As mentioned above, the writing of Pre-laboratory Reports, which was strongly endorsed, threw responsibility for learning upon each student. These Reports thus positively encouraged constructivist learning. The awarding of assessment marks for these Reports undoubtedly encouraged students in this direction. The Reports also usefully enabled the coordinator regularly to monitor student effort and progress in each of the units.

- **The development of chemical concepts, *ab initio,* through an historical approach in much of the pre-laboratory reading**

This was the integrated historical approach (Matthews, 1994). Some respondents appreciated this aspect of the course to the extent of wanting more chemical history included. By contrast, one student couldn't see the point. The point was (Broe, 1959) that, with some exceptions, the development of chemical ideas in the minds of contemporary learners is more likely to be successfully and efficiently achieved when presented in the same sequence as in the evolution of those same chemical ideas by *Homo sapiens*. The generally positive responses to this approach, together with the virtual absence of contrary views, categorise this strategy as successful.

- **Thinking tasks, set in both the pre-laboratory reports and the laboratory activities**

As already indicated, the pre-labs were applauded by students as an important feature of the course. The thinking tasks therein were accordingly endorsed as focussing their thinking and extending or intensifying their learning. However, in the laboratory techniques permitted the study of some systems which otherwise would have been too dangerous, expensive or inconvenient for students to perform. The smallness of the samples of reagents and of the apparatus tended to offer a focus of attention and a control of reagent concentration. These favoured enhanced learning experiences.

- **A high "signal-to-noise" ratio in design, layout and word usage.**

The principles of the reduction of "noise" in laboratory manuals, as proposed by Johnstone and Letton (1991) had been adopted for the design, layout and usage of *Introducing Chemistry*. With the exception of the small size of the divisions on the graph grids provided in some units of *Introducing Chemistry,* the layout and presentation of the books received no criticism, either from the respondents or the researcher, a satisfactory outcome.

9.1.3 What factors worked *against* understanding?

Clearly, the common hurdles to understanding, such as personal and cultural background, the lack of natural ability and the abstract nature of many of the chemical concepts, are not usually within the ambit of the course presenter to change. But were there detrimental aspects of the course which could be removed or altered by the presenter in order to allow quality learning to be achieved more readily? Answers to this question can lead to debate about educational objectives for tertiary bridging courses. Such answers include the following two aspects of the course.

- **Time and coverage constraints**

  There was early anecdotal evidence from a few students that the course was proceeding too quickly, covering too much "content". Within tertiary institutions there can be found a "quality *versus* quantity" debate with respect to the content of courses and the teaching thereof. A number of teachers, (secondary as well as tertiary) continue to regard themselves essentially as "transmitters of the discipline" (Tobin and McRobbie, 1997). In terms of a bridging course, this debate could be focussed around the question, "Is it preferable for the university to admit to undergraduate study only the Distinction level Candidate X with a narrow range of chemistry content very well understood, or to enrol Pass level Candidate Y with a wide range of chemistry content less well understood?" Such a debate appears unresolveable, although the intensity of debate might be diminished to an extent by the allocation of extra time to a course of fixed content. Perhaps a better solution to the issue lies in the answer to the question, "How well have the Candidates X and Y *learned to learn*?" It seems that bridging courses, and this one in particular, should give greater priority to the teaching/learning and assessing of *quality learning skills.*

Quality learning of concepts should then more readily follow from quality teaching within the available time: coverage of course content diminishes in importance.

- **Development of an integrated approach to constructivist teaching/learning by the coordinators of each of the program's component courses.**
  The success of this approach depends on the attitudes and criteria of the relevant Faculties and Schools for whom the bridging course is a source of students (Fensham, 1997). The advantages of such an approach to the current bridging course, not available in 1996, could be a unified emphasis upon quality learning as well as conceptual support between disciplines (for example in graphing, indices, density, Kinetic Molecular Theory).

9.2 Recommendations arising from this project

These recommendations relate to improving current responses to the Research Problem and to aspects of the course defined by the Research Questions.

9.2.1 Recommendations for course structure

Since neither the students' responses nor the researcher's judgement suggest that major changes are necessary, the recommendation is for retention of the *status quo*. This means the retention of six hours of contact per week (a noticeable improvement upon the five hours per week available in 1995); the same relative allocation of time to lectures (class-meetings), tutorial and laboratory; retention of the study of the eleven units of *Introducing Chemistry* and its format incorporating Pre-laboratory Reports and Post-laboratory Reviews.

9.2.2 Recommendations for teaching and learning

Because the various evaluations of learning and teaching in the course have provided no indications of major faults, the following recommendations (not necessarily listed in order of importance) seek refinements rather than radical change to the current approaches to teaching and learning.

- Consider means by which students can be assisted to form mutually acceptable learning partnerships. Perhaps there could be a supplementary, voluntary tutorial. Notes on such possible partnerships could be provided in the manner of Sleet et al (1996). The notes might cover topics such as expectations, advantages, disadvantages, mutual give-and-take, problems with academic dishonesty. Input on group dynamics, as adopted by Wood with Sleet (1993), could be valuable.
- Consider earlier and greater emphasis upon approaches to metacognition (as in Baird and Northfield, 1992) and constructivist learning, as, for example, in Fensham,

Gunstone and White (1994) and Grant, Johnson and Sanders (1990), while keeping in mind the 1995 student comment about "over-emphasising" this aspect;

- reconsider the format of the Post-laboratory Review Sheets, emphasising metacognition but also, perhaps, including a relevant short problem which requires synthesis of the chemical ideas developed in the unit.
- consider giving more time and general oral guidance for the completion of the metacognitive aspects of the Post-laboratory Reviews.
- Consider a revision of *Meeting Chemistry* in order more nearly to complement the thrust of *Introducing Chemistry*. Include answers to exercises in *Meeting Chemistry*.
- Retain the employment of two marker/demonstrators each for the current 2.5 hours of laboratory contact per week.
- Consider the treatment of one of the existing laboratory sessions as wholly problem-solving-at-the-bench (as with Acids, Bases and Salts). Alternatively, or additionally, consider incorporating a short problem-solving-at-the-bench section into each laboratory session with a corresponding reduction of other practical material.
- Incorporate teaching approaches to obviate the alternative conceptions which have been revealed during the course (for example, elements combining in any proportions).
- Examine concepts with low Group CLIIs (for example, No. 2, Mixture/compound; No. 4, Base/salt; No. 9, Halogen) to ascertain ways of anticipating difficulties or improving teaching approaches.
- Analyse each assessment item which proved especially challenging to the class, with a view to diagnosing lack of clarity or precision in the item *per se,* or assessing conceptual difficulties. Adapt teaching approaches accordingly.

9.2.3 Recommendations for Assessment

The Concept-learning Test Sequences were uneven in diagnostic "power" and comparability, for at least two reasons. One reason was that the number of Two-tier Multiple-choice segments varied from one to five items. The set of ten Sequences would appear to be more effective and give a more balanced perspective of concept-learning and improvement in learning if there was a more even balance of these kinds of items across the Sequences. This balance is not easily achievable, because the Two-tier Multiple-choice assessment items are more easily set for some concepts, noticeably the more abstract ones, such as structure/bonding. Furthermore, initially, the students have no experience of this kind of assessment and take some time to develop confidence in answering them. A second reason for unevenness in diagnostic power of the Concept-learning Test Sequences is that the Post-instruction Questions Part B varied in difficulty, sometimes surprisingly so. Accordingly, adoption of the following recommendations would help to obviate these difficulties.

- consider developing a set of "practice" or "trial" Two-tier Multiple-choice items for use early in the semester (before administration of the first assessment test).
- increase the number of Two-tier Multiple-choice items in Concept-learning Test Sequences containing only one such item.
- examine the degree of difficulty of the Two-tier Multiple-choice items relative to each other. Where possible, adjust to a consistent degree or gradation of difficulty.
- re-examine the pre- and post-instruction items in each Concept-learning Test Sequence for consistent degrees of difficulty.

An additional recommendation is that initial teaching approaches could be assisted if the Pre-Instruction Questionnaire was re-examined with a view to developing a more probing or analytical assessment of the respondents' initial skills in conservation of mass, conservation of volume and in logical and proportional reasoning.

9.2.4 Recommendations for Research

In Chapter 6, the development and application of Concept-learning Improvement Categories and Indices raised the issue of the best form of assessment of concept-learning. Given the nature of the current bridging course, with its intake of students of very varied background and levels of academic achievement (Table 4.1), the attainment of certain *levels* of achievement in chemistry does not necessarily give the university a sensitive indicator of a student's ability to deal with the demands of undergraduate studies. The proposal in Chapter 6 that concept-learning *improvement* appeared to be as good if not better indicator of ability to do well at tertiary studies, led to suggestions for further research in concept-learning improvement. Suggested topics included the following questions: *What fundamentally constitutes improvement in concept-learning? How well do Concept-learning Improvement Categories and Indices measure improvement in concept-learning? Is a capacity to improve one's concept-learning a satisfactory indicator of likely future success at tertiary studies? What influence, if any, does the quality of the prior experience of the respondents have upon their improvement in concept-learning in the bridging course? What influence upon improvement in concept-learning, if any, does a constructivist approach to teaching/learning have?*

Clearly many of these questions raise issues concerning current approaches to bridging courses as effective measures of potential future tertiary success. Research in such questions could therefore prove useful.

A number of other research topics have arisen from the various results and findings of the present research. Answers to the questions inherent in the topics would be particularly useful to those presenting bridging courses as well as to those generally concerned with the enhancement of quality learning. The research topics include

- factors which lead to the formation of a workable and effective learning partnership.
- the nature and extent of concept-learning outcomes attributable to participation in a workable learning partnership.
- the extent to which concept-learning is enhanced by practical problem-solving at the bench.
- effective strategies for the use of the laboratory as a 'confidence lab' and the subsequent influence upon concept learning.
- the extent to which taught visualisation techniques can assist the construction of concept maps and the enhancement of concept-learning.
- the extent to which taught skill at metacognition influences constructivist learning.
- the formative use of Two-tier Multiple-choice items for the development of enhanced concept-learning.
- the use of tertiary tutorials as a means of assisting students to learn constructively.

9.3 Limitations of the study

9.3.1 Data sources for constructivist approaches

An emphasis in this thesis has been on the collection of data concerning the content aspects of the presentation and the text resources. The collection of more data on constructivist approaches and situations could have given the reader a broader appreciation of the study. Furthermore, the inclusion of such data - some direct evidence of the constructivist presentation of the program (such as vignette/s of teaching segment/s) would have enhanced the trustworthiness of the data and its interpretations (Guba and Lincoln,1989). Such evidence might well have been acquired through the use of video-recording/radio microphones to capture the discourse and actions of the students as they worked.

9.3.2 Assumptions underlying the Concept-learning Improvement Scale - data analysis

Some of the assumptions made in developing the Concept-learning Improvement Scale ultimately led to limitations or reservations in its application during the research. Two such assumptions were concerned with interpretation of the responses to the Two-tier Multiple-choice items. One of these assumptions was that "as the two-tier format of these items produced such probing tests of understanding, it seemed reasonable to assume that a respondent's selection of the correct combination of Response with Reason was good evidence for substantial growth in concept-learning" (Section 6.2 and dot-point two, Table 6.2). In practice, although the Two-tier Multiple-choice items were indeed challenging, such a statement could only be supported with complete confidence in the light of evidence that the student could not give a satisfactory answer at an earlier stage. In the form in which the Concept-learning Test Sequences evolved, this evidence was not available, thus limiting, to a degree, the strength of any conclusions based upon the Concept-learning Improvement Indices.

A second assumption made in constructing the Concept-learning Improvement Scale was that "in cases where the Concept-learning Test Sequence contained several Two-tier Multiple-choice items, the *proportion* of successfully answered items was itself an indicator of the extent of concept-learning" (Section 6.2). In practice, this principle proved difficult to apply in awarding Concept-learning Improvement Scale categories because reservations arose, particularly in the lower proportions of correct items, as to whether there was an improvement in learning as distinct from a demonstration of lack of understanding.

A third assumption was that "improvement in concept-learning is considered to have occurred when...a correct response is given to an element of a Post-instruction Test Question Part B" (dot-point three, Table 6.2). Again, as in discussing the first assumption above, such a statement could only be supported in practice in the light of evidence that the student could not give a satisfactory answer at an earlier stage. In most Concept-learning Test Sequences this evidence was not available.

In the awarding of the N (nil) Category on the Concept-learning Improvement Scale, "ceiling effects" were displayed in the results of students who already knew the correct answer to a pre-test item. These students were precluded from showing improvement in the identical post-test item and received the same category (N) as the students who scored incorrect in both pre-test and post-test. In such cases it would have been more satisfactory to score the correct pair of pre-test/post-test answers as "no data", leading to a more realistic treatment of the data and to the derivation of the Improvement Indices. The "ceiling effects" may have been reduced had more extensive test items on each concept been developed.

9.3.3 Data analysis

In Section 6.2.2, the Concept-learning Improvement Categories are assigned numerical values which are then treated as interval data from which means are calculated. In view of the acknowledged subjective nature of the Categories, it may have been more appropriate to treat them as ordinal data (non-parametric) and to use medians rather than means of the data to achieve more meaningful discussion.

In Section 6.3.1, statistical data were used to establish a link between students' Concept-learning Improvement Indices and their ability at the Logical Reasoning and Proportional Reasoning tasks (full data in Appendix 6). Since these reasoning tasks were only performed prior to instruction, a limitation to this statistical analysis was the absence of data on any improvement in the students' reasoning skills arising from participation in the course.

9.4 Reflections on the course

9.4.1 Attitudinal issues:

At the commencement of the course there was anecdotal evidence that a number of members of the class, especially the mature-age students, were quite nervous about their ability to cope with the challenge of university study, albeit through a bridging course oriented towards actual entry into undergraduate study. This was understandable, given that a number of the Australian students had been away from serious study for as long as 10-25 years. Later, responses in the the Post-laboratory Reviews revealed that, even mid-way through the semester, there was a nervousness amongst the more capable students about coping with the rigours of study in the bridging course. (By this time, most of the over-challenged students had withdrawn). In the previous year one or two mature-age students had given themselves a trial at study by attending the local TAFE College to attempt one or two Year 12 subjects. This strategy had worked, apparently, because their success in these subjects had given them enough confidence to enrol in the bridging course. Notwithstanding the likelihood that most young undergraduates may temporarily feel nervous on entering a new tertiary institution, the fears and nervousness of the older students seemed to be founded in a more complex web of responsibility, dignity, self-esteem, challenge and the perceived disadvantage of a background which was apparently out-of-date. It must be acknowledged that a number of these mature-age students were attending the course with the financial and moral support of partners, parents or relatives, and felt an obligation to achieve success, in response to these not inconsiderable sacrifices. This seemed particularly so in the case of international students, who were coping, not only with the stresses already described, but also with the difficulties of a foreign language and the customs of a strange country.

In this context, the generation of confidence seems to have been under-rated, discounted or ignored as a pre-requisite for quality learning and academic success in the bridging course. Research concerning the laboratory as a "confidence lab" (Section 9.2.4) is therefore justified.

9.4.2 Problems of the second-language students

Some of the cultural and language skill difficulties of second-language students have been described in Section 4.3. Unfortunately it seems that most of these problems are outside the ambit of the course coordinator to solve. The best that can be done by teaching staff is to be aware of and sympathetic to the range and diversity of the problems which such students face. In particular this includes the careful use of the English language to avoid culturally-based metaphors and similes, and to be particularly tolerant of written imperfections of spelling, syntax and grammar.

The university gave general assistance to such students by providing a Study Adviser and by requiring academic staff to give extra reading time for accredited second-language students for the completion of written examination papers.

9.4.3 Comparison of final results in courses within the bridging program

Most of the students were enrolled in the full-time bridging program, which involved courses in chemistry, mathematics and physics. Table 9.1 displays the final results of all the students who sat for the final chemistry examination. It is of interest that the pass/fail rates for the three courses are very similar, yet un-moderated. (The pass rates are comparable with those reported by Fensham (1997) for bridging courses in chemistry for engineering students at Monash University. In each year since 1989, over 80% of students met "the exacting requirements for completion"). Some idea of the students' success in bridging into University of South Australia undergraduate programs is indicated by the seventeen 1997 enrolments. It is also of interest that no student was accepted into the Bachelor of Applied Science program, a program which caters for several kinds of chemistry-based careers. It is clear that some of the university's departments were willing to admit students (for example students Nos 1 and 2) who had done poorly in chemistry yet had performed adequately in bridging courses more akin to that department's normal pre-requisites. Two students (Nos 13 and 19) successfully reverted to the undergraduate programs whence they came on probation. The 1997 academic program of two other successful students (Nos 6 and 15) is unknown. They may have been accepted into another university. The poor health and low academic results of Student No 16 may have discouraged him from applying for enrolment.

Table 9.1: Final Results, Bridging Program, 1996

Final %, Grades and 1997 Enrolment
for those who sat the final chemistry examination.

Student	Chem	Maths	Physics	Program at UniSA - 1997
1 MAb	34 F2		59 P1	B of IT (Software Eng)
2 MAr	46 F1	60 P1	56 P1	B Eng
3 CB	64 P1	70 C	71 C	B Eng (Mining)
4 AC	58 P1	54 P2	63 P1	B Eng & BA (Intl & Regl Studs)
5 BE	83 D	94 HD	83 D	B Eng
6 PF	70 C	10 F2	65 C	
7 JG	61 P1	68 C	68 C	B Eng
8 VG	62 P1	71 C	66 C	B Eng
9 CG	39 F2	4 F2	36 F2	
10 MG	75 D	74 C	78 D	B Eng
11 NH	55 P1	64 P1	53 P2	Dip Comput & Info Sc
12 M-NI	50 P2	53 P2	63 P1	B Eng
13 EK	58 P2			B Biomed Sc
14 TK	77 D	70 C	68 C	B App Sc (Env Managemt)
15 SL	65 C	51 P2	53 P2	
16 GM	54 P2	51 P2	33 F2	
17 LN	67 C	72 C	67 C	B A
18 BR	76 D		88 HD	B App Sc (Ma & Comp Mod)
19 AR	61 P1			B Pharm
20 JV	79 D	96 HD	83D	B Eng
21 SW	59 P1	73 C	81D	B Eng
Summary				
N =	**21**	**17**	**19**	**17**
≥P2	18	15	17	
≤F1	3	2	2	

9.4.4 The Research Problem and its solution

In terms of the basic objective of giving particular disadvantaged students an opportunity to enter science-related tertiary disciplines, the bridging program, as indicated by the results in Table 9.1, must be regarded as a success by the students and by the university. In terms of the Research Problem, the course as designed, presented and evaluated, has not only met these basic needs, but also has provided the students with significant opportunities for the quality learning of chemical concepts through constructivist approaches. The wide range of data presented in this thesis indicates that, in general, the students have accepted these opportunities to their educational advantage.

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Appendices

Appendix 3.1

Unit 4: Acids, Bases and Salts

from

Chittleborough, G. (1996). *Introducing Chemistry.*
Adelaide, South Australia: University of South Australia.

UNIT 4
ACIDS, BASES AND SALTS

Outline

Section A Pre-laboratory reading and study

1 **Introduction - background**

Development of understanding from antiquity to the present.

2 **Further reading**

- 2.1 Textual material. Appendix 2, 'Meeting Chemistry'.
- 2.2 Section B of this unit.

  Choice of practical activities based on experience.

3 **Pre-lab report**

Completion of three concept maps for submission.

Section B Laboratory Work

Part 1 Properties of acids

Part 2 Properties of alkalis

Part 3 Salt preparations

(from metal, oxide of a metal, hydroxide, carbonate; insoluble salts)

Part 4 A classification of oxides

Part 5 Protons anyone? A theory introduced and applied

- 5.1 Introducing the theory
- 5.2 Applying the theory. Salt hydrolysis

Part 6 Problem-solving at the bench.

Challenges 1,2,3,4 available by consultation

Part 7 Post-lab review

Section A Pre-laboratory reading and study

Introduction - Background

The people of ancient times were aware of some of the properties of acids and bases. For example, the beautiful and famous Cleopatra (69-30 BC), Queen of Egypt, is reputed to have so wished to impress Mark Antony (a Roman leader) at a banquet in his honour that she took a precious pearl ear drop (jewellery) and dissolved it in her wine, which she then drank.

Wine contains **weak acids** which are able to react with and dissolve the pearl, a precious form of the **base** calcium carbonate, secreted by some kinds of shell fish.

Acids

The ancients knew of acids in the form of common *vinegar* or crude **acetic acid,** produced by the oxidation of wine or beer, which become sour on exposure to air, as do fruit juices and sour milk. They knew that vinegar effervesced with natural sodium carbonate. The **mineral acids** (sulphuric, nitric, hydrochloric) were discovered by the alchemists. (Alchemists were mainly interested in finding potions to produce gold or to confer immortality). Scheele (1742-1786) isolated a number of **organic acids,** containing carbon, hydrogen and oxygen, of which acetic acid ($C_2H_4O_2$), is an example. These acids, such as **citric** ($C_6H_8O_7$), **tartaric** ($C_4H_6O_6$), and **malic** ($C_4H_6O_5$), impart a sour taste to unripe fruits, whilst the acidity of sour milk is due to **lactic acid** ($C_3H_6O_3$).

Knowledge of the **properties of acids** was summarised by Robert Boyle in 1663 as being at least four-fold.

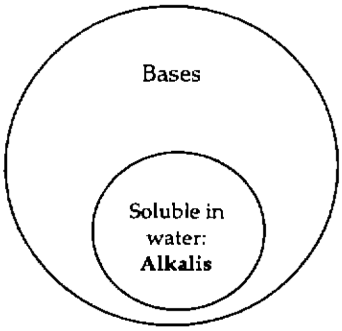
- they have a **sour** taste (**acidus** (Latin) = sour)
- they **'dissolve'** other substances, but with varying 'power'.
- they change many **blue vegetable colours** to red (eg litmus), the colour being restored by alkalis.
- they react with **alkalis,** the characteristic properties disappearing and a neutral **salt** being formed.

A century later, the Englishman Henry Cavendish (1766) showed that **hydrogen** gas forms by the action of acids (except nitric) on the **metals** zinc, iron and tin.

Alkalis

From early times the term 'alkali' referred to any substance **soluble in water** which could neutralise acids to form salts. 'Mild' and 'caustic' (burning) alkalis referred to the bases we nowadays recognise as **soluble carbonates** and **soluble hydroxides.** The early alkalis were derived from wood ashes (al qili, Arabic, ashes of a plant) by reaction with water.

The more modern term, **base**, covers the substances, both soluble and insoluble in water, which neutralise the properties of acids. The Venn diagram illustrates this.



3 In those earlier times the following **general properties of alkalis** were recognised

- their solutions **feel soapy** to the touch
- they **restore the blue colour** of dyes reddened by acids (eg red cabbage, litmus)
- they **neutralise acids** to form salts
- the 'mild forms' **effervesce (fizz)** with acids, giving off 'fixed air' (we would say 'carbonates release carbon dioxide').

The Scot Joseph Black, (1728 - 1799) contributed very significantly to the understanding of alkalis. Prior to his doctoral thesis (1754) three pairs of alkalis were known.

- 'mild vegetable alkali' (as we know it, **potassium carbonate**, obtained from plant ashes) and 'caustic vegetable alkali' **(potassium hydroxide)**
- 'mild marine alkali' **(sodium carbonate** obtained from sea shore plants) and caustic marine alkali **(sodium hydroxide)**
- 'mild volatile alkali'(**ammonium carbonate,** obtained from bones or urine) and 'caustic volatile alkali' **(ammonia solution)**

To these Black added knowledge about the relation between three bases bearing the name 'lime'.

- **limestone** (now known as **calcium carbonate**) which if heated strongly, yields
- **quick lime (calcium oxide**) with carbon dioxide
- **slaked lime (calcium hydroxide**), formed when quick lime is wetted (slaked) with water.

Black also worked with the related compounds magnesia **(magnesium oxide),** 'milk of magnesia' **(magnesium hydroxide),** and 'magnesia alba' **(magnesium carbonate).** In so doing, he contributed data of great importance in overthrowing the Phlogiston Theory. (This theory had long retarded progress in understanding chemistry. We will not discuss it here).

Although the properties of acids and bases were becoming well researched, an understanding of the structure and bonding of matter was needed before a theoretical understanding of the behaviour of acids, bases and salts could begin.

Svante Arrhenius (1859 - 1927) provided an **ionic theory for acids and bases in solution.**

According to the Arrhenius Theory

- Acids are substances which produce **hydrogen ions** (H^+) in solution
- Bases are substances which produce **hydroxide ions** (OH^-) in solution

This theory explains many aspects of acid-base reactions in water solution. Note however that the hydrogen ion, that is a proton, is not able to exist as such **in water.** Rather, the proton, bonds covalently to a water molecule to form the ion H_3O^+. Sometimes this ion is called the **hydronium ion.** Sometimes it is represented as $H^+_{(aq)}$. Sometimes the (aq) subscript (aqua = water) is omitted but understood to be present. H^+, $H^+_{(aq)}$, H_3O^+, $H_3O^+_{(aq)}$ are all representations of 'hydrogen ion'.

One inadequacy of the Arrhenius theory is that is **does not account for bases which are insoluble in water.** Examples are **oxides, hydroxides and carbonates of 'heavy' (dense) metals** like copper, lead and cobalt.

These substances are all capable of neutralising the properties of acids, so the following **definitions** include a broader **working definition for bases**—you will find them used in the course.

- **an acid is a substance which forms hydrogen ions**
- **a base is a substance with accepts hydrogen ions**

When you study Appendix 2 of 'Meeting Chemistry' you will see that this means that **bases can be hydroxide ions** (OH^-) oxide ions (O^{2-}) **carbonate ions** (CO_3^{2-}) or **ammonia molecules** (NH_3). In other words **bases can be particles, not necessarily complete compounds.**

$$OH^- + \underset{\text{(from acid)}}{H^+} \rightarrow H_2O$$

$$O^{2-} + 2H^+ \rightarrow H_2O$$

$$CO_3^{2-} + 2H^+ \rightarrow (H_2CO_3) \longrightarrow CO_2 + H_2O$$

$$NH_3 + H^+ \rightarrow NH_4^+$$

The ionic bases are always accompanied by 'spectator' ions formed from metals. Thus bases include oxides, hydroxides and carbonates of metals, and ammonia solution.

The above Appendix gives you good broad coverage of the notions of acids, bases, salts and their reactions. The laboratory work will include a number of opportunities to study examples. Let's develop acid-base ideas a little further.

In 1923 Johannes **Bronsted** and T.M. **Lowry** independently extended these ideas to include **solvents other than water** to produce very simple, but broad description and definitions.

These statements do not exclude the Arrhenius notions about hydrogen ions in water. Rather, they focus on the **source of protons** and **their destination.**

You may find an opportunity to meet 'Bronsted' acids and bases in Section 5 of the laboratory work.

Oxides and ideas about acids and bases

We have seen that metals produce oxides which are bases. If these oxides react with and dissolve in water, a solution of a **hydroxide of a metal** is formed. the solution is described as **alkaline** and the solutes (the dissolved **hydroxides**) are classed as **alkalis.** The alkalis are also bases.

The metal, sodium, is a good example.

sodium $\xrightarrow{\text{oxygen}}$ sodium oxide $\xrightarrow{\text{water}}$ sodium hydroxide solution
(a **metal**) (a **base**) (an **alkali**)

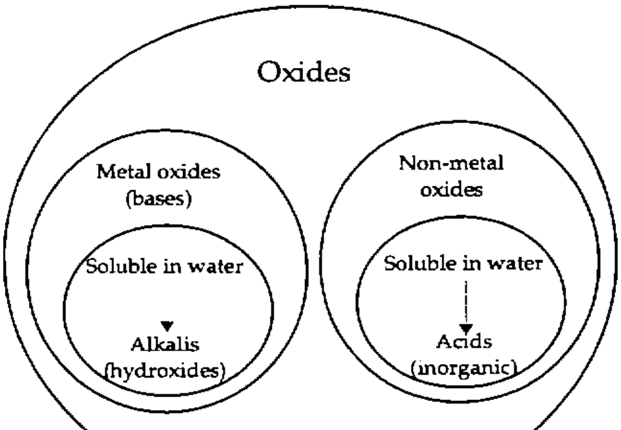
By contrast, many **oxides of non-metals** dissolve in water form **acids.**

Example

sulfur $\xrightarrow{\text{oxygen}}$ sulfur dioxide $\xrightarrow{\text{water}}$ sulfurous **acid** solution

(This kind of acid is often described as **inorganic**. Organic acids are derived solely from carbon, hydrogen and oxygen and are very often found in nature.)

The following Venn diagram summarises these ideas about oxides.



Question:

What properties might be possessed by the oxides **outside** the two larger circles, but within the oval shape? ♦

2 Further reading

2.1 Text material

Having read this introduction you should **now study Appendix 2 Acids, Bases, Salts of 'Meeting Chemistry'**. The summaries and exercises are an excellent means of developing or checking your understandings. The laboratory work will provide further support.

2.2 Unit 4 - Section B

NOTE PLEASE: STUDENTS DO NOT HAVE TO COMPLETE ALL OF THE WORK SHOWN

You should read through the laboratory activities to check which of them suit your present knowledge and experience.

The sections available are:

Part 1 Properties of acids

Part 2 Properties of alkalis

Part 3 Salt preparations

- four soluble salts
- two insoluble salts

Part 4 A classification of oxides

Part 5 Protons anyone? A theory introduced and applied

Part 6 Problem-solving at the bench. Challenges 1,2,3.

Your selection should be guided by your experience, knowledge and confidence.

- if your experience of practical chemistry and of theory is relatively slight you should try to complete **at least:**

  Parts 1, 2, 3 (at least two soluble and one insoluble salt), and 4.

- if you are more experienced and feel confident of your knowledge and theory, you should try to complete

  Parts 3 (one soluble salt, one insoluble salt), 4, 5, and 6 (one challenge).

- REMEMBER PLEASE: There are no marks for **quantity.** The main aim is to achieve **quality** of learning and experience.

3 Pre-lab report

- use your knowledge to complete the three incomplete concept maps provided.
- Remember that two ideas or concepts in a 'box' need to be linked by a word or phrase which tells about the **relationship** between the linked concepts
- Attach these maps to the cover sheet

- Complete the cover sheet, including your planned sequence of study.

← Staple here

Name: ____________________

Bench Number: ____________

Tutor: ____________

Pre-laboratory Report—Unit 4

Acids, Bases and Salts

Cover sheet

Please tick

1 I have studied Section A and B of this unit ☐

2 Here are my **three completed concept maps** ☐

3 I choose to attempt at least the following part of the Unit

Either: Parts 1, 2, 3 (three salts) 4 ☐

Either: Parts 3 (two salts) 4, 5, 6 ☐

4 Please clarify the following ideas or concepts

-
-
-

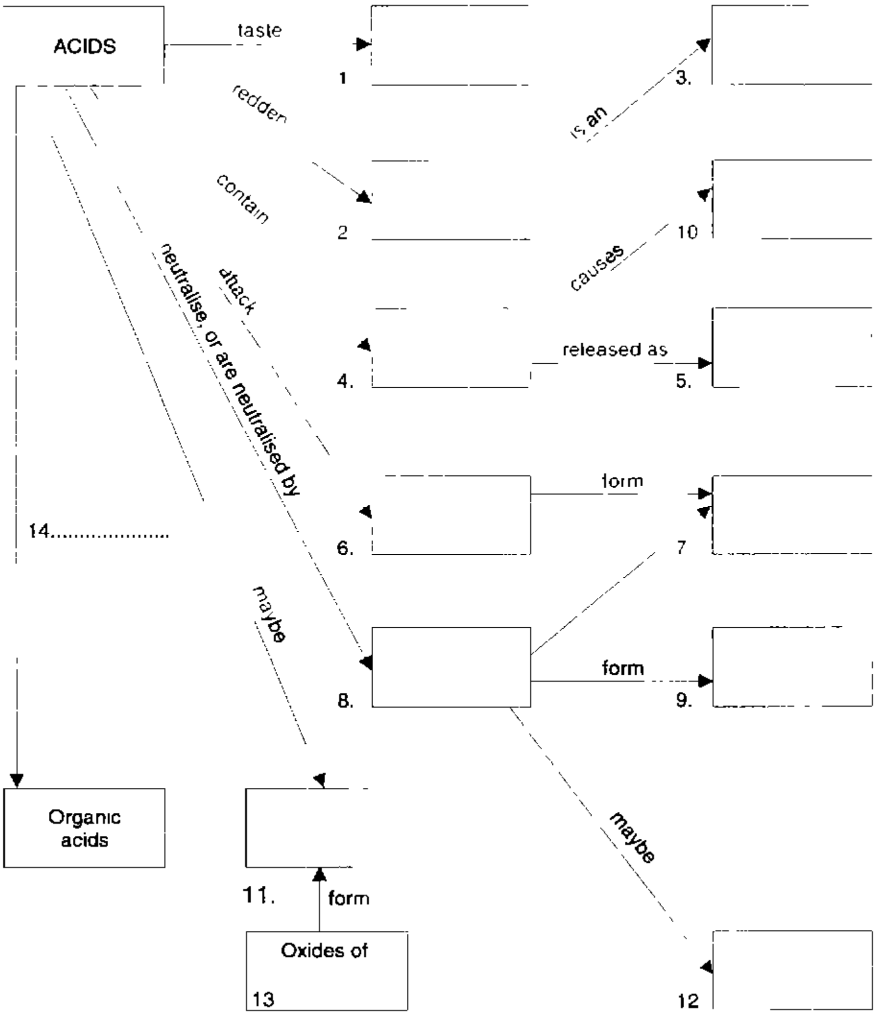
Signature: ____________________

Date: __________

Pre-laboratory Report

Concept Map for Acids

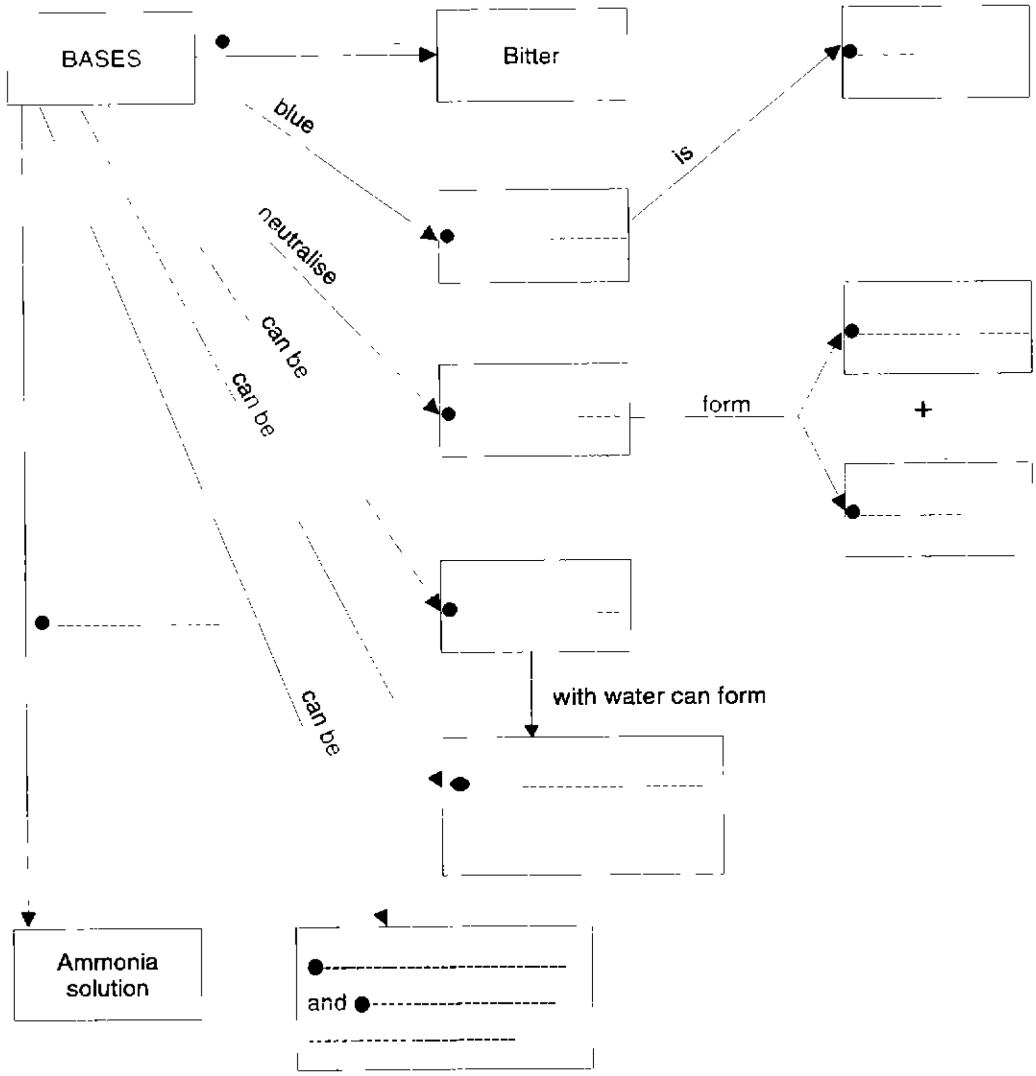
Complete numbers 1 to 14 if possible. Possible items to fill most of the boxes are given at the bottom of the page.



Possible concepts: hydrogen ions; salts; inorganic acids; indicator; water; active metals; blue litmus; bases; sour; hydrogen gas; non-metals; acidic properties; hydroxides, oxides and carbonates of metals

Concept Map for Bases

Complete the map by adding the best word or phrase at the points marked with a dot. Suggestions are given below.



Suggestions: oxides of metals; salt(s); an indicator; taste; red litmus; water; hydroxides of metals; include; acids; carbonates and hydrogencarbonates of metals.

Concept Map For Salts

In the space below present your own concept map. Include as many relationships as you can. You will first need to work on a draft on a separate sheet, perhaps using cut out squares of paper for concepts and strips of paper to write relationships. This will allow you to juggle the concepts before finalising your written map Choose terms from the following list:

Salts; active metals; hydrogen ions; water; bases; acids; hydrogen gas.

Add other terms and relationships if you can.

Section B Laboratory work

Please complete the Post-laboratory Review after finishing your chosen sections.

Part 1 Properties of acids

Requirements:

5 squares of magnesium ribbon	2 microscope slides
3 r.g. sodium carbonate	2 M tartaric acid

Procedure:

1.1 **Reaction with indicators**

- Place 1 drop each of litmus, phenolphthalein and methyl orange separately on a white tile.
- Add 1 drop of dilute sulphuric acid to each drop.
- Record your observations:

- Repeat this procedure with dilute nitric and dilute hydrochloric acids:

Indicator	Litmus	Phenolphthalein	Methyl orange
Colour (in water)			
Colour (in acids)			

1.2 **Reaction with carbonates**

Note: carbon dioxide produces a white suspension when passed through lime water.

1.2.1 The reaction

- Place 1 r.g. of sodium carbonate powder and three drops of lime water in separate test tubes. Add 2 drops of dilute hydrochloric acid to the solid.

◆

1.2.2 Testing the gas formed

- Withdraw a sample of the gas evolved with a teat pipette.
- Bubble the sample through the lime water. Repeat the procedure until a change is detected.

◆

- Repeat using 1 r.g. of sodium carbonate with each of dilute nitric and dilute sulphuric acids.
- Record each result.

◆

1.3 Reaction with a metal

1.3.1
- Place a square of magnesium ribbon (2 mm x 2 mm) in a test tube.
- Add 2 drops of dilute hydrochloric acid.
- Seal the test tube with your finger for 10 seconds.
- Bring the test tube to the bunsen flame and remove your finger.

Note: The hydrogen set free is much less dense than air. You may prefer to collect it with an inverted test tube held over the reaction tube. You can test the gas by bringing the inverted tube full of gas to the flame.

◆

1.3.2 Establishing that the reaction produces a salt

- Place 1 drop of **concentrated** hydrochloric acid on a microscope slide.
- Pour off excess liquid into the sink.
- Warm the remaining liquid in the hot air 12 cm **above** a low bunsen flame until dryness is reached.
- Note whether a residue remains.

◆

- Place a square of magnesium on another slide.
- Add 1 drop of concentrated hydrochloric acid and repeat steps in 1.3.2 above. Check for the presence of a residue Record your result.

  ◆

1.4 Neutralising the properties of the acid

Note: Make sure that drop sizes are similar.

- Place 2 drops of dilute hydrochloric acid in a test tube.
- Add 3 drops of sodium hydroxide solution (an alkali). Shake.
- Test for acid by dropping 1 square of magnesium into the test tube. Has the acid property been destroyed?

  ◆

- Repeat with dilute sulphuric and dilute nitric acids, using the same square of magnesium.

  ◆

  ◆

- Name the salt formed in each case.

  ◆

  ◆

  ◆

1.5 Weak and strong acids

You will compare the effect of magnesium upon equal volumes of equal concentrations (2M) of hydrochloric and tartaric acids.

- Place 10 drops of each acid in separate test tubes.
- Add, simultaneously, 1 square of magnesium to each tube.

- Compare the rates of effervescence after 2 minutes.
- Feel the tubes for temperature change.

  which is the warmer?

  ♦

  ♦

  which is the **weaker** acid?

  ♦

Part 2 Properties of alkalis

Alkalis considered:

solid sodium hydroxide, potassium hydroxide, calcium hydroxide (lime water), ammonia solution (behaves as ammonium hydroxide).

Requirements:

flake or pellet of sodium or potassium hydroxide. Equipment, indicators as for acids. Glass stirring rod, 2M NaOH solution, spatula. Solutions as above (dropper bottles).

Procedure

2.1 **Appearance and solubility**

- Observe carefully the appearance and surface of a pellet or flake of sodium (or potassium) hydroxide. DO NOT TOUCH (corrosive).

  ♦

- Place the solid in a test tube and add 10 drops of water.
- Stir with rod. This is your solution for 2.2.

2.2 Reaction with indicators

- Place one drop of each of litmus, phenolphthalein and methyl orange separately on a white tile. Note the colour.
- Add one drop of your prepared sodium hydroxide solution to each drop of the tile.
- Repeat this procedure with fresh drops of indicator using in turn, limewater and ammonia solution from the reagent shelf. (Each is an **alkali**).
- Summarise your observations on the Table.

Indicator	**Litmus**	**Phenolphthalein**	**Methyl orange**
Colour (in water)			
Colour in alkalis			

2.3 The slippery feel of alkalis

- Place 1 drop of dilute sodium hydroxide in a test tube.
- Add 10 drops of water. Shake/stir.
- Place 1 drop of this solution on your finger. FEEL the solution by rubbing between your finger and thumb.

◆

- Immediately wash your fingers thoroughly.

2.4 Neutralisation

In the previous session you saw that acids destroyed the properties of sodium hydroxide (or vice versa). This is true, not only for sodium hydroxide, but for all alkalis. Verify this by performing the following:

2.4.1 Acid-alkali reactions

- Place 1 drop of ammonia solution and 1 drop of lime water separately on a white tile. To each drop add 1 drop of phenolphthalein solution.
- Add 2 drops of one of the three DILUTE acids to each mixture.
- Record the effect on phenolphthalein and the effect of acid on alkali.

◆

Since this destruction of properties must be a chemical change, the action of acid on an alkali must produce AT LEAST ONE new substance, a SALT.

2.4.2 To isolate the salt left when an acid reacts with an alkali

- Place 1 drop of dilute hydrochloric acid on a clean microscope slide.
- Add 1 drop of sodium hydroxide solution. Mix with a glass rod.
- Pour off excess liquid into the sink.
- Warm the remaining liquid in the hot air 7.5 cm above a low flame).
- ◆

The product is called **sodium chloride.** This is one of a large class of compounds called **salts.** It is a product of the **neutralisation** of the acid by the alkali.

Note that acids may be neutralised by substances other than alkalis. See later work.

Part 3 Salt preparations

The preparation of **soluble** salts may be performed by the action of an acid on either:

- a metal
- a oxide of a metal
- a hydroxide
- a carbonate (or hydrogencarbonate)

The general procedure for making a salt involves two stages:

- Add just enough of the solid (or solution) to use up all of the acid
- Separate the pure salt

3.1 Salt preparation: Action of an acid on a metal

Requirements:

25 mm of magnesium ribbon

Procedure:

- Place 25 mm depth of dilute sulphuric acid in a test tube.
- Add 25 mm of magnesium ribbon rolled up.
- Shake until the reaction ceases in the presence of excess magnesium.
- Decant the solution onto a watch glass. Hold this with a test tube holder.
- Concentrate the solution by **slow** evaporation 75 mm above a **tiny** flame until the solution is saturated.
- Cool — most of the salt crystallises out as $MgSO_4 .7H_2O$.

Note: On a larger scale preparation, the crystals formed on cooling would be further treated to gain a pure sample. For example:

Filter crystals; wash with a small quantity of water; dry between filter papers.

3.2 Salt preparation: Neutralisation of an acid with a basic oxide

Preparation of copper sulphate

Requirements:

Copper oxide.

Procedure:

- Place 25 mm of dilute sulphuric acid in a test tube.
- Add 1 r.g. of black copper oxide.
- Warm - to assist reaction ('dissolving').

◆

- Add more copper oxide while warming and shaking until excess black copper oxide remains.
- Filter onto a watch glass.
- Concentrate the solution until saturated using a **tiny** flame.
- Cool — most of the salt crystallises as $CuSO_4 .5H_2O$

◆

3.3 Salt preparation: Action of a carbonate on an acid

Preparation of lead nitrate

Requirements

1 dry test tube
hand lens
lead carbonate

Procedure:

- Place 25 mm depth of dilute nitric acid in a test tube. Warm the liquid.
- Add lead carbonate 1 r.g. at a time until no more effervescence occurs in the presence of excess solid.
- Moisten a folded filter paper with DISTILLED water and filter onto a watch glass.
- Concentrate the filtrate over a **tiny flame** holding the watch glass in a test tube holder.
- Cool — crystals are $Pb(NO_3)_2$.
- Examine product with a hand lens.

◆

3.4 Salt preparation: Neutralisation of an acid with an alkali

Preparation of sodium sulphate

Requirements:

No extra materials.

Procedure:

3.4.1 How much alkali?

- Place 6 drops of dilute sulphuric acid in a test tube.
- Add 1 drop of phenolphthalein solution.
- Add dilute sodium hydroxide drop by drop with shaking until a faint pink colour develops. Record the number of drops used. ◆
- Wash out the test tube.

3.4.2 Preparing the salt

- Repeat the procedure using the same number of drops but without the indicator.
- Pour the neutral solution onto a watch glass.
- Evaporate about three-quarters of the solvent with a tiny flame.
- Cool — the crystals are $Na_2SO_4 .10H_2O$

◆

Now proceed to the next section—the preparation of insoluble salts.

3.5 Salt preparations: Precipitation of insoluble salts

Requirements:

copper sulphate solution

3.5.1 Preparation of barium sulphate

Procedure

- Place 10 drops of barium chloride solution in a test tube.
- Add 10 drops of dilute sulphuric acid.
- Mix solutions with a glass rod.
- Filter - collect filtrate in a 25 mL conical flask.
- Wash residue from test tube into the filter paper cone, using about 10 drops of water from a squeeze wash bottle. When filtering stops, add a further 10 drops of water to remove solution from the residue.

  Keep the filtrate to test as indicated below.
- Press the thoroughly drained residue between two dry filter papers.

- Dry the filter paper and residue by laying the open paper on a watch glass, and heating it in the hot air well above a small flame.
- Scrape the residue together, using the chisel end of your spatula. Examine the product, barium sulphate.

  ♦

- **Test for excess of either reactant:**
  - ♦ to 2 drops of filtrate add more (1 drop of) sulphuric acid.

    ♦

  - ♦ to 2 drops of filtrate add more (1 drop of) barium chloride solution.

    ♦

3.5.2 **Preparation of copper carbonate**

Procedure:

- Repeat the procedure as in 3.5.1 using 10 drops each of solutions of copper sulphate and sodium carbonate instead.
- Describe the dried residue.

  ♦

- Test the filtrate to determine which reactant was used in excess.

  ♦

Part 3 Salt preparations

Thinking tasks

1 In all methods for the preparation of soluble salts, one particular kind of reagent is needed. What is it?

♦

What are the types of substances that react with this reagent to produce the soluble salts?

♦

Hence summarise the methods of preparing soluble salts.

-

2 Complete the following table:

Salt to be prepared	**Chemicals required**	**Word equation**	**Method used to detect when reaction is complete**
ammonium sulphate			Litmus turns purple
copper nitrate			
barium chloride	barium carbonate and		

3 What kind of reaction occurred when

1 an acid 'dissolved' a metallic oxide,

2 an acid reacted with an alkali?

Why was an indicator necessary in 2 but not in 1?

4 Write word equations for the preparation of:

1 ammonium sulphate

2 potassium chloride

3 sodium nitrate

4 sodium chloride

5 copper sulphate

5 You have a metallic oxide MO. Write word equations showing how you could convert it to:

1 the sulphate of M

2 the nitrate of M

3 the chloride of M

6 In answering the following questions, you will realise how necessary it is to know which salts are soluble, and which are insoluble. Therefore revise the rules thoroughly from the appendix of 'Meeting Chemistry'.

1 What other insoluble salt may be made from the solutions available in 3.5.1 and 3.5.2?

Write an equation.

◆

2 Suggest two other pairs of substances which could have been used in 3.5.2 to obtain copper carbonate:

It is essential that the four substances you select have one property common to all of them. What is it? ◆

Write equations for the possible reactions.

◆

Part 4 A classification of oxides

This part develops another aspect of the concepts 'acid' and 'base'. It contributes to an understanding of the 'mineral', (or inorganic) members of the universe of acids. And it establishes that whether an element is metallic or non-metallic determines the potential of its oxide to form an alkali or an acid with water. The oxide is formed from the element by heating it in a flow of air in a teat pipette.

Requirements:

6 dry teat pipettes

sodium, magnesium, roll sulphur (lump), red phosphorus, (½ r.g. each)

Note:

The procedure below is a safe and convenient way of examining the formation and properties of oxides of metals; the number chosen is limited only by the time available.

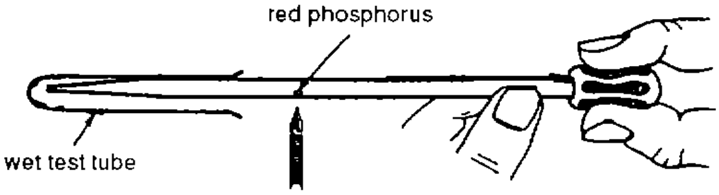
Procedure:

4.1 **Metals**

- Place a sliver of sodium (**no more:** danger) freshly cut, in a dry pipette near the tapered end, and replace the teat.
- Heat the sodium. Hold the pipette horizontally and maintain a flow of air over the sodium by squeezing the teat at second intervals. Rotate the pipette, which should not soften and sag.
- Cool the pipette on a heat resistant mat. (Heat the next metal while you wait).
- Draw the water into the cool pipette from a test tube quarter full. Squeeze and release the teat several times to wash any soluble contents of the pipette into the test tube.
- Add 2 drops of litmus solution to the test tube. Record the result on the table.
- Classify the oxide.
- Repeat this procedure, using magnesium (12 mm length)

4.2 **Non-metals**

- Place a fragment of sulphur in a dry pipette, near the tapered end and replace the teat. Keep the pipette horizontal.
- Cover the tapered end of the pipette with a wet test tube.
- Heat the sulphur, and at the same time puff air in and out of the pipette (squeeze the teat!) until the test tube is full of fumes. Lay the hot teat pipette on a mat to cool.
- Add 10 drops of water to the test tube, and 2 drops of litmus solution. Record the result.
- Classify the oxide.
- Repeat this procedure, using ¼ r.g. of red phosphorus.



Result Table: Classification of oxides

Element	Behaviour on heating	Appearance of Product	Action on litmus	Nature of oxide
Sodium Magnesium				
Sulphur Phosphorus				

Summary:

Oxides which form acids with water are **acidic oxides,** and are formed by **non-metals.** Oxides which turn litmus solution blue are **basic oxides,** and are formed by the most active METALS. Many metallic oxides have no reaction with water (and therefore with litmus). The basic nature of these oxides can be shown in later experiments.

4.3 Thinking tasks

1 An element burns in air producing a solid. This solid, shaken with water produced a liquid which turned phenolphthalein red. What kind of element was used? (Give reasons).

2 Write word equations for the reactions which occurred when the elements used in the experiment were heated in air and the oxides shaken with water.

3 Create your own Venn diagram or concept map to summarise the links between

- the kind of element
- the kind of oxide

Part 5 Protons anyone? A theory introduced and applied

5.1 Introducing the theory

This work investigates some reactions which may be unfamiliar to or unsuspected by most students. The reactions, each quite different in reactants and products, possess a common feature. You will need to think through the implications of your observations.

Requirements:

sodium chloride solution (made up from tap water)	1 r.g. powdered magnesium
lead acetate paper (3 mm wide)	3 r.g. powdered sulfur
2 dry test tubes	1 r.g. ammonium chloride
	1 r.g. sodium acetate

5.1.1 Preliminary work

5.1.1.1 Test for excess H_3O^+ or OH^- ions

- Arrange 3 sets of red and blue litmus paper squares on a clean dry tile.
- Test the behaviour of sodium chloride solution on one set of papers, using 1 drop on each of the 2 squares.
- Repeat the test using
  - a dilute hydrochloric acid; and
  - b sodium hydroxide solution instead of sodium chloride solution
- Record your results on the table and hence state tests for excess of H_3O^+ and excess of OH^- ions in solution.

Solution	Red litmus	Blue litmus
sodium chloride		
hydrochloric acid		
sodium hydroxide		

5.1.1.2 Preparation of a reactant, $Mg^{2+}S^{2-}$ (Check: safety spectacles!)

- Place **no more than** 1 r.g. magnesium powder in a dry test tube.
- Cover the solid with 3 r.g. (ie excess) powdered sulfur.

- Heat the mixture gently (above the flame) so that air is excluded from the magnesium by the rising sulphur vapour.
- Heat more strongly until the magnesium combines with the sulfur with a sudden flash.

  Equation:

- Cool in the air for about a minute.
- Scrape the cool magnesium sulfide from the test tube and transfer the solid to a clean dry test tube for use in 5.1.2.

5.1.2 Reaction mixtures

5.1.2.1 Magnesium sulfide and water

From your previous experience of soluble ionic compounds state what you expect will happen to magnesium sulfide when placed in water.

◆

- Add 2 drops of tap water to the solid. (Any unreacted sulfur will not dissolve - ignore it).
- Moisten the tip of a clean stirring rod with the resulting solution and touch it on both red and blue litmus papers.

  ◆

What ion is present in solution? ◆

From which of the species Mg^{2+}, S^{2-}, H_2O must this ion have been formed? ◆

- Try to detect the odour of a gas, cautiously warming the tube if necessary. ♦

- Identify any such gas by holding a lead acetate paper inside the tube. (Any brown colouration produced is lead sulfide, PbS Its formation is used as a test for the gas hydrogen sulfide).

- Suggest a formula for the gas. ♦

Apparently two new substances, one ionic, the other molecular, have been produced by a reaction of magnesium sulphide with water.

- Suggest an equation for this reaction and name the spectator ions. ♦

- State in your own words how each new molecule and ion might have been formed from the original reactants. ♦

5.1.2.2 Ammonium chloride and sodium hydroxide

- Make a solution of 1 r.g. of ammonium chloride and 2 drops of water.
- Add 1 drop of sodium hydroxide solution.
- List the species (atoms, molecules or ions) which you expect to be present in the liquid.

- Warm the solution and try to detect the odour of the gas, ammonia, NH_3.

Your task is to suggest how this substance might have been formed from the ions originally present.

◆

Write a possible equation.

$+ \quad \rightarrow \quad NH_3 \; +$

Review

You have studied two different reactions which were brought about by the same process, the simple transference of protons from one species to another. In other words, one species supplied protons and another species accepted them. Such reactions are called **proton-transfer reactions.** The reactions studied above are but a few of the many such reactions. The following thinking task may give some idea of the range.

Thinking task

Which of the following reactions may be classified as proton-transfer reactions?

a $H_3O^+ + CO_3^{2-} \rightarrow HCO_3^- + H_2O$ ( )

b $Mg + S \rightarrow Mg^{2+} + S^{2-}$ ( )

c $H_3O^+ + OH^- \rightarrow 2H_2O$ ( )

d $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$ ( )

e $Zn_{(s)} + Cu^{2+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$ ( )

f $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$ ( )

g $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ ( )

h $2H_2O \rightarrow H_3O^+ + OH^-$ ( )

i $O^{2-} + H_2O \rightarrow 2OH^-$ ( )

j $Ag^+ + Cl^- \rightarrow AgCl_{(s)}$ ( )

k $O_2^{2-} + 2H_3O^+ \rightarrow H_2O_2 + 2H_2O$ ( )

l $H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)} + H_2O$ ( )

m $NO_2^- + H_2O \rightarrow HNO_2 + OH^-$ ( )

5.2 Applying the theory - salt hydrolysis

Requirements

¼ r.g. samples of solid - sodium carbonate, lead nitrate, ferrous sulphate, aluminium sulphate, sodium chloride, potassium nitrate, sodium acetate, sodium sulphite. Neutral water source.

2 strips of 'narrow-range' indicator paper pH6-8 (or red and blue litmus paper).

5.2.1 Are all salt solutions neutral?

(If the narrow range paper is being used for the first time, test squares of the paper with *water, dilute acid and alkali).

- Place 9 squares of indicator paper on a CLEAN DRY white tile. (If litmus has to be used, use 9 pairs of red and blue paper squares).
- Place the tiny DRY samples of the solids on separate squares. Note any results in the table below.

  Add 1 drop of water* to the empty square, and then 1 drop to each of the solids.
- Record the results in the table. Place a tick (✓) in the appropriate column to indicate any effect on the indicator.

Salt	**Effect on the Indicator**			
	Dry	**Salt + water**		
		Neutral	**Acidic**	**Basic**
Na_2CO_3				
$Pb(NO_3)_2$				
$FeSO_4$				
$Al_2(SO_4)_3$				
NaCl				
KNO_3				
CH_3COONa				
Na_2SO_3				
water	xxx			

---

* **It is essential** that the water used in this experiment be neutral. **Tap water** is generally suitable. If 'distilled' water is to be used for this experiment, it should be boiled to drive off dissolved carbon dioxide and the ion-exchanger checked for acid by-products.

5.2.2 A comment and discussion

Evidently, some of the salts have reacted with water.

A substance which reacts with water to produce either an acidic solution or a basic solution is said to have been ***hydrolysed.***

Remember that if litmus turns red, an excess of H_3O^+ *ions is indicated; if litmus turns blue, an excess of OH ions is present. Also recall that salts are ionic compounds and if they dissolve in water, they dissociate, setting free their ions. If a reaction occurs when a salt dissolves in water it is reasonable to expect that one*** *of the liberated ions of that salt has actually reacted with the water.*

- **If litmus turns red:**

  Some of the H_2O molecules must have become H_3O^+ ions. For this to occur, one the salt's ion species must have provided protons.

H^+	$+$	H_2O	$\longrightarrow$	H_3O^+
(from ion of the salt)		(in water)		(solution acid to litmus)

  You have seen that a substance providing a proton is called an **acid.** Hence some of the ions used must have been acids.

Thinking task

Here is a list of the ions - draw a ring around those which behaved as **acids,** donating protons to water.

*** $Na(H_2O)_x^+$, $CO_3{}^{2-}$, Pb^{2+}, Cl^-, $Fe(H_2O)_6^{2+}$, SO_4^{2-},

$Al(H_2O)_6^{3+}$, $K(H_2O)_x^+$, NO_3^-, CH_3COO^-, SO_3^{2-}

** In certain salts, eg ammonium acetate, both ions hydrolyse. Such salts are not considered in this activity.

*** All cations are hydrated in solution to some extent. Where a particular number of hydrating molecules per ion has been established, this number is stated. (Cations are positively charged).

- **If litmus turns blue:**

  Some of the H_2O molecules must have been converted to OH^- ions.

  For this to occur, one of the salt's ion species must have accepted protons from water molecules.

$$H_2O \longrightarrow OH^- + H^+$$

(solution basic to litmus) (bonded to salt ion)

We know that a substance which can accept protons is called a **base** - ie some of the salt's ions act as a base.

Thinking task:

Draw a ring around those which must have behaved as **bases,** accepting a proton form water.

*** $Na(H_2O)_x^+$, CO_3^{2-}, Pb^{2+}, Cl^-, $Fe(H_2O)_6^{2+}$, SO_4^{2-},

$Al(H_2O)_6^{3+}$, $K(H_2O)_x^+$, NO_3^-, CH_3COO^-, SO_3^{2-}

Thinking task:

Write out equations for the hydrolysis reactions which occurred. (Your tutor may discuss this).

Part 6 Problem solving at the bench

When you have satisfactorily completed earlier parts of the laboratory work you may care to accept the challenge of solving a practical problem which relates to acids, bases and salts. **Unit 11** gives help on problem solving.

A separate **challenge sheet** will be given to you. The sheet will state the challenge and indicate limits of chemical reagents and apparatus to be available.

To solve the problem you will need to have clearly understood the theory of acid-base reactions and you may need to find out some extra information about the properties of the substance(s) involved.

Before you begin practical work **you must submit a plan** or method for the approval of your laboratory tutor. This provides both a **safety precaution** and a teaching-learning context. The tutor will not approve a plan which is unsafe, but, in the interests of learning from mistakes, **may** allow a possibly imperfect plan to proceed.

Record your problem and your plan in the space below.

☐

Obtain your lab tutor's initial to proceed.

Then proceed with your investigation. Record results below, with conclusion and recheck of results.

Part 7 Post laboratory Review

Please complete the separate sheet, outlining your review of learning within the unit.

Post-laboratory Review

Name __________________________________

Bench Number __________________

The previous three post-lab review sheets have give a mainly formal framework to your review. By now you may wish to establish your own format. Please do. However, please remember that the review is intended to help improve your own insights into learning and the causes of improved learning.

The teaching staff is particularly interested in the question

What effect, if any have the experiences of the laboratory (especially the chemical change) **had upon your learning of concepts or ideas in chemistry? How did these effect influence your learning** (for better or worse)?

Use the back of this sheet if more space is needed

Please hand this review to the laboratory tutor before leaving the laboratory.

Appendix 4.1a & 4.1b:
Appendix 4.1a

University of South Australia
Faculty of Biomedical and Health Sciences
School of Chemical Technology

Applied Science & Engineering Bridging Course
Unit 04143 *Introductory Chemistry*

Introductory Information and Questionnaire

In the interests of providing learning/teaching conditions which are as effective as possible,we ask you to provide the following information and to answer the accompanying questions. This will give us an idea of the range of chemical backgrounds to be found within the class--we can then act accordingly.

Part A

1. Please state your names
   Family name: Given name:

   Student identity number:

2. Previous study of science and chemistry:
My highest level of study of chemistry has been in one of the following:
(please tick **one** box):

Year 10 Science ☐ Year 11 Science ☐ Year 11 Chemistry ☐

Year 12 Chemistry ☐ a Year 12 science ☐ Undergraduate ☐

DTAFE ☐ Other ☐

3.Language

* English is my first language: Yes ☐ No ☐

*If English is not your first language, please state your first language:

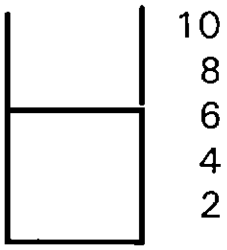
Part B. Pre-instruction questions and puzzles:

On the following pages you will find a number of tasks designed to give us an idea of 'where you are at' before we begin the course. Please attempt every question, if possible.

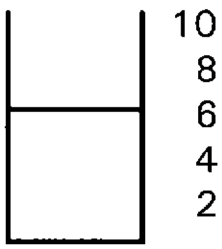
The Volume Puzzle

(source: Karplus et al, 1977)

Here are drawings of two vertical tubes (cylinders) which are filled to the same mark with water: the cylinders are identical in size and shape.



cylinder 1

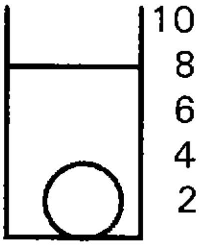


cylinder 2

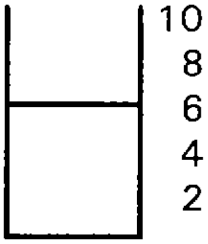
Here are drawings of two marbles, one made of steel and one made of glass. Both marbles have the same volume (that is, they the same size).

The steel marble is heavier than the glass one, but both marbles will sink if placed in one of the cylinders.
We are going to put one marble into each of the cylinders.

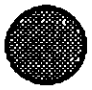
After we have put the glass marble into cylinder 1, both cylinders and their contents look like this:



cylinder 1



cylinder 2



If we now put the steel marble into cylinder 2, what will happen to the water level? Please tick your answer:

rises	falls	stays the same
☐	☐	☐

If it rises or falls,state the level: ☐

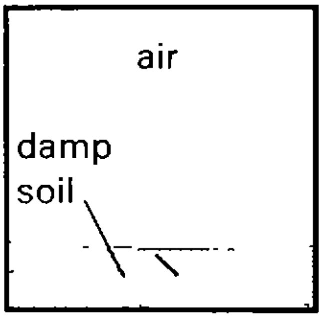
Explain why you predicted the above result:

Changes inside a terrarium

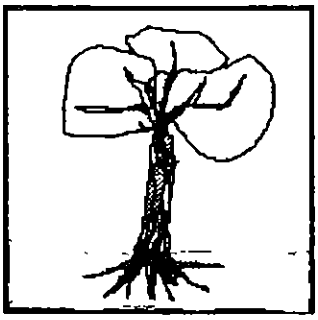
(source: Mitchell & Gunstone, 1984)

A very large glass box is constructed, soil added, and a seed planted and watered (Box 1). Three years later a tree has grown (Box 2). This tree is then cut down and burned (Box 3).

1



2



3

(a) By ticking in the appropriate box, give your opinion about **changes** in the box (increase, I; decrease, D; remain the same, S).

	I	D	S
* the total mass of the box:	☐	☐	☐
* the total number of atoms in the box:	☐	☐	☐
* the total number of molecules in the box:	☐	☐	☐

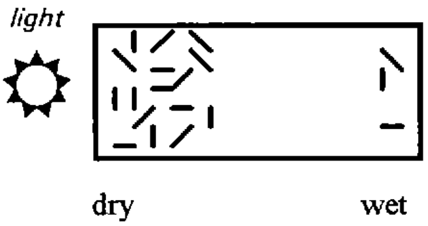
(b) Where did the atoms in the tree come from?

The Mealworm Puzzle

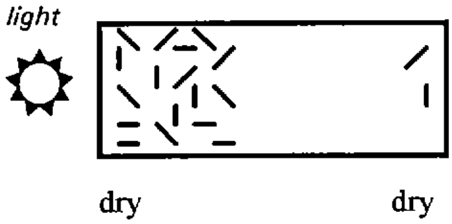
(source: Karplus et al, 1977)

A researcher wanted to test the response of mealworms to light and moisture. To do this she set up four boxes as shown in the diagrams below. She used lamps for light sources and constantly watered pieces of paper in the boxes for moisture. In the centre of each box she placed 20 mealworms. Twenty-four hours later she returned to count the mumber of mealworms that had crawled to the respective ends of the boxes.

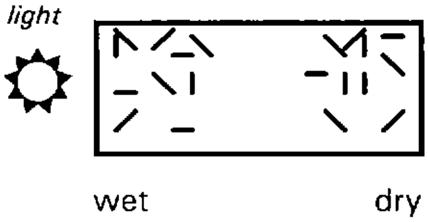
Box 1



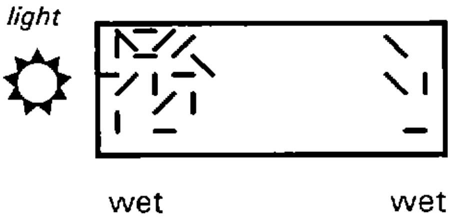
Box 2



Box 3



Box 4



In your opinion, what conclusion should the researcher make from these results? Please tick the box which seems the best conclusion.

The mealworms respond (move toward or away from):

(A) light but not moisture ☐

(B) moisture but not light ☐

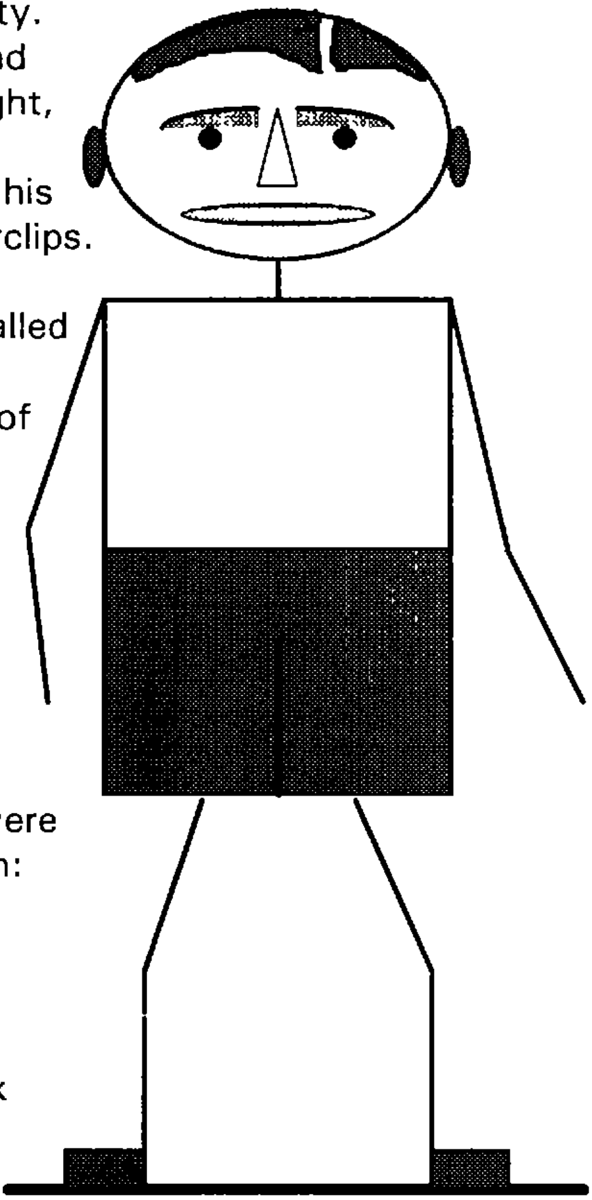
(C) both light and moisture ☐

(D) neither light or moisture ☐

Please explain your choice:

Shorty and Lofty

(adapted from Karplus et al, 1977)



The figure shown is called Shorty. We used large paperclips laid end to end to measure Shorty's height, starting from the floor between his feet and going to the top of his head. His height was **four** paperclips.

Then we took a similar figure called Lofty, and measured him in the same way, with the same kind of paperclips. Lofty was **six** paper clips high.

Now please do these things:

1 Measure Shorty's height using a convenient coin:
His height is:

2 Predict Lofty's height if he were measured with the same coin:

3 Explain how you worked out your prediction. Use the back of this sheet if you need more space:

Appendix 4.1b Pre-instruction Questions: Concepts 1 - 10

Question 1

The *density* of liquid water is very close to 1000 grams per litre.
Do you think that you understand the term *density*?
Please indicate (tick) yes (Y), no (N) or uncertain (U)

Y	N	U
☐	☐	☐

Consider the following statement.

The density of water vapour is about 500 grams per litre.

True, false or uncertain?

T	F	U
☐	☐	☐

Question 2

Air is a ***mixture,*** *water is a* ***compound.***

Do you believe that you have a good understanding of the terms *mixture* and *compound* ? Please tick yes (Y), no (N) or uncertain (U).

Y	N	U
☐	☐	☐

Please mark the boxes with the letter C (compound) or M (mixture) in the examples given below:

glass	sugar	baking soda	rubber	curry powder	wine
☐	☐	☐	☐	☐	☐

Question 3

Consider the following statements.

- ** Iris says that Table Salt, sodium chloride, is an* ***ionic*** *substance.*
- ** Mavis claims that it is a* ***molecular*** *substance.*

Who is correct? Please tick the box- I (Iris), M (Mavis) or U (if you are uncertain).

I	M	U
☐	☐	☐

Please tick the box for the most likely melting point of Table Salt, sodium chloride (given as Celsius degrees). Use U if you are uncertain.

-80^{0}	80^{0}	300^{0}	800^{0}	U
☐	☐	☐	☐	☐

Question 4

The word *base* has a number of meanings in daily life.
Do you think that you understand the meaning of the term *base* as it is used in chemistry?
Please tick one of the boxes Y (yes), N (no) or U (uncertain).

Y	N	U
☐	☐	☐

Please tick the substances below which you believe to be bases or have the properties of bases.

limestone	vinegar	table salt	"bicarb soda"	ammonia	table sugar	alcohol
☐	☐	☐	☐	☐	☐	☐

Question 5
The terms *reduce* and *reduction* have a number of meanings in daily life.

Do you think that you understand their chemical meaning? Please tick a box Y (yes), N (no) or U (uncertain).

T	F	U
☐	☐	☐

Consider the following chemical statement:

Hydrogen can reduce hot copper oxide to form steam and copper.

Please tick a box to show whether you think this is true (T) , false (F) or that you are uncertain (U).

T	F	U
☐	☐	☐

Question 6 follows:

Question 6

Do you feel confident about your skill in the use of indices (for example $5x10^{12}$) in arithmetic operations involving multiplication or division ?

Please tick Yes or No: Yes ☐ No ☐

Now attempt the following calculations:

*At supermarkets one can buy a **2kg** bag of table sugar. The bag itself has neglible volume and mass. If the sugar has a volume of **3 litres** and contains **$1x10^9$ granules,** answer the following questions. (You need not show your calculations unless you wish).*

1.How many bags are needed to have 12 kg of sugar?

2.How many bags are needed to provide $6x10^9$ granules?

3.How many granules are there in 7 bags of sugar?

4.How many granules occupy 1.5 litres?

5.What is the weight of $4x10^8$ granules?

6.Find the volume of $2x10^8$granules.

7.In 500 grams of sugar how many granules are there?

8.How much do 100 granules weigh?

Acknowledgement:

Gabel, D. & Sherwood, R.D. (1984). Journal of Research in Science Teaching 21(8) 843-851.

Question 7

In a chemical change the speed at which the reaction forms products is called the rate (R) of the reaction.
Often, when solids are involved, R *is proportional to* the surface area of the solid.
Do you feel that you understand the phrase *is proportional to* ?
Please tick a box.

Yes	No	Unsure
☐	☐	☐

In a study of a reaction in which R is proportional to the surface area (A) of a metallic reactant, a chemist did two experiments at the same temperature.The first had A = 100 units of area, and R was measured at 40 rate units.
In the second experiment, A was increased by 25 units of area.

What do you predict for the second value of R?
Please show your prediction in the box: ☐ rate units

Question 8

Here are some opinions from a discussion about metals and non-metals.

Arvo claims that coins are metallic. Darco insists that chlorine is a non-metal. Bruno thinks that copper is a metal, granite (rock) is non-metallic.
Ivo believes that brass is a metal, sulfur is a non-metal. Mirko says that both Bruno and Ivo are half right. Eduardo states that each is half wrong; in a chemical context they should be discussing the matter in terms of ***elements.***

What is your opinion about the following statements? Please indicate true (T), false(F)or uncertain (U).

	T	F	U
*copper is a metal	☐	☐	☐
*brass is a metal	☐	☐	☐
*brass is an element	☐	☐	☐
*pencils contain the metal lead.	☐	☐	☐
*granite is a non-metal	☐	☐	☐
*silicon is a non-metal	☐	☐	☐
*neon is a non-metal	☐	☐	☐
*iron ore is metallic	☐	☐	☐

Question 9

You may have heard of 'household bleach' or 'pool chlorine'. Each contains the same kind of compound of chlorine.The element *chlorine* is a member of the chemical family called *The Halogens*.
The elements *fluorine* and *iodine* are also members of this family.

Are you aware of some daily life uses or commercial applications of substances containing a halogen? Please tick: Yes ☐ No ☐

If you answered 'Yes', please indicate a use or application for the element or one of its compound(s) in the boxes below:

chlorine: ☐

fluorine: ☐

iodine: ☐

Question 10
Here are some daily life substances. Please try to complete the table.

substance	chemical name(s) of component(s)
petrol	
'bottled gas'	
petroleum jelly ('vaseline')	
kerosene	
lubricating oil	

In the box write one property which these substances share:

☐

Appendix 4.4.1.2 Two-tier Multiple-choice items

Concept-cluster 1: Density

Item 1

Under ordinary laboratory conditions, gaseous carbon dioxide has a density near 2 grams per litre.

Liquid carbon dioxide is likely to have a density of about

(1) 2.5 grams per litre
*(2) 2000 grams per litre
(3) 0.002 grams per litre
(4) 0.20 grams per litre

Reason

(A) In the gaseous state the molecules of carbon dioxide weigh less than those in the liquid state.

(B) One gram of liquid carbon dioxide is about one thousand times heavier than a gram of gaseous carbon dioxide.

(C) The much smaller volume of 2 grams of liquid carbon dioxide leads to a smaller density for the liquid.

*(D) In the gaseous state the molecules of carbon dioxide are much further apart than those in the liquid state.

Item 2

A rigid box containing only air at 20°C is firmly sealed. The temperature is raised to 100°C.

Which of the following properties of the air would experience an increase?
(1) viscosity and density
(2) average intermolecular distance
(3) cohesive forces and compressibility
*(4) average molecular velocity

Reason
*(A) increased molecular motion is indicated by increased temperature of the air.
(B) the increased pressure increases the density and thus the cohesive forces of the molecules.
(C) the molecules of air expand on heating, increasing the intermolecular forces and the compressibility.
(D) intermolecular distances increase with increasing energy of the molecules.

Concept-cluster2: Mixture/Compound

Item

The following data were reported by an accomplished chemist, Jules, after analysis of the contents of containers X and Y, both known to contain only the elements A and B either as a mixture or a compound.

analysis	**1**	**2**	**3**	**4**	**5**
%A in X	35.96	38.41	41.05	33.72	40.26
%B in X	64.04	61.59	58.95	66.28	59.74
%A in Y	36.40	36.38	36.41	36.36	36.39
%B in Y	63.60	63.52	63.59	63.64	63.61

Another person, Hector, claimed that Jules' data proved that the substance in Y was a compound of A and B.

Which of the following statements best represents your opinion of Hector's claim?
(1) Hector's claim is correct.
(2) Jules' data are good evidence for a compound in Y, but do not prove it to be so.
(3) The data could be proof of a pure compound if more precisely measured.

Reason:

(A) The Principle of Constant Composition is the only criterion which must be met to prove the presence of a compound.

(B) The presence of a compound is only indicated when the substance has properties different from those of the constituent elements. There is no evidence of this here.

(C) The proportions of the sample by weight must reflect a simple ratio of atoms of the elements in a compound.

(D) The virtually constant composition in Y may simply reflect a very uniform mixture.

Concept-cluster 3: Structure/Bonding

Item 1

Sodium chloride has a melting point of 801°C. The compound boron carbide, B_4C, has a melting point of 2350°C. B_4C is an electrical insulator above and below 2400°C

In the solid state B_4C is likely to be a
(1) metallic lattice
(2) covalent molecular substance
*(3) continuous covalent lattice
(4) continuous ionic lattice

Reasons:
(A) The high melting point and low conductivity indicates very strong bonding forces between the molecules of B_4C.
(B) The non-conductivity of B_4C is evidence that the molecules are strongly bonded to each other.
*(C) Non-conducting properties in the molten state prove that the bonding must be covalent in a continuous lattice of atoms.
(D) Since boron is present as B^{3+}, the ions present are unable to dissociate during melting.

Item 2

Which of the following diagrams best represents the position of the shared electron-pair in the HF molecule?

*(1) $\mathrm{H} \qquad :\overset{\cdot\cdot}{\underset{\cdot\cdot}{\mathrm{F}}}:$ (2) $\mathrm{H} \; : \; \overset{\cdot\cdot}{\underset{\cdot\cdot}{\mathrm{F}}}\,:$

Reason:

(A) Non-bonding electrons influence the position of the bonding (shared) electron-pair.

(B) Since hydrogen and fluorine form a covalent bond, the electron-pair must be centrally located.

*(C) Fluorine has a stronger attraction for the shared electron-pair.

(D) Fluorine is the larger of the two atoms and hence exerts greater control over the shared electron-pair.

Item 3

The commercially available substance 'Vaseline' has a thick, smooth, cream-like structure. On the basis of this information, 'Vaseline' would be classified as having

*(1) a covalent molecular structure
(2) a continuous covalent structure

Reason:

(A) The substance has a continuous linear lattice structure.

(B) The high viscosity of the substance results from the continuous covalent

*(C The molecules of the substance experience weak cohesive forces and can move easily to accommodate changes in shape .

(D) The bonds within the molecules of the substance break easily to accommodate changes in shape.

Item 4

A student wrote a series of statements about the elements of Groups I (one) to VII (seven) on the Periodic Table.

(a) In any Period the atomic radius increases with Atomic Number.

(b) In any Group the non metallic character of the elements increases with Atomic Number.

(c) The bonding between any Group I (one) element and any Group VII (seven) element is most likely to be ionic.

(d) In any Group the atom's attraction for electrons (electronegativity) increases with increasing core charge.

Which of the following statements are correct?

(1) (a) and (b)

*(2) (c)

(3) (b) and (d)

(4) (d)

Concept-cluster 4: Base/Salt
Item

Barium salts in solution are poisonous to human beings if swallowed.

A suspension of $BaSO_4$ is swallowed by patients about to undergo X-ray examination of their stomach/intestines. ($BaSO_4$ is opaque to X-rays). There are no ill effects; $BaSO_4$ is insoluble in stomach acids.

If $BaSO_4$ were in short supply, could $BaCO_3$ be safely used in its place?

(1) yes

*(2) no

(3) more information needed

Reason:

(A) Like $BaSO_4$, $BaCO_3$ passes through the digestive system unchanged and is excreted.

*(B) Unlike $BaSO_4$, $BaCO_3$ neutralises digestive acids to produce soluble barium salts.

(C) $BaCO_3$ is poisonous whether in solution or in solid form.

(D) $BaCl_2$ formed from $BaCO_3$ in the digestive tract is insoluble in water solution and is harmless to human beings.

(E) The solubility of $BaCO_3$ in acid needs to be known.

Concept-cluster 5: Redox

Item 1

In the reaction represented as

$$Fe_{(s)} + CuSO4_{(aq)} \rightarrow FeSO4_{(aq)} + Cu_{(s)}$$

The copper species is

(1) oxidised
*(2) reduced
(3) neither oxidised nor reduced
(4) a reducing agent

Reason

*(A) electrons are transferred from the iron atoms to copper ions
(B) iron atoms act as an oxidising agent
(C) copper sulfate loses oxygen atoms
(D) Electron-transfer cannot occur
(E) the oxidation number of copper increases.

Item 2

In the reaction

$$Cu_{(s)} + 2NO_3^- + 4H^+_{(aq)} \rightarrow Cu^{2+}_{(aq)} + 2NO_{2\,(aq)} + 4H_2O$$

the reducing agent is
(1) nitrate ions
*(2) copper atoms
(3) hydrogen ions

Reason

(A) nitrate ions have lost electrons
(B) nitrate ions have lost oxygen
*(C) the oxidation number of nitrogen has decreased algebraically
(D) hydrogen ions have gained electrons
(E) hydrogen ions have gained oxygen

Item 3

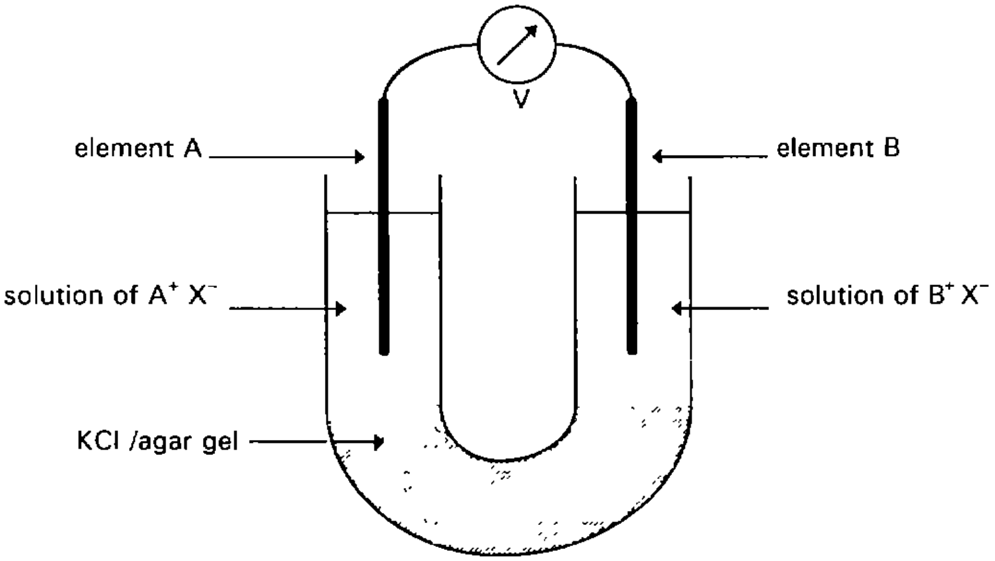


Figure 1

In Figure 1 the chemical change producing the current can be summarised as

*(1) $B + A^+ \rightarrow A + B^+$
(2) $B^+ + A \rightarrow A^+ + B$
(3) $A + B \rightarrow A^+ + B^+ + 2e^-$
(4) $A^+ + B^+ + 2e^- \rightarrow A + B$

Reason

The direction of the needle of the voltmeter shows that
(A) positive charges are lost by B^+
(B) electrons are moving in the external circuit from A to B
(C) X^- ions are moving through the KCl/agar from the B^+X^- arm to the A^+X^- arm.
*(D) A^+ is being reduced by electrons released by B atoms.

Item 4

In the reaction

$$CO_3^{2-} + 2H^+_{(aq)} \rightarrow CO_2 + H_2O$$

the element carbon is
(1) reduced
(2) oxidised
*(3) neither oxidised nor reduced

Reason

(A) carbonate ion loses oxygen
(B) carbonate ion loses electrons
*(C) the oxidation number of carbon does not change
(D) the oxidation number of carbon increases algebraically
(E) the oxidation number of carbon decreases algebraically

Item 5

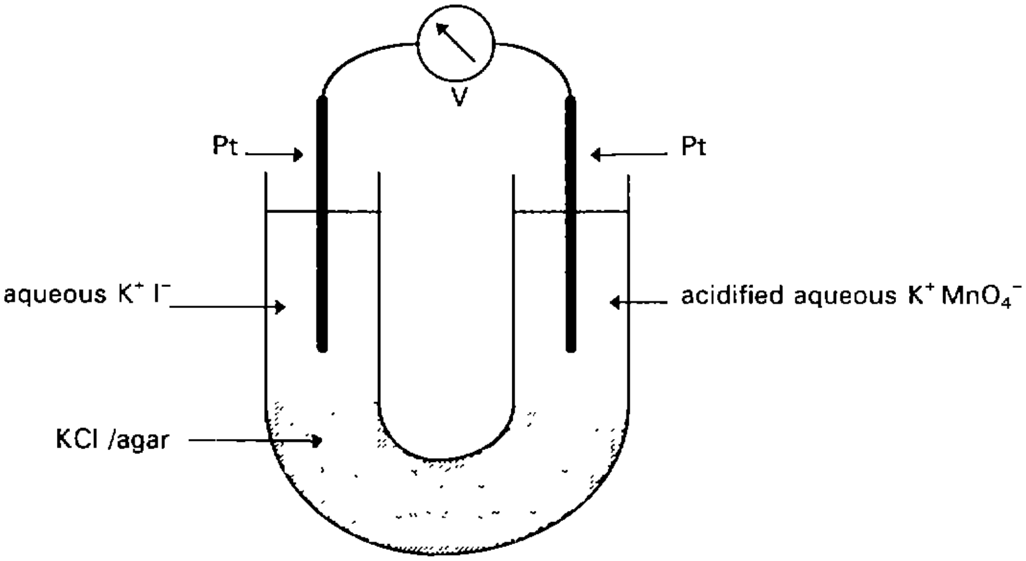


Figure 2

For the working cell (Figure 2), a student wrote four possible half-reactions:

(a) $2I^-_{(aq)} + 2e^- \rightarrow I_{2\,(s)}$

(b) $2I^-_{(aq)} \rightarrow I_{2\,(s)} + 2e^-$

(c) $MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 4H_2O + 5e^-$

(d) $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

The correct pair of half-reactions is

(1) a + c
(2) b + c
(3) a + d
*(4) b + d

Reason: In the external circuit

(A) positive charge is flowing from left to right
(B) electrons are flowing from right to left
*(C) electrons are flowing from left to right
(D) positive charge is flowing from right to left

Concept-cluster 6: *Mole*

Item

In Unit 6 of 'Introducing Chemistry' Joanna measured the temperature rise (ΔT^oC) in a series of 100mL mixtures of solutions of 1.0M Cu^{2+} and 2.0M OH^-. She called this Experiment 1. Here are her results.

mL Cu^{2+} (1.0M)	0	10	20	30	40	50	60	70	80	90	100
mL OH^- (2.0M)	100	90	80	70	60	50	40	30	20	10	0
$\Delta T(C^o)$	0	1.2	2.4	3.6	4.8	6.0	4.8	3.6	2.4	1.2	0

These results confirmed the formula $Cu(OH)_2$ for copper hydroxide and the reaction equation to be $Cu^{2+} + 2OH^- \rightarrow Cu(OH)_{2\,(s)}$.

Joanna plans to make a similar series of mixtures as Experiment 2, using 1.0M Cu^{2+} and **4.0M** OH^- solutions. (She wants to find the maximum value of ΔT and the number of mLs (V) of 4.0M OH^- in the mixture when this maximum occurs).

Which of the following sets of results should she expect in Experiment 2?

	ΔT (C^0)	V (mL)
(1)	3.0	50
(2)	12.0	50
*(3)	6.0	25
(4)	12.0	25

Reason:

In Experiment 2:

(A) At V = 50 the number of moles of $Cu(OH)_2$ formed is twice as many as at V = 50 in Experiment 1.

(B) At V = 50 the number of moles of $Cu(OH)_2$ formed is the same as at V = 50 in Experiment 1.

(C) The number of moles of $Cu(OH)_2$ formed is limited only by the number of moles of OH^-.

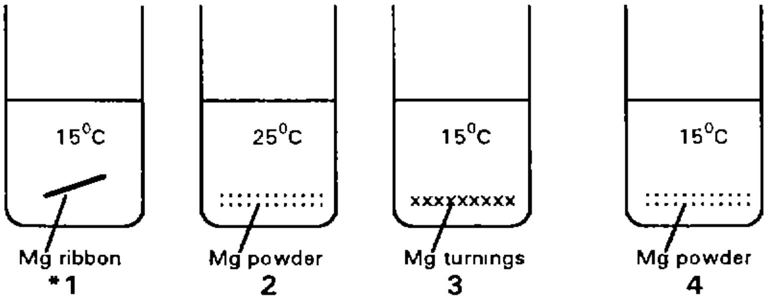
(D) At V = 25 the number of moles of $Cu(OH)_2$ formed is twice as many as at V = 50 in Experiment 1.

*(E) At V = 25 the number of moles of $Cu(OH)_2$ formed is the same as at V = 50 in Experiment 1.

Concept-cluster 7: Rate

Item 1

Masses of 1 gram of magnesium metal were reacted with hydrochloric acid (1.0 mol/L) under the conditions shown in the diagrams.



In which one of the beakers will the initial reaction rate be slowest?

Reason

A. Reactant collision frequencies are increased by a rise in temperature and decreased by greater surface area of solids.

B. Increased surface areas of solid decrease the chance of collision between reactants.

C. Lower temperatures reduce inter-molecular distances thus increasing the number of reactant collisions.

*D. Collision frequencies are increased by both increased surface area of solids and an increase in temperature of the reactants.

Item 2

A chemist studied the effects of two catalysts, P and Q upon the initial rate of the reaction

$$X + Y \rightarrow Z .$$

The rate was measured in five experiments under conditions starting as shown in the table.

Experiment number	[X] (mol/L)	[Y] (mol/L)	[P] (mol/L)	[Q] (mol/L)	Rate (mol/L/hr)
1	1.0	1.0	1.0	1.0	1.0
2	2.0	1.0	1.0	1.0	2.0
3	2.0	2.0	1.0	1.0	4.0
4	1.0	2.0	2.0	1.0	4.0
5	1.0	1.0	1.0	2.0	4.0

The catalyst with the largest influence upon the rate was

(1) P
*(2) Q
(3) P and Q equally
(4) not able to be deduced

Reason

A. The different concentrations of X and Y in experiments 1,2,3,4 prevent valid conclusions from being made.

B. Doubling [X] or [Y] has the same effect as doubling [P] or [Q].

*C. Doubling [Q] leads the quadrupling (four times) the rate of experiment 1.

D. Doubling either [P] or [Q] results in quadrupling (four times) the rate in experiment 1.

E. Doubling [P] leads the quadrupling (four times) the rate in experiment 1.

Acknowledgement: This item is based on Question 18, Application section of Beard, Fogliani, Owens & Wilson (1995). Multiple Choice Chemistry Questions. Senior Years 11 & 12 Vol 1. Australian National Chemistry Week.

Item 3

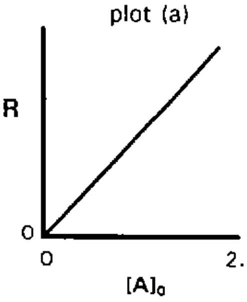
A chemist studied the decomposition of substance A in five experiments. The chemist was interested in the relationship between the initial rate (R), the rate coefficient (k) and the initial concentration, $[A]_0$. The following results were obtained, all other variables being kept constant.

Experiment number	1	2	3	4	5
$[A]_0$ (mmol/L)	0.5	1.0	1.5	2.0	2.5
R (mmol/L/h)	0.48	1.92	4.30	7.60	12.0

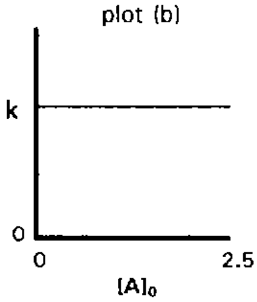
Which of the following plots (a), (b), (c), (d), (e) seem to be true statement(s) for the experiments?

(1)	(a) and (d)
(2)	(c) and (e)
(3)	(a)
(4)	(d)
*(5)	(b)

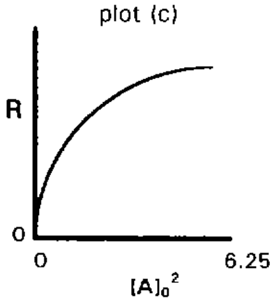
plot (a)



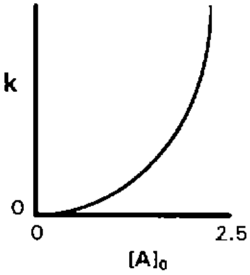
plot (b)



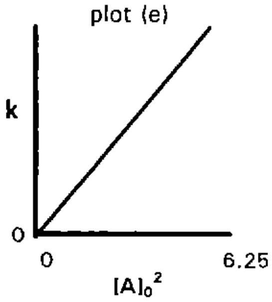
plot (c)



plot (d)



plot (e)



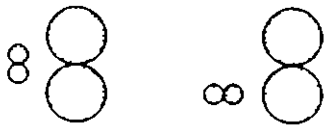
Reason

*A. k is independent of $[A]_0$
B. The reaction is first order in $[A]_0$
C. The reaction is not second order in $[A]_0$
D. k is proportional to the square of $[A]_0$
E. R is independent of the order in $[A]_0$.

Item 4

For the system $H_{2\,(g)} + I_{2\,(g)} \rightarrow 2HI_{\,(g)}$

- Figure 1 shows two possible orientations of the reactant molecules
- Figure 2 shows plots representing the fractions of the total molecules which have particular energies at two temperatures.



(a) **(b)**

Figure 1: Orientations of H_2 and I_2

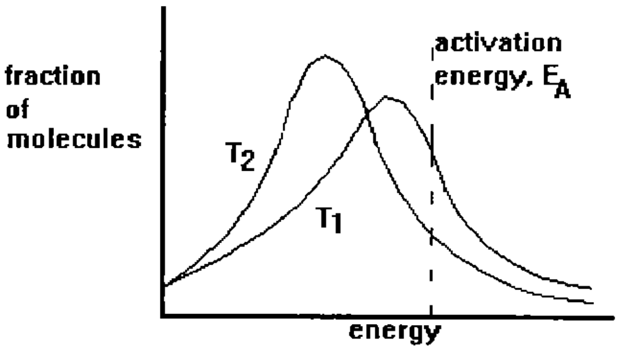


Figure 2: Energies of molecules at temperatures T_1 and T_2

Which combination of conditions is most likely to produce a reaction?

(1) T2 plus (a)
(2) T1 plus (b)
(3) T2 plus (b)
*(4) T1 plus (a)

Reason:

A. At T2, more molecular collisions exceed E_A ; (b) is a more favourable orientation for bond-breaking.
B. At T1, more molecular collision exceed E_A ; orientation (b) is more favourable for bond-making.
C. At T2, more molecular collisions exceed E_A ; orientation (a) is more favourable for bond-making and bond-breaking.

*D. At T1, more molecular collisions exceed E_A ; orientation (a) is more favourable for bond-making and bond-breaking.

Concept-cluster 8: Metal

Item

Consider the following statements about metals and the Periodic Table.

(a) In any Group the atom's attraction for electrons (electro-negativity) decreases with increasing Atomic Number.

(b) The bonding between any Group II (two) element and a halogen is likely to be covalent.

(c) In any Period the metallic character decreases with increasing Atomic Number.

(d) The most powerful oxidisers are to be found nearer the bottom of Groups I and II.

(e) Sodium, potassium and mercury are exceptional metals in that they are good electrical conductors.

Which of the following statements (or pairs of statements) is true?

(1) d+e

(2) c

*(3) a+c

(4) b

(5) a

Reason:

*(A) An atom's attraction for electrons is partly controlled by the size of the atom - Coulomb's Law indicates that the larger the atom the smaller will be its attraction for outer shell electrons.

(B) Across a Period the atoms' attraction for electrons decreases according to Coulomb's Law.

(C) In Periods and Groups electronegativity increases with increasing Atomic Number.

(D) Halogen atoms can achieve a stable octet by sharing electrons with metals to form covalent bonds.

(E) The most powerful oxidisers are the largest atoms because they can lose their electrons most readily.

Concept-cluster 9: Halogen

Item

Chlorine gas can be used to sterilise water. When chlorine is passed through the water it forms a mixture of hypochlorous acid and hydrochloric acid.

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$

The polar covalent compound iodine chloride (ICl, m.pt. 27°C) is well known. If it were used to sterilise water **would the most likely reaction be**

(1) $ICl + H_2O \rightarrow HOCl + H^+ + I^-$ or

•(2) $ICl + H_2O \rightarrow HOI + H^+ + Cl^-$?

Reason:

•(A) The bonds in both ICl and H_2O are polar. The δ+ charge on the I atom is attracted to the δ– charge on the O atom leading to the formation of an I—O bond and the breaking of O—H and I—Cl bonds.

(B) Iodine is lower in Group VII than chlorine and the I^- ion is therefore more stable than the Cl^- ion. Accordingly I^- forms together with HOCl and H^+.

(C) HOCl is a more stable molecule than the HOI molecule because the O—Cl bond is more polar than the O—I bond.

(D) Reaction 2 involves oxidation of the iodine species.

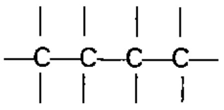
Concept-cluster 10: Hydrocarbon

Item

A test tube contains 100mmole of a hydrocarbon X whose formula is C_4H_6.
X does not react with ammoniacal cuprous chloride. When the tube of X is added to 100mmole of bromine (Br_2) as 'bromine water', the bromine is decolourised and a new substance Y is formed. Y, however, decolourises bromine water also. After addition of Y to another 100mmole of bromine water, the mixture is no longer able to decolourise it. A new substance, Z, is present.

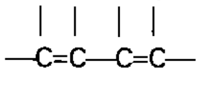
The more likely skeletonic structure of Z is

(1)



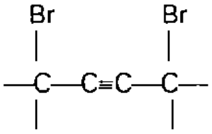
$$\begin{array}{ccccccccc} & & Br & & Br & & Br & & Br & \\ & & | & & | & & | & & | & \\ — & & C & — & C & — & C & — & C & — \\ & & | & & | & & | & & | & \end{array}$$

(2)



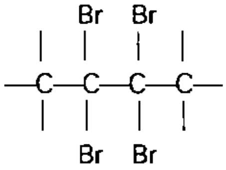
$$\begin{array}{ccccccccc} & & Br & & Br & & Br & & Br & \\ & & | & & | & & | & & | & \\ — & & C & = & C & — & C & = & C & — \end{array}$$

(3)



$$-\overset{\overset{\displaystyle Br}{|}}{\underset{|}{C}}-C\equiv C-\overset{\overset{\displaystyle Br}{|}}{\underset{|}{C}}-$$

(4)

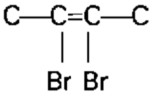


$$-\overset{|}{\underset{|}{C}}-\overset{\overset{\displaystyle Br}{|}}{\underset{\underset{\displaystyle Br}{|}}{C}}-\overset{\overset{\displaystyle Br}{|}}{\underset{\underset{\displaystyle Br}{|}}{C}}-\overset{|}{\underset{|}{C}}-$$

Reasons: (reasoning sequences)

(A)

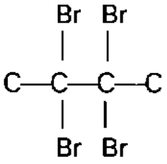
- The formula C_4H_6 is consistent with the family formula $C_nH_{(2n-2)}$ of the alkynes, which have one triple covalent bond per molecule. A possible carbon skeleton of this molecule is C—C≡C—C .
- Substance Y can form by adding one molecule of Br_2 across the triple bond to form



$$C-\underset{\underset{\displaystyle Br}{|}}{C}=\underset{\underset{\displaystyle Br}{|}}{C}-C$$

(skeletonic)

- Mixing with another 100mmol of bromine adds Br_2 across the double bond to give



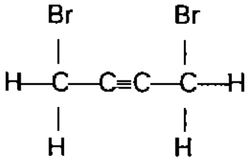
$$C-\overset{\overset{\displaystyle Br}{|}}{\underset{\underset{\displaystyle Br}{|}}{C}}-\overset{\overset{\displaystyle Br}{|}}{\underset{\underset{\displaystyle Br}{|}}{C}}-C$$

(skeletonic)

which is a likely structure of Z.

(B)

- In the first reaction, $C_4H_6 + Br_2 \rightarrow C_4H_5Br + HBr$, Y forms by substitution.
- The second reaction, $C_4H_5Br + Br_2 \rightarrow C_4H_4Br_2 + HBr$, is also a substitution reaction where $C_4H_4Br_2$ is Z, which has the structure



$$H-\overset{\overset{\displaystyle Br}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-C\equiv C-\overset{\overset{\displaystyle Br}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-H$$

consistent with C—C≡C—C (skeletonic) for X.

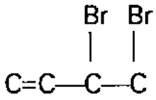
(C)

- Bromine is a good oxidising agent, having a strong attraction for the electron-rich double bonds in a possible C=C—C=C structure of X.
- Accordingly it forms four C—Br bonds by substituting one Br atom for an H atom on each atom of carbon, thus forming Z.

(D)

- The failure of X to react with ammoniacal cuprous chloride indicates that no triple bond is present. Perhaps there are two double bonds in each molecule of X. A possible carbon skeleton of X is C=C—C=C .

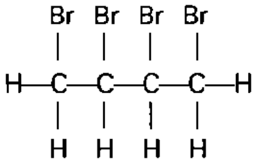
- Addition to 100mmol of bromine permits bromination of only one of the double bonds to form



$$\mathrm{C{=}C-\overset{\overset{Br}{|}}{C}-\overset{\overset{Br}{|}}{C}}$$

(skeletonic).

- Addition to a second portion of Br_2 brominates the other double bond forming



$$\mathrm{H-\underset{\underset{H}{|}}{\overset{\overset{Br}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{Br}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{Br}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{Br}{|}}{C}}-H}$$

end of appendix 4.4.1.2

****

Appendix 4.4.1.3: The Post-instruction Questions Parts A and B

Section One of the End-of-semester Examination paper

[*This section originally contained eleven questions. The eleventh question has been deleted here because it is irrelevant to the understanding of the ten concept-clusters, a focus of this research].

Explanation

This section contains eleven* questions, mainly with short answers. Part A of each question was asked at the beginning of the course. Please answer each Part A question again. The Part B question is an extension of Part A.

Question 1
Part A
The *density* of liquid water is very close to 1000 grams per litre.
Do you think that you understand the term *density*?
Please indicate yes (Y), no (N) or uncertain (U) .

Y ☐ N ☐ U ☐

Consider the following statement.
The density of water vapour is about 500 grams per litre.
True, false or uncertain?

T ☐ F ☐ U ☐

Part B
The density of ice is 0.92g/mL. What is the volume of 100grams of ice?
Calculation:

Volume: ☐

Question 2
Part A
Air is a *mixture,* water is a *compound.*

Do you believe that you have a good understanding of the terms *mixture* and *compound* ?
Please tick yes (Y), no (N) or uncertain (U).

Y ☐ N ☐ U ☐

Please mark the boxes with the letter C (compound) or M (mixture) in the examples given below:

glass	sugar	baking soda	rubber	curry powder	wine
☐	☐	☐	☐	☐	☐

Part B
A test tube contains 8.0 grams of iron powder and 4.0 grams of powdered sulfur, well mixed. When the test tube is heated, iron combines with sulfur, forming iron sulfide FeS.

$$\mathrm{Fe + S \rightarrow FeS}$$

No reactant or product escapes from the test tube and the reaction is as complete as the proportions of the mixture allow. The Relative Atomic Weights of Fe and S are 56 and 32 respectively.

Are the final contents of the test tube only FeS? If so, how much FeS is formed?

(working space:)

Answer:
FeS:

If not, what is the composition of the mixture?
(working space:)

→

Answers:

Fe:	S:	FeS:

Question 3

Part A

Consider the following statements.

- *Iris says that Table Salt, sodium chloride, is an ionic substance.*
- *Mavis claims that it is a **molecular** substance.*

Who is correct? Please tick the box - I (Iris), M (Mavis) or U (if you are uncertain).

I	M	U
☐	☐	☐

Please tick the box for the most likely melting point of Table Salt, sodium chloride (given as Celsius degrees).

-80°	80°	300°	800°	U
☐	☐	☐	☐	☐

Part B

The melting point of MgO is 2800°C. The radius of the metal species in MgO is 65pm (picometres).

Please tick a box to indicate the most likely value of each of these properties for BaO.

Melting point (°C)	100 ☐	4000 ☐	2000 ☐
Radius of Ba species (pm)	59 ☐	135 ☐	65 ☐

Question 4

Part A:

The word *base* has a number of meanings in daily life.

Do you think that you understand the meaning of the term *base* as it is used in chemistry?

Please tick one of the boxes Y (yes), N (no) or U (uncertain).

Y	N	U
☐	☐	☐

Please tick the substances below which you believe to be bases or have the properties of bases.

limestone	vinegar	table salt	"bicarb soda"	ammonia	table sugar	alcohol
☐	☐	☐	☐	☐	☐	☐

Part B:

State the formula of one of the bases in Part A: ☐

Include this formula in an equation representing a reaction in which a salt is formed:

☐

Question 5
Part A:

The terms *reduce* and *reduction* have a number of meanings in daily life.
Do you think that you understand their **chemical** meaning? Please tick a box Y (yes), N (no) or U (uncertain).

T ☐ F ☐ U ☐

Consider the following chemical statement:

Hydrogen can reduce hot copper oxide to form steam and copper.

Please tick a box to show whether you think this is true (T) , false (F) or that you are uncertain (U).

T ☐ F ☐ U ☐

Part B

At high temperatures carbon reacts with copper oxide to form carbon monoxide and metallic copper.

Please tick a box T (true) or F (false) in response to the following statements about this reaction:

- * Red hot carbon is a reducing agent — T ☐ F ☐
- * Copper gains electrons — T ☐ F ☐
- * The oxidation number of oxygen changes from -2 to +2 — T ☐ F ☐

Question 6
Part A:

Do you feel confident about your skill in the use of indices (for example $5x10^{12}$) in arithmetic operations involving multiplication or division ?
Please tick Yes or No:

Yes ☐ No ☐

Now attempt the following calculations:

*At supermarkets one can buy a **2kg** bag of table sugar. The bag itself has neglible volume and mass. If the sugar has a volume of **3 litres** and contains **$1x10^9$ granules**, answer the following questions. (You need not show your calculations unless you wish).*

1. How many bags are needed to have 12 kg of sugar?
2. How many bags are needed to provide $6x10^9$ granules?
3. How many granules are there in 7 bags of sugar?
4. How many granules occupy 1.5 litres?
5. What is the weight of $4x10^8$ granules?
6. Find the volume of $2x10^8$granules.
7. In 500 grams of sugar how many granules are there?
8. How much do 100 granules weigh?

Acknowledgement:
Gabel, D. & Sherwood, R.D. (1984). Journal of Research in Science Teaching 21(8) 843-851.

Part B
What is the weight (mass) in grams of 1.5×10^{21} molecules of SO_3 ?
(S = 32.0; O = 16.0)
(Working space:)

Answer: ☐

Question 7
Part A:
In a chemical change the speed at which the reaction forms products is called the rate (R) of the reaction.
Often, when solids are involved, R *is proportional to* the surface area of the solid.
Do you feel that you understand the phrase *is proportional to* ?
Please tick a box.

Yes	No	Unsure
☐	☐	☐

In a study of a reaction in which R is proportional to the surface area (A) of a metallic reactant, a chemist did two experiments at the same temperature.The first had A = 100 units of area, and R was measured at 40 rate units.
In the second experiment, A was increased by 25 units of area.

What do you predict for the second value of R?
Please show your prediction in the box: ☐

Part B:
In one kind of reaction, R is proportional to the concentration (C) of one of the reactants.
In a second kind of reaction, R is proportional to the **square** of the concentration (C^2) of one of the reactants.

In two experiments with this latter kind of reaction, the first experiment had C = 1 unit of concentration, that is, $C_1 = 1$. The second had C = 0.5 units of concentration, that is, $C_2 = 0.5$. The respective rates R_1 and R_2 were measured at the same temperature.

Tick the correct relationship between the rates R_1 and R_2 :

$R_2 = 2R_1$	$R_2 = 4R_1$	$R_2 = R_1/4$	$R_2 = R_1/2$
☐	☐	☐	☐

Question 8
Part A:
Here are some opinions from a discussion about **metals** and **non-metals.**

Arvo claims that coins are metallic. Darco insists that chlorine is a non-metal. Bruno thinks that copper is a metal, granite (rock) is non-metallic.
Ivo believes that brass is a metal, sulfur is a non-metal. Mirko says that both Bruno and Ivo are half right. Eduardo states that each is half wrong; in a chemical context they should be discussing the matter in terms of ***elements****.*

What is your opinion about the following statements? Please indicate true (T), false(F) or uncertain (U).

	T	F	U
• copper is a metal	☐	☐	☐
• brass is a metal	☐	☐	☐
• brass is an element	☐	☐	☐
• pencils contain the metal lead.	☐	☐	☐
• granite is a non-metal	☐	☐	☐
• silicon is a non-metal	☐	☐	☐

→

	T	F	U
* neon is a non-metal	☐	☐	☐
* iron ore is metallic	☐	☐	☐

Part B:
List five general physical properties of metals.
[five dot-point spaces here]

Name two metals which are exceptional in at least one of these properties.
[two dot-point spaces here]

Question 9
Part A:
You may have heard of 'household bleach' or 'pool chlorine'. Each contains the same kind of compound of chlorine.The element ***chlorine*** is a member of the chemical family called *The Halogens.*
The elements *fluorine* and *iodine* are also members of this family.

Are you aware of some daily life uses or commercial applications of substances containing a halogen? Please tick: Yes ☐ No ☐

If you answered 'Yes', please indicate a use or application for the element or one of its compound(s) in the boxes below:

chlorine:

fluorine:

iodine:

Part B:
Write down the formula of hypochlorous acid showing the oxidation number of the chlorine:

Write a balanced chemical equation for any reaction involving hypochlorous acid or the hypochlorite ion:

Question 10 follows:

Question 10
Part A:
Here are some daily life substances. Try to complete the table.

substance	**chemical name(s) of component(s)**
petrol	
'bottled gas'	
petroleum jelly ('vaseline')	
kerosene	
lubricating oil	

In the box write **one** property which these substances share:

Part B:
Name and draw a structural formula of the fourth member of the homologous series which has the general formula $C_nH_{(2n-2)}$:

Name:

Structural formula:

****

Appendix 4.4.2.4: The End-of-semester Questionnaire

UNIVERSITY OF SOUTH AUSTRALIA
FACULTY OF HEALTH AND BIOMEDICAL SCIENCES
SCHOOL OF CHEMICAL TECHNOLOGY

Applied Science and Engineering Bridging Program

UNIT 04143 INTRODUCTORY CHEMISTRY

Semester 2 1996

Student evaluation of the unit using a voluntary, anonymous questionnaire

Overview:

Your considered opinions and suggestions are sought in the following areas.

the context of the unit (the subject-matter)
particular aspects of the unit
learning and teaching
assessment
general comments

Your views are valued. They can assist in improving the unit for students in 1997 and beyond.
Please take time. *Thankyou. Glen Chittleborough (coordinator).*

A. Context: The practical units in *Introducing Chemistry*. Please make comments or suggestions for improvement. You might consider aspects like difficulty, presentation, interest, deletion, or usefulness.

Unit	Comments or suggestions for improvement in 1997
Introduction; Intro to microchemistry:	
1. Phys Props & KMTheory	
2. Chem change, Dalton & Atoms	
3. Bonding, Structure & Properties	
4. Acids,Bases & Salts 11. What's your problem?	
5. Introducing Redox Reactions	
6. Introducing the Mole	
7. How fast?	
8. Metals & Compounds of Metals	
9. Group VII - The Halogens	
10. Organic Chemistry	

Please use the opposite side of the paper if more space is needed. .../3

B. Particular aspects of the unit:

Aspect	Comments or suggestions for improvement in 1997
pre-labs:	
post-labs:	
constructivism:	
micro-scale labwork:	
thinking tasks:	
lab-work (in general):	
Film (KMT & Changes of State):	
Video (Structure & Bonding):	
The Periodic Table:	
Books • *Introducing Chemistry* • *Meeting Chemistry*	

Please use the opposite side of the paper if more space is needed. .../4

C. Learning and teaching:

1. What have been the 'pluses' and 'minuses' of the unit for the quality of your learning?

   Pluses:

   Minuses:

2. What have been the 'pluses' and 'minuses' of the teaching?

   Pluses:

   Minuses:

3. Please comment specifically on teaching in

   - **lectures:**

   - **tutorials:**

   - **labs:**

   - **informal situations:**

Please use the opposite side of the paper if more space is needed.

D. Assessment.: Please comment on assessment in

Pre-labs:

Labwork:

Test 1:

Test 2:

Test 3:

Final exam:

E. General

1. Your expectations of the course - were they fulfilled? If so, how? If not, what were they?

2. What were your objectives in doing the unit? Have they changed? If so how?

3. Please give a general comment on the unit:

Please use the opposite side of the paper if more space is needed.

4. Please grade the unit from an overall perspective. Place a cross (X) on the line below:

of no use very poor poor fair very fair OK good very good excellent

0 1 2 3 4 5 6 7 8 9 10

Thank you very much for taking time to give your comments.

Appendix 4.4.3: Interview Documents

* * *

Appendix 4.4.3a Interview for Case Study

Interview with student B.R. on 11/12/96 using a focus sheet.
Notes of significant points taken from repaginated transcript

pages **description**

1-8 **Bases & Salts:**

- Demanding, difficult to get whole thing.
- (in problem-solving at the bench) catalysis: liked copper forming when Mg added to acid containing some copper sulfate catalyst. Interesting, ... wonderful...sticks in the mind.. displacement concept appreciated... Enjoyed the labs..sometimes would like a demo...
- concept development ?
    - acid: confident
    - salt: very confident
    - base: less confident
- concept map (for salt)
    - got ideas locked in
    - tended to remember the picture:
        - drawing that line to that
    - having that picture of the boxes and arrows
    - it was an overall picture...worked quite well
    - it did make you think about the connections
    - was beneficial

10-11 **Asking Questions (in general)**

- marks in text 'ask Glen, ask Glen, ask Glen'.
- informal leader as questioner in class
- Lecturer's Question Box not used by students because of time and precision required to write Qn

12-18 **The Mole**

- particle aspect: analogy of an egg very successful [*1mole of eggs yields 1mole of yolks + 1mole of whites + 1mole of shells*]
- $m/M = N/N_A$ was easy - used with significance [not as an algorithm]
- logical - as I used it, whole notion became clear...able to help other people
- working with others clarified it together
- *[nonetheless messed up final exam Qn on SO_2 molecules]*

- lab work: liked titration.. took a while to get the mole ratio
- copper hydroxide experiment V-shape plot ??
- problem of finishing lab work ??

18-22 **Hydrocarbons**

- liked, enjoyed... logical ...nice formulas and they were progressive
- (less-than-successful practical synthesis)
- remembered (colour) changes with
    - bromine
    - permanganate
    - ammoniacal cuprous chloride
- also remembered the last because of difficulty in pronunciation
- demo of the ammoniacal cuprous chloride/acetylene ppt helped..hence..
- Visualisation (p21): realisation during the interview that she learns through visual stimulation - initially through recalling the sight of the copper displacement in the catalysis investigation (p.5, bases & salts) and then recalling the colour changes here. Also recalled visualising a table comparing alkanes, alkenes and alkynes.... 'I sort of picture things'.
- agreed that she is learning about her learning ..and has helped others with visual forms of explanation.
- appreciated everyday examples as interesting way of clarifying...possibly not enough in the course.

23-26 **Mixtures, Compounds (& Dalton's Atomic Theory)**

- felt need of a definition of element and mixture even before capable of understanding it.
- film on Kinetic Molecular Theory (KMT) used the picture (again realising her visile characteristic)..
- appreciated the analogy for the molecules of a liquid which was evaporating - bees flying off from other bees crawling over their honeycomb.
- Dalton - had difficulty linking the name with the ideas (which themselves seemed to have been understood).
- successful completion of the Fe/S/FeS problem in the final exam (test 4 no.2B)seem to indicate that the ideas of Dalton Theory were consolidated without linking his name to them - confirmed here by indicating understanding that the mole was linked with the problem.

27-58 **Teaching: opportunities for meaningful learning**

- The film on KMT: good - (caters for those who visualise)
    - linking the film to the prelab was good
    - analogies were good (as above)

- need a break in the multi-hour blocks of lectures/lab

- 'Chemistry in a plastic bag' *(solid sodium bicarbonate + solid calcium chloride in separate corners followed by addition of methyl red solution, sealing and some mixing)* student activity in lecture session was good for learning and remembering
    - involved acid-base
    - hot spot and cold spot in the one bag - a new experience... Q:now a *tactile* as well as a visile? "Yes. There you go , learning, learning, learning".

- lectures need lightening a bit - need everyday stuff dropping in occasionally. Highly intensive, yes, pretty overwhelming - some other students more so than me. [the reason was] partly that the content was difficult conceptually. Certainly there was too much . We just couldn't fit everything into your brain at once.

- tutes - were more relaxed ...I got a lot out of the tutes...clarifying, questions..examples ...that was very good, that clarified things.

- the lecture room..is not a wonderful room [during a long session - *it had no windows*]

- Q: Did you learn much in lectures? A: It's a mixture of everything....need an independent text....etc etc....(chemical) dictionary was handy...didn't use recommended list of references on reserve in library, nor library itself..(need to) have own book which you've got with you all the time. *'Meeting Chemistry'* useful some of the time...the table layout for Hydrocarbons was very good. *[Then follows a half para in which she lists the lect/lab/tut sequence in the timetable and how she used it effectively to learn and to deal with any lack of understanding... " a good progression" - bottom of p32 quotable?]* ... (problem was) having sufficient reading matter in the first place.

- pre-labs: a daunting task at first, then forming a learning partnership with another student led to learning "quite well" together...and that's when I started to get more out of pre-labs and get better at them. (page34 top) then follows a "lovely example of constructivism at work" (GC) one para, very quotable. In this context :

- choosing a learning partner: ("rather than having that person thrust upon you".,continued on pp.35, 36...mostly quotable....the right person ...an example of a wrong person (very negative). Barbara's learning partner's husband had remarked upon the helpful effect of Barbara's positive attitude upon her (Lea).."pulled her along when she might have got bogged down". .."it worked for her (Lea) in the end" [*pass grade in the unit*]. *See also 'laughed a lot at each other' during molecular model construction - p44-45.*
- Tests: worked in a formative way for her. But some students were concerned or despondent about effect of poor results on final marks. More worked test exemplars early on would have helped to prepare for the tests. ..Set a less demanding first test in order not to demoralise people . Also need explanation of key words like 'describe' and 'define'. Initially thought one or two words were adequate for 'describe'.

- 2TMC: The amount of reading (in the items) put students under pressure ....need more time than given....got better at them as I went along...tricky because of the infinitesimal differences between answers...touch and go...maybe in the early ones the differences need to be more clear-cut..the wrong ones more clearly wrong. Many students require back-of-the-book answers to exercises in *Meeting Chemistry* ...would have helped a lot.

- Question Box put out at lectures and tutes did not work because of the time delay in getting an answer. [*Sessions were Wed-Thur for her*].

- Informal / formal group discussions - useful...and I was getting asked a lot of questions later on in the lab.. we referred to each other in the lab like sometimes came up and said did you get so-and-so...didn't get this to work...show us.... at times people said can I come and work with you..that was fine. [*peer group suggestion didn't get taken up*]. She did get a lot out of dealing with at least one other person in her learning transactions...She agreed that she had learned something about her own learning.

- Molecular model-making (p.44-46) *[using toothpicks and styrofoam spheres]:* learned sulfur molecule's crown shape when working with a partner (Lea)... could remember the shape and the fun trying to actually construct the model...depends a bit on your partner too. When you've got that...same level of humour I suppose....laugh at yourselves which we did frequently. *[some problems with the toothpicks which often broke when inserted in the sphere].*

- Post-labs: a bit tedious getting near the end [of the unit]... a bit hard to find anything new to write...but it also got to the point where I just wanted to get out of the lab...lunch time *[and after 4h of contact]...* But first, yes I could ..make the links..

- Introducing Chemistry - good for lab and introducing theory. Layout OK . Structure of the book was fine. Thinking tasks: prelab: fine, easy .. lab: more difficult, pressure of time was a factor..did get you thinking...found easier as I went along...wherever you go you've got to learn the way of doing things...

- Q: A big course? got easier towards the end..(in contrast to physics)....not under-demanding. Ease students in a bit, as in the first lab...Lab safety precautions well explained.

- Q: Favourite lab? hydrocarbons, although halogens were quite interesting....the chemical activity of fluorine..the vigorous nature of it..... I did find the hydrocarbons interesting 'cause there were a lot of analogies with day-to-day stuff...funnily enough then when I look at my shampoo bottle and I see all those names and I think I know that's go something to do with that and I see it coming in and I use it.

- Redox: was quite interesting, it became clearer...a lot clearer, I've still some confusion betweem that and acid-base....I quite liked redox...was quite good. Q: What was good about it? A: (extended) probably quotable pp54-58, indicating the evolution of the redox concept from oxygen gain/loss to the use of Oxidation Numbers and the discarding of of the earlier ideas. "Redox was OK in the end. That came fine". "Progressive revelation you might say?". "Yes." "Lovely". "Yeah, so we slowly got there."

End of interview

Appendix 4.4.3b: Focus Sheet for the Interview

* *

04143 Introductory Chemistry

RESEARCH
about
THE LEARNING & TEACHING OF CONCEPTS

Unit	Concept cluster
1	DENSITY
2	MIXTURE/COMPOUND
3	STRUCTURE/BONDING
4	BASE/SALT
5	REDOX
6	MOLE
7	RATE
8	METAL
9	HALOGEN
10	HYDROCARBON

over

TEACHING: providing opportunities for meaningful learning.

These opportunities include

- video, film
- problem-solving
- laboratory activities - studying chemical systems
- pre-laboratory reports
- post-laboratory reports
- tutorial exercises
- feed-back on written tests, reports, exercises
- informal one-to-one chatting
- answering questions
- advice on learning styles
- formal lectures
- group discussions (2 or more people)
- written text and laboratory manual
- summaries and overviews
- Periodic Tables

MEANINGFUL LEARNING:

- Learning which involves **understanding**
- learning which can be used to **solve problems** in new settings

* *

Appendix 4.4.3c Interview: Three documents for students as required by the protocol of the Human Research Ethics Committee of the University of South Australia

Document 1

****

The University of South Australia
Faculty of Health and Biomedical Sciences
School of Chemical Technology

16/10/96

Addressee name

Dear *Addressee,*
Research in Teaching/Learning in 04143, *Introductory Chemistry*
This letter is about the possibility of the School of Chemical Technology receiving your voluntary assistance in some science education research in the above unit of the Applied Science & Engineering Bridging Course. The title of the research is *Student perceptions of the teaching/learning of concepts in 04143 Introductory Chemistry.*

Before the end of the semester I hope to interview 5-10 volunteers (each for about 1 hour) concerning their perceptions of the teaching and learning of chemical concepts. The principal objective of the research is to acquire a rich supply of data which can guide an improvement in the quality of teaching/learning in the unit in 1997 and later years. Volunteers will be selected for interview accordingly.

Participation is **entirely voluntary**. There will be **no advantage nor disadvantage** in participating. **You are guaranteed that there are no academic, personal or financial pressures to take part.** Further, in conducting this research as part of a doctoral program of another university I am required to approach the project in a strictly impersonal manner: I therefore assure you that **considered negative and positive responses are equally acceptable.**

You may, of course, **opt out at any time without any disadvantage whatever.**

I wish to assure you, too, that your opinions will be received in the **strictest confidence** and that **your identity will be protected at all times.**The Advice Sheet which accompanies this letter provides more information. Please read this and the Consent Form carefully before you decide to assist us. Discussion with another person may help your decision-making. If you need more information from me, I can be contacted at the Levels on telephone number (08) 3023723 (with voicemail).

I advise that the Head of the School of Chemical Technology, A/Prof Dennis Mulcahy, endorses this project.

I hope that you will consider this letter.

Cordially yours,

Glen Chittleborough
Senior Lecturer.

Appendix 4.4.3.c Document 2

****

The University of South Australia
Faculty of Health and Biomedical Sciences
School of Chemical Technology

Information for volunteers in a Science Education research project titled
Student perceptions of the teaching/learning of concepts in 04143 *Introductory Chemistry*

Researcher : Mr Glen Chittleborough , Tel: 8302-3723 (for specific enquiries)

(The Chair, Human Research Ethics Committee, Mr John Hepworth, Tel: (08) 83023965, Fax: (08) 8302-3737 is available for general enquiries about the research)

Dear *studentname*

In order to investigate the above topic I propose to conduct strictly confidential interviews of 5-10 volunteers from the class.The interviews will enquire about each student's perceptions of the development of 10 chemical concepts in the context of

- her/his own learning of the concepts
- the presentation the concepts (this includes teaching, books, tutorials, laboratory and related experiences).

The interviews will take 50-60 minutes and will be recorded on an audio tape. Later the tape will be audited by the researcher and some parts may be transcribed for further study. Transcriptions will be available for checking and retention by the volunteer. The identity of the volunteers will be known only to the researcher. Records of the interviews will be stored securely within the School for seven years.

Volunteers are free to leave the project at any time, without prejudice.

Taking part in the study will not provide students with any advantage or disadvantage in relation to their own academic results. However, the conclusions derived from a close study of the interviews will be used to improve the teaching/learning of the unit in 1997 and beyond. This is the principal objective of the research.

In any reporting of the outcomes of the interviews, either in Mr Chittleborough's doctoral thesis or in the research journals, names of interviewees will be replaced by pseudonyms or alternative initials.

Before taking part in an interview each volunteer will be asked to sign a Consent Form, a blank copy of which accompanies this sheet. Intending volunteers are invited to discuss the research with a relative or friend before signing the form.

This research is being conducted with the approval of the University's Human Research Ethics Committee. The research is also endorsed by the Head of the School of Chemical Technology. You are cordially invited to take part in it.

Volunteers are asked to send or take the Consent Form in an envelope marked
***"Intro Chem Research"** to* *The Secretary, School of Chemical Technology*
First Floor, North Wing, Chemical Technology Building
The Levels Campus, UniSA.

By Thursday 31st October 1996.

Thank you.

Glen Chittleborough
(Senior Lecturer).

Appendix 4.4.3c Document 3

****

The University of South Australia
Faculty of Health and Biomedical Sciences
School of Chemical Technology

Consent Form for the project
Student perceptions of the teaching /learning of concepts in 04143 *Introductory Chemistry*

Investigator: Mr Glen Chittleborough. Telephone: 8302-3723 (for specific enquiries)

Statement of consent by the subject (person to be interviewed)

1. I have read the Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
2. I understand that I may not directly benefit from taking part in the study.
3. I understand that while information gained during the study may published, I will not be identified and my personal results will remain confidential.
4. I understand that I can withdraw from the study at any stage and that this will not affect my status now or in the future.
5. I have had the opportunity to discuss taking part in this study with a family member or friend.
6. I confirm that I am over 18 years of age.

Name of subject
....

Signed..

Dated......................................

Statement by researcher:

I certify that I have explained the study to the volunteer subject and consider that he/she understands what is involved.

Signed..

Dated......................................

Appendix 6

Statistical Analysis:

Comparing students on the basis of Concept-learning Improvement Indices

Table A: Mean, standard deviation and sample size of Concept-learning Improvement Indices by Leaving Year: All Students

Group	N	Mean	Standard Deviation
Year 10	4	47.0	2.6
Year 11	7	46.0	18.5
Year 12	10	49.0	14.8
All Years	21	47.6	14.3

Table B: Analysis of variance of Concept-learning Improvement Indices by leaving year: All Students

Source	df	SS	MS	F	p
Year	2	44.7	22.3	0.099	0.906
Error	18	4029.6	223.9		
Total	20	4074.3			

Table C: Mean, standard deviation and sample size of Concept-learning Improvement Indices by leaving year: Elimination of students with "outside difficulties"

Group	N	Mean	Standard Deviation
Year 10	4	47.0	2.6
Year 11	4	59.0	12.1
Year 12	8	54.0	11.6
All Years	16	53.5	10.6

Table D: Analysis of variance of Concept-learning Improvement Indices by leaving year: Elimination of students with "outside difficulties"

Source	df	SS	MS	F	p
Year	2	294.37	147.1	1.37	0.288
Error	13	1395.5	107.3		
Total	15	1689.8			

continued →

Table E: Mean, standard deviation and sample size of Concept-learning Improvement Indices by level of thinking: All students

Level of Thinking	N	Mean	Standard Deviation
Proportional only	12	40.2	12.6
Logical & Proportional	8	59.3	9.0
All students	20	47.8	14.6

Table F: Analysis of variance of Concept-learning Improvement Indices by level of thinking: All students

Source	df	SS	MS	F	p
Level of Thinking	1	1748.0	1748.0	13.54	0.002
Error	18	2323.2	129.1		
Total	19	4071.2			

Table G: Mean, standard deviation and sample size of Concept-learning Improvement Indices by level of thinking: Elimination of students with "outside difficulties"

Level of Thinking	N	Mean	Standard Deviation
Proportional only	7	48.3	10.1
Logical & Proportional	8	59.3	9.0
All students	15	54.1	10.6

Table H: Analysis of variance of Concept-learning Improvement Indices by level of thinking: All students

Source	df	SS	MS	F	p
Level of Thinking	1	448.0	448.8	4.95	0.044
Error	13	1178.9	90.7		
Total	14	1627.7			

Appendix 7: Summary of Results
04143 Introductory Chemistry - Semester 2 1996

Short assessm't:	1	2	3	Total→	Scaled	Exam	Lab	Total	%	Grade
I.D.	Max: 24	22	32	78 →	30	90	55	175	100	
1 MAb	5	0.5	12	17.5	6.7	20	33.5	60.2	34	F2
2 MAr	6	5.5	12.5	21.5	8.3	27.5	46.0	81.8	46	F1
3 CB	14	13	19	46	17.7	43.5	51.4	112.6	64	P1
4 AC	7	8	13	28	10.8	50	41.8	102.6	58	P1
5 BE	15.5	14.5	25.5	55.5	21.3	72.5	52.6	146.4	83	D
6 PF	17.5	14.5	15.5	47.5	18.3	61.5	43.0	122.8	70	C
7 JG	11.5	8.5	12.5	32.5	12.5	44	50.7	107.2	61	P1
8 VG	10	8	14	32	12.3	47	49.5	109.8	62	P1
9 CG	2.5	mc#	10	12.5#	6.7#	20	43.1	69.8	39	F2
10 MG	11.5	6.5	17.5	35.5	13.7	65	51.6	131.3	75	D
11 NH	10.5	10	24	44.5	17.1	45.5	33.6	96.2	55	P1
12 M-NI	3.5	5.5	14	23	8.8	33	45.3	87.1	50	P2
13 EK	13	8.5	14	35.5	13.7	56.5	45.4	102.6	58	P1
14 TK	19.5	14.5	21	55	21.2	67.5	47.5	136.2	77	D
15 SL	17.5	9.5	14.5	41.5	16.0	52.5	47.3	115.8	65	C
16 GM	8	3.5	10	21.5	8.3	43.5	44.4	96.2	54	P2
17 LN	8.5	8	18	34.5	13.3	52.5	52.3	118.1	67	C
18 BR	13	16	21	50	19.2	61.5	53.1	133.8	76	D
19 AR	7	2	9.5	18.5	7.1	58	42.9	108.0	61	P1
20 JV	13	17.5	21.5	52	20.0	68.5	50.6	139.1	79	D
21 SW	13	6	18	37	14.2	39	50.4	103.6	59	P1

Key:

mc: medical certificate. # averaging of marks applied.

Distribution of Grades

HD	0
D	5
C	3
P1	8
P2	2
F1	1
F2	2
Total	21

Appendix 8: Responses to the End-of-semester Questionnaire

Student evaluation of the course through the End-of-semester Questionnaire is presented here as summaries of entries (where possible) in the respective items of the document. The presentation follows the format of the five main sections of the Questionnaire.

- Section A - Context: the units in *Introducing Chemistry*
- Section B - Particular aspects of the course
- Section C - Learning and Teaching
- Section D - Assessment
- Section E - General

The number of respondents actually making a comment on an item is shown in parenthesis next to the relevant heading. The researcher's comment or summary follows, where applicable. In some items, where quotations from the scripts are presented, upper case letters (A, B,..L), are used to identify the script.

Summary of twelve responses to the End-of-semester Questionnaire

A. Context: The units in *Introducing Chemistry.*

Please make comments or suggestions for improvement. You might consider aspects like difficulty, presentation, interest, deletion, or usefulness.

> Notes by the researcher:
> There were, on average, only 4 respondents per item in this section. Some of the comments offered in this section were also made during the semester and are already reported in the discussion of the Post-laboratory Reviews (Section 8.2). Accordingly they will be omitted here unless qualified in some way. One respondent made an identical comment for all of the twelve headings below, indicating that all were "good" and related to the topic, but some were long and "daunting when rushed" leading to an effect on results. These comments can be taken into account when considering the following responses.

Comments or suggestions for improvement in 1997

Introduction; Introduction to micro- chemistry (2):
"OK"

Unit 1 - Physical Properties & Kinetic MolecularTheory (3)
One respondent felt that the film *The States of Matter* should be scrapped and replaced by hand-outs summarising the analogies in the book.

Unit 2 - Chemical Change, Dalton & Atoms (5)
Most respondents were satisfied. One wanted more historical material, another queried the value of an historical treatment.

Unit 3. Bonding, Structure & Properties (3)
"OK"

Unit 4 - Acids, Bases & Salts (3)
"OK"

Unit 11 - What's your problem? Acids, Bases & Salts (context) (7)
Five positive comments. Two respondents assessed the Challenges as difficult.

Unit 5 - Introducing Redox Reactions (5)
Two respondents still have difficulty in understanding. Others satisfied.

Unit 6 - Introducing the Mole (4)
No dissatisfied respondents.

Unit 7 - How fast? (4)
Two respondents were satisfied, two had difficulty, one suggested, "Perhaps [the unit] assumes too much with regard to graph interpretation".

Unit 8 - Metals & Compounds of Metals (4)
No difficulties reported. One respondent claimed, "Perfect. Very easy to understand"

Unit 9 - Group VII - The Halogens (4)
One respondent suggested that more time be allocated to the unit. Another wanted some macro- rather than micro-chemistry experiments.

Unit 10 - Organic Chemistry (4)
Two respondents asked for more allocated time. One needed more explanation about systematic nomenclature.

B. Particular aspects of the course

Comments or suggestions for improvement in 1997
pre-labs: (8)
General agreement that these are a very helpful aspect of the course.

post-labs: (9)
Only a few could see the usefulness of post-labs. Some felt that the addition of a requirement to answer the lab thinking tasks or extra problems had merit. Others felt the need of more time to answer. Many saw themselves repeating the same responses in different weeks.

constructivism: (5)
Mixed responses, two positive. One respondent expressly not interested in theories of learning. Another felt that group work needed a better mix of student experience.

micro-scale labwork: (4)
General positive agreement. One respondent, "Mostly good fun." Another thought demonstrations were more apt on some occasions.

thinking tasks: (2)
Both respondents : "Good." One appreciated their occasional difficulty.

lab-work (in general): (7)
Two respondents wanted more exciting reactions (more flames & explosions).
Some want more time, others wanted a shorter session. More frequent marking was wanted by one respondent, to make *others* more serious about the work. One found it good fun and helpful.

Film (*The States of Matter*): (6)
Mixed responses , mainly positive, but two thought it outdated.

The Periodic Table: (4)
General agreement: "very useful".
B: Realised complete importance of the Periodic Table for chemistry.
D:Very useful for other subjects & future chemistry.

Books:
Introducing Chemistry (10)
General approval. Specific comments were mostly more extensive and constructive than earlier ones. Some relevant comments were:
A: Some chapters need more content (redox, acid-base & organic) instead of passing off to "Meeting Chem".
B: Good for elementary understanding.
D: Very well structured & clear to understand.
G: Both [books] helpful although I used the book by Chang more.
H: Too much shared material between the two books...
J: Not enough questions to practice.
K: Some of the material is interesting and could be expanded, eg, who were the people? A bit of history could go a long way.

Meeting Chemistry *(9)*
General approval as a complement to *Introducing Chemistry*. Valued for summaries and extra examples.
L commented: Also a bit of optional background on subjects covered could be good as well...possibly a chapter on how it ties together.

C. Learning and teaching:

1. What have been the 'pluses' and 'minuses' of the unit for the quality of your learning?
The range of responses is diverse:

Pluses: (8)
A: Prelabs...Quite useful as a week-to-week topic-to-topic guide to progress. Excellent for revision.
B: gained more chemistry knowledge.
C: All the way through this I thought I would fail.
D: In preparation for the essay section of the exam I have learned a lot & the quality of this learning is high.
H: Labs very useful, self-paced learning useful
I: development of working with a partner.
J: have "Meeting Chemistry" to refer to.
L: Good - relearnt a lot of what I forgot since Year 12.

Minuses: (8)

A:"Intro Chem" could have been a bit more helpful in a number of chapters.

B: I found it hard to motivate myself, especially after the mid-semester break. [Apparently this was a student enrolled for remedial purposes, as required by another faculty]

D: Sometimes the quality [of teaching] was too good. [Add same comment] as [2.] minuses below.

I: Too much, too soon.

J: not quite enough basic understanding material in 'Introducing Chemistry'.

K: ...it takes time to come to grips with the equations, everything else was easy to undertstand.

L: Sometimes moved too slow.

2. What have been the 'pluses' and 'minuses' of the teaching?

Pluses: (6)

A: Prelabs and course structure.

B. gained more chemistry knowledge.

D: Answers are always thorough & helpful to relate to other topics or examples.

E: Not always answering the asked question.

G: Lectures and pracs were very helpful.

H: Relearned a lot.

Minuses: (8)

A: Sometimes intimidatory teaching style, some lack of flexibility (structure good though, perhaps just a little more laid back approach [needed]).

C: Please encourage students

D: Sometimes the topic at hand was gone over too many times & became monotonous. This could have been due, however, to the varying experiences & learning capabilities of the students.

H: Lack of answers to questions (exercises) in books. The only time that you knew what you were doing was right was in seeing (briefly) results of tests & results in prelabs.

I: Not interactive enough

J: Some sections still remain unclear even with it explained to me many times.

L: Sometimes taught at lowest common denominator. Possibly outside help for certain students rather than holding the whole class up.

3. Please comment specifically on teaching in

lectures: (9)

A: Not bad. Good back up to "Intro. Chem"

B: OK

C: Please encourage students

D: Very helpful, especially examples & reviews of "Meeting Chemistry'

E: Quite good; only course is in depth

G: Good

H: Perhaps more interaction during lectures - gets a bit monotonous.

K: Demos in lectures are good. It ties in with what the lecturer is talking about.

L: Good

tutorials: (9)

A: Better than lectures. Able to take more time.

B: Good.

C: More flexible, instead of teacher up front

D: Sometimes helpful. Questions were always answered thoroughly & questions [were] asked to students to provoke thought.

E: fair.

G: good.

I: helpful to clear [up] lab problems etc

labs: (7)

A: Good but sometimes impatient - also JM (lab tutor)

B: Sometimes felt scared to answer questions because I didn't understand it.

E,G,L: good

J: very helpful for each unit.

informal situations: (3)

A: Okay. Sometimes intimidatory to other students. You stand too close to other students and because you are taller than most people you look down on them. You need to give people a bit more space and appear more open (uncross arms).

B: V.Good

E: good

D. Assessment.: Please comment on assessment in

Pre-labs: (7)

A high degree of general approval, but two respondents were concerned about inconsistency of the marking.

Labwork (5)
General approval, but some felt that this work should have attracted more marks.

Test 1: (7)
Generally thought to be fair, but the two-tier tests raised comment.

B: I couldn't seem to get the 2-tier multiple-choice questions. Probably a combination of not much motivation to study. I felt like I understood the units, but found the questions very hard.
D: Good. Two-tiers were OK once I got used to them.
F: Not enough time to think.
J: it was a bit hard to get used to the two tier multiple choice.

Test 2: (6)
Little criticism except lack of time to think for Respondent F

Test 3: (6)
Regarded as fair, but Respondent F again needed time to think

Final exam: (5)
Comments were quite positive and typifiedby comments in Scripts A,B,D, and L:
A: generous time. Not too bad at all.
B: Much better than the 3 tests...
D: Good. The essay system was useful to enable students to display knowledge rather than just guess in multi choice.
L: fair, good range of .

E. General

1. Your expectations of the course - were they fulfilled? If so, how? If not, what were they? (10)

Many expectations were indeed fulfilled, or partially so, in gaining chemical knowledge. One respondent found disappointment in finding irrelevant content, such as "Dalton's stuff", in the course. In Script "I", another respondent, apparently anticipating a less-than-satisfactory result, wrote, "I used to do very well in chemistry. This is not so now." There is further comment on this script in Section 8.3.1.

2. What were your objectives in doing the unit? Have they changed? If so how? (7)

Stated objectives were either to simply gain more chemical knowledge of to get sufficiently high marks to get into a baccalaureate course. In some cases the original objective of obtaining a Pass with Distinction was reduced during the course to obtaining a simple Pass.

3. Please give a general comment on the course: (7)
All responses obtained for this item are quoted in full. Most are positive statements.

A: Good structure, good assessment & content. Perhaps personal style needs a bit of work but otherwise okay.
D: This unit [course] was useful to learn the basics of chemistry and also the basics behind how to learn. The pracs & lectures were well integrated & the tutes very useful.
E: Difficult, but teaching was not too bad, which helped.
G: In general the unit was well presented and conducted.
H: I felt that greater feedback was required throughout the course - to know what you are doing is right. Perhaps answers to exercises [in books]?
J: I found it much better than the Year 12 chemistry I did in 1995.
K: It's a good introduction and achieves its goals well.

Item 4 follows →

4. Please grade the unit from an overall perspective. Place a cross (X) on the line below: (11)

(In the interests of clarity, the continuum line has been omitted for each respondent and the awarded X placed in a corresponding space between, or in place of, the numerals of the scale. Script C did not have a grading).

of no use very poor poor fair very fair OK good very good excellent

A	0	1	2	3	4	5	6	7		X	9	10
B	0	1	2	3	4	5	6	X		8	9	10
D	0	1	2	3	4	5	6	7	X	8	9	10
E	0	1	2	3	4	5	6	7 X		8	9	10
F	0	1	2	3	4	5	6	X		8	9	10
G	0	1	2	3	4	5	6	7 X		8	9	10
H	0	1	2	3	4	5	X	7		8	9	10
I	0	1	2	3	X	5	6	7		8	9	10
J	0	1	2	3	4	5	6	7	X	8	9	10
K	0	1	2	3	4	5	6	7		X8	9	10
L	0	1	2	3	4	5	6	7	X	8	9	10

(The mean of the numerical values was 7.0)

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