QUESTIONING FOR APPROPRIATE ASSESSMENT AND LEARNING

By

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Authors Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Masters of Science (CHPM2) is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Dedication

This thesis is dedicated to my family; parents, Ben and Kathleen McCrudden, sisters, Emma and Claire and brother, Matthew.

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Abstract

Assessment methods/formats have come to the forefront of issues concerning educationalists in the last few decades as they began to question established methods. These questions were mainly concerned with the understanding that was being assessed of students and what results were telling educators about the way in which their students were engaging with chemistry material. All assessment formats have been grouped essentially into two types: summative and formative assessment. Summative assessment is concerned with an end of term/module assessment which examines students understanding of information/concepts covered during the course of a topic. This provides teachers/lecturers with a grade to award students based on a single examination.

This study has investigated three forms of assessment: the summative assessment employed at Leaving Certificate level for Chemistry and the formative assessment methods used in two chemistry modules in Dublin City University. This study is divided into four separate chapters, dealing with the aforementioned studies conducted and a the first chapter dealing with comprehensive literature review on assessment formats, question styles and technology employed in this study.

For the second chapter analysis was performed on the current Leaving Certificate Chemistry Curriculum (implemented in 2000, first examined in 2002) and the examinations completed by students at Higher Level since 2000. One method of analysis performed utilised Blooms Taxonomy to identify the level of questioning used at Leaving Certificate Level. Results have shown that the majority percentage of questions employed at Higher Level are of the lower order identified by Bloom, with little or no questions of the higher orders, such as analysis, synthesis and evaluation questions being identified. Further analysis performed have shown that there is a lack of assessment of students understanding of some core/sub topics, while others are over assessed, in comparison to the number of classes allocated to them in the Chemistry curriculum.

The third chapter has investigated the implementation of a continuous assessment element into a physical chemistry module for second year undergraduate chemistry students. This study employed the use of an electronic assessment tool to encourage student engagement with lecture material. Results have shown that the continuous assessment element has successfully identified problem areas in chemical kinetics and thermodynamics which requires more focus and explanation on the part of the lecturer. Results have shown

that students displayed a lack of engagement with lecture material and also student surveys have supported these findings. Data has shown however that students enjoyed the use of these electronic assessment tools and began to take a more active role in their learning towards the end of the module as they used the CA elements in their revision for the end of module examination.

The fourth and final chapter deals with the formative assessment introduced into a practical laboratory session through the use of pre and post laboratory tasks for first year undergraduate chemistry students. In this study a VLE was used to host a series of pre laboratory quizzes and post laboratory activities which aimed to help encourage engagement with laboratory material out of the practical session. The pre laboratory quizzes were designed to help prepare students for their practical session. The post laboratory questions were designed to assess students' understanding through the application and analysis of concepts covered within the practical session. Results have shown that the use of pre and post laboratory sessions has engaged students outside of the practical session and that students feel readily prepared for their practical upon completion of the pre - laboratory quiz. However students displayed a lack of engagement with chemical concepts in the majority of the completed chemistry laboratories and have admitted to finding the post - laboratory questions employed particularly challenging. Those laboratories which did show an increase in student engagement with chemical concepts, have displayed a large degree of linkage between the elements of the concept questioned on both pre and post laboratory tasks.

This study has highlighted that regardless of the assessment method employed at either second or third level, the information that is provided by formative assessment can be appropriately utilised to ensure that students engage with chemical content. The most important conclusion which has been made in relation to all of the assessments analysed is the importance of appropriate question use. In order to assess student understanding of a chemical concept or completion of learning outcomes/objectives, educators must ensure that the questions employed are challenging but doable for all students, no matter what their chemical background and that the information provided by student attempts will help to identify problem areas for the entire cohort of students.

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Chapter 1

Assessment – an overview

Assessment

The term assessment is often interlinked or confused with evaluation. Assessment is understood as the collection of data about a learner's understanding while evaluation is the passing of judgment on the learner's understanding based on the data collected through assessment[1]. Evaluation is a necessary part of the educational process but appropriate evaluation requires good assessment strategies and tools. It has been highlighted that further work is required on the evaluation of the accuracy and precision of data collected through assessment is required[1]. While the reliability and validity of education assessments can be established through statistical analysis[2], the purpose of assessment is to collect high quality data about students' competency in an area. This leads to the inevitable question "what are the educators trying to assess?"

Assessment when appropriately used can provide information to[3]:

- Students, about the extent of their learning and possibilities for success in future courses;
- Teachers, about the extent to which their teaching practices are facilitating student learning, and how they might make modifications to those practices;
- Administrations and other stakeholders, about course design, program effectiveness and what students are able to do as they complete a program.

While a great deal of discussion has occurred concerning what content should be taught and how this content should be taught[4], it is only in the recent decade that the area of assessing what we are assessing has come to the forefront.

One of the recommendations made by Bodner et al.[5] stated that "the methods we use for assessing our students and our teaching must change so that it no longer focuses on the lowest levels of learning and must provide us with the insight into our methods and our tools that we need to drive change."

Assessment has now moved to the heart of considerations of teaching and learning and is back, centre-stage and is of widespread interest and concern[6]. It is impossible to ignore assessment issues as they can aid or inhibit our endeavors in improving teaching and learning. Learning is often concerned with elements of input and output. While inputs include teachers, students and others involved in education along with rules, curricula, syllabi, standards and points/grade requirements, the outputs of successful learning are satisfied and fulfilled students, better test results and content teachers. It is also expected that students will be more knowledgeable about the studied topic and it is through assessment that a students' understanding is ascertained.

Assessment generally drives learning. It is essential that the correct assessment is selected for each individual circumstance as poorly designed or badly constructed assessment can have a more detrimental effect on a student than the teaching employed during the completion of a course/module[7]. If assessment methods are not employed effectively good learning will not be promoted, and also a concern has been raised that some grading methods used promote unhealthy competition within class groups rather than personal development. During the construction and development of assessment, educators need to ensure that they keep in mind the purpose of their assessment and what information the assessment will provide them with.

While Black and Wiliam[7] defined assessment broadly to include all activities which educators and students undertake to obtain information that can be used diagnostically to alter teaching and learning, it was Scriven[8] who made the distinction between formative and summative assessment methods.

Assessment is an integral part of effective learning whereby students are provided with comments on their progress[9]. However, this is not a characteristic of summative assessment. Summative assessment encompasses any assessments occurring after the learning has taken place, such as end-of-year examinations or projects that are graded to make a judgement about the extent and quality of learning that has been demonstrated[10].

Summative assessment has been distinctly associated with determining the extent to which a student has achieved a curricular objective[11]. Summative assessment does not allow reflective practice on the part of either the educator or the student. The student cannot assess how well their study practices have succeeded for them, while the teachers cannot determine how well their teaching methodologies employed have engaged their students[11].

The characteristics of summative assessment [12] are that it:

- Takes place at certain intervals when achievement has to be reported;
- Relates to progression in learning against state or national curricula;
- Allows for the results of different pupils to be compared for various purposes because they are based on the same criteria;
- Requires methods which are as reliable as possible without endangering validity;
- Involves some quality assurance procedures;
- Should be made on evidence from the full range of performance relevant to the criteria being used.

The summative assessment format employed at both Leaving Certificate in Ireland and at A-level in the UK provides information to potential future employers and also to third level establishments as to the grade a candidate achieved in this summative assessment[13]. However this form of assessment, in contrast to the last point made by Harlen and James[13] above, provides no distinction between students' strengths and weaknesses in a given subject but rather their performance or overall grade for a select amount of content.

Formative assessment, however, encompasses teacher observation, classroom discussion and analysis of student work including assignments and tests. While summative assessment provides information at the end of a term or year of study as to a student's performance on a limited section of content, assessment becomes formative when the information is used to adapt teaching and learning to meet students' needs when applied at a number of stages or at the end of a topic.

Formative assessment is effective in virtually all educational settings, content areas, knowledge and skill types, and levels of education[14]. The research conducted by Black and Wiliam[7] indicated that grades and marks do not deliver as much formative information to a student as do tailored comments and in some situations can be counterproductive, particularly with learners of lower ability. This is a very interesting finding as the majority of student assessments are graded and students may look to their grade only rather than focussing on the comments.

Formative assessment helps to support the expectation that all students can learn to high levels and counteracts the cycle in which students attribute poor performance to lack of ability and therefore become discouraged and unwilling to invest in further learning[15]. It is a form of assessment that supports students in their learning. Black and Wiliam[7] also encourage educators to use questioning and classroom discussion as an opportunity to increase their students' knowledge and improve understanding. They caution that educators need to make sure to ask thoughtful, reflective questions rather than simple factual ones and then give their students adequate time to respond[7]. They suggest strategies such as:

- Inviting students to discuss their thinking about a question or topic in pairs or small groups, then ask a representative to share the thinking with the larger groups;
- Presenting several possible answers to a question and ask students to vote on them;
- Asking all students to write down an answer then read a select few out loud.

Formative assessment is essentially feedback both to the educator and the student about present understanding and skill development in order to determine the way forward. Assessment for this purpose is part of teaching and learning: learning with understanding depends on it.

Formative assessments are always made in relation to where students are in their learning in terms of specific content or skills[14]. The justification for this is that the individual circumstances must be taken into account if the assessment is to help learning and to encourage the learner.

The characteristics of formative assessment[16] include:

- Positive in intent – it is directed towards promoting learning;
- Takes into account the progress of each individual, the effort put in and other aspects of learning which may be unspecified in the curriculum;
- Takes into account several instances in which certain skills and ideas are used and there will be inconsistencies as well as patterns in behaviour; with formative assessment "errors" provide diagnostic information;
- Validity and usefulness are paramount in formative assessment and should take priority over concerns for reliability;
- Formative assessment requires that students have a central part as they are required to be active in their own learning.

The basis of formative assessment is that if students don't come to understand their strengths and weaknesses and how to deal with them, they will not make progress;

Tests and assignments can be used formatively if teachers analyse where students are in their learning and provide specific, focused feedback regarding performance and ways to improve it. For example, there is now a lot of literature on areas of chemistry that students find difficult and even the misconceptions that students have of particular concepts, both at 2nd and 3rd level. Suitable assessments focussing on these areas of potential misconception or difficulty could be of immense benefit to the student learner and teacher alike.

Black and Wiliam make the following recommendations[7] for good use of formative assessment:

- Frequent short tests are better than infrequent long ones;
- New learning should be tested within about a week of first exposure;
- Be mindful of the quality of test items and work with other teachers and outside sources to collect good ones.

As stated earlier, feedback on assessment is crucial if a student is to benefit from it. Feedback usually consists of reporting right or wrong answers to the students, where a

teacher tells a student if something is correct or incorrect. This form of feedback can be automated though objective testing and a key to responses for students.
However if the feedback is set to be more informative there are various types that may be employed such as the written form or oral statements which can be interpreted by students.

Educators sometimes take for granted that providing feedback to the learner about performance will lead to self-assessment and improvement. Feedback must be expressed by the teacher in language that is already known and understood by the learner[15]. Students must be informed as to how feedback should be interpreted and how to make connections between their work and their feedback. It cannot be assumed that when students are “given feedback” that they will know what to do with it.

As assessment is used to drive learning and also as a measure of learning, it is important to have a good understanding of how particular assessments are constructed and conducted. In this study, different assessments are analysed to determine the efficiency of each assessment for its stated purpose along with relevant literature in these areas.

In Chapter 2, the Leaving Certificate examination in Chemistry is analysed in relation to the stated aims and objectives of the curriculum. This is important as, as stated earlier, assessment can drive learning, so if the assessment questions are related closely to the aims and objectives, then the curriculum is successful. Detailed analysis of examination questions that have appeared on the past nine years of Leaving Certificate examinations is given in Chapter 2.

At 3rd level, much of the current assessment is summative. Difficulties with the inclusion of formative assessment methodologies are often due to large numbers of students, marking of extensive examinations, transmission of grades from pen/paper to electronic methods etc. In Chapter 3, the use of technology in the form of Personal Assessment Devices (PADs) has been investigated with a focus on the development of appropriate questions for formative assessment.

Within the subject area of chemistry, laboratory work is considered to be of great importance. However, assessment of laboratory work is often reduced to marking of the end of experiment/end of module laboratory reports. Again from the viewpoint of formative assessment, this type of assessment has its flaws as it does not take account of a students' prior knowledge, of their laboratory skills and it gives little scope for students to reflect on the completion of their own work. Therefore in Chapter 4 we have included a form of formative assessment in 1st year undergraduate chemistry laboratories in order to assess both students' prior and basic knowledge of chemistry before laboratory completion and also their understanding of the concepts covered in each of the laboratory sessions in a post laboratory task.

In both of these situations of formative assessment, it was hoped that by the use of these formative assessment processes that it would encourage student engagement with lecture material and help to promote independent learning.

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Chapter 2

Leaving Certificate Chemistry – Analysis of examinations in relation to the curriculum

2.1 Introduction

The Leaving Certificate Chemistry Examination is performed by Leaving Certificate students of ages 17 to 18 years old, following two years of study. Students are expected to have acquired, during the course of their studies, an understanding of core chemical topics which will be assessed during their examination and to have fulfilled a series of stated curriculum objectives.

In this Chapter, the Leaving Certificate examination in Chemistry is analysed in relation to the stated aims and objectives of the curriculum. This is important as, as stated earlier, assessment can drive learning, so if the assessment questions are related closely to the aims and objectives, then the curriculum is successful. However, if the examination questions are not closely aligned to the stated aims and objectives of the curriculum, then there is a serious mismatch between the curriculum and the assessment. As the Leaving Certificate is a summative assessment, any mismatch can have a detrimental effect on standards achieved.

2.1.1 Established Leaving Certificate Chemistry Examination

In Ireland, chemistry is taught in the first three years of secondary education as part of a science course for the Junior Certificate (ages 13-15). The curriculum consists of a core component composed almost equally of Physics, Chemistry and Biology, and extensions, of which Chemistry is one (other extensions are Biology, Physics and Applied Science). The course is offered at both higher and ordinary levels.

At the senior cycle (ages 16-17), the Leaving Certificate is a two year course, and students take seven subjects at the Leaving Certificate summative examination at the end of the two years of study. Chemistry is one of five separate science subjects offered again at higher and ordinary levels.

In response to the falling number of students opting to take chemistry for Leaving Certificate, the curriculum was changed in 1983 to try to promote this perceived "difficult" science among Leaving Certificate students. These changes included an increase in employment of practical work and a greater emphasis on the applications of Chemistry than the curriculum which preceded it. While the changes implemented in this revised curriculum had the desired effect of increasing demand for the subject, this rise in demand only lasted until 1987[1]. The years following showed a steady fall in the numbers taking Leaving Certificate Chemistry (as seen in Figure 2.1), unlike the other major science subjects, Physics and Biology. The fall was seen to be even more alarming, because the fall in numbers taking Chemistry took place at a time when the total number of students taking Leaving Certificate had generally been rising[2]. In recent years (Figure 2.2) a similar trend has been evident in relation to the three science topics offered at Leaving Certificate Level in Ireland.

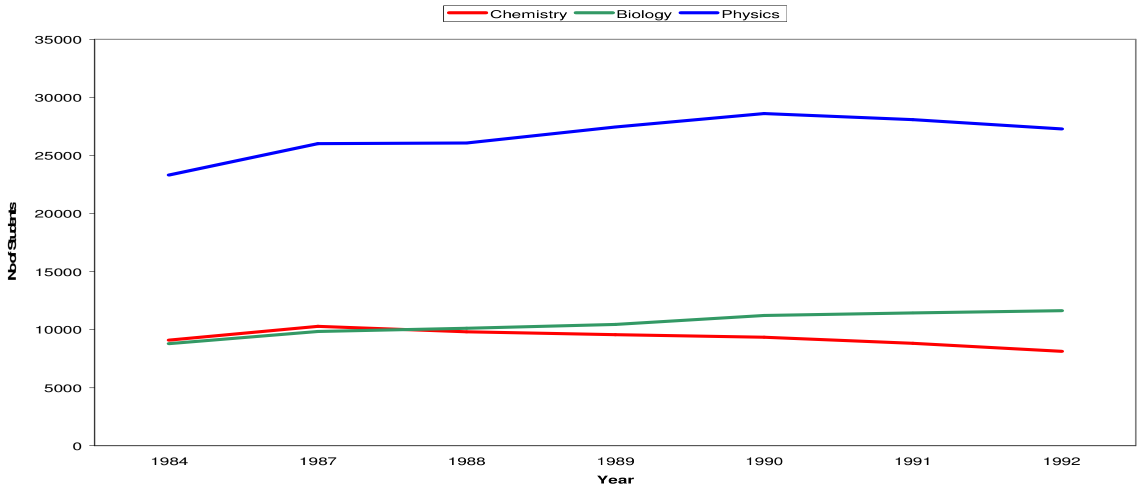

Figure 2.1 – Number of students taking science subjects 1984 – 1992
(Taken from ref 2)

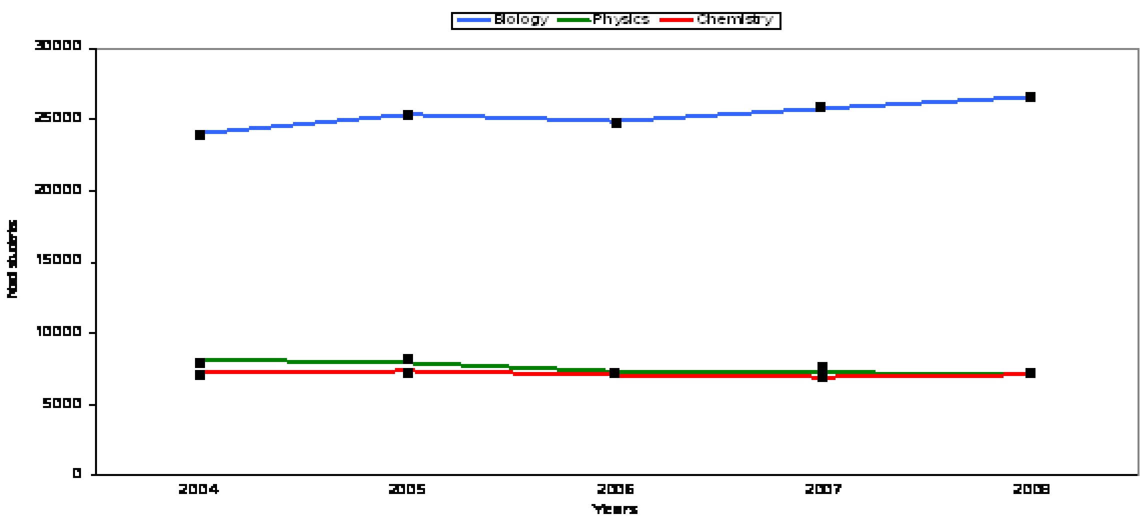

Figure 2.2 – Number of students taking science subjects 2004 – 2008
(data from www.examinations.ie)

The development of the current Leaving Certificate curriculum began in February 1992, with recommendations from the Department of Education and Science that science in the senior cycle should reflect the changing needs of students and the recognition of the growing significance of science for strategic development in Ireland[3].

The changes in comparison to the 1983 curriculum included[4]:

- An expanded curriculum, rather than the outline curriculum provided in 1983;
- Differently presented material with a new four column arrangement, see Figure 2.3 below;
- Division of the curriculum into two separate sections – higher level and ordinary level (the 1983 curriculum presented both syllabi in one document);
- Alteration of several of the section headings in the 1983 curriculum with a consequent rearrangement of the content;
- Elimination of some content of the curriculum;
- Restriction of the number of mandatory experiments to 28;
- Greater emphasis on social and applied aspects.

1. PERIODIC TABLE AND ATOMIC STRUCTURE			
Content	Depth of Treatment	Activities	Social and Applied Aspects
1.1 Periodic Table (Time needed: 3 class periods)	Elements. Symbols of elements 1–36.		History of the idea of elements, including the contributions of the Greeks, Boyle, Davy and Moseley.
	The periodic table as a list of elements arranged so as to demonstrate trends in their physical and chemical properties.	Arranging elements in order of relative atomic mass; note differences compared with the modern periodic table.	History of the periodic table, including the contributions of **Dobereiner**, **Newlands**, Mendeleev and **Moseley**. Comparison of Mendeleev's table with the modern periodic table.

Figure 2.3 Example of revised curriculum lay out (those in bold are on HL only)

The current Leaving Certificate Chemistry Curriculum was implemented in 2000 with its first examination in 2002[4] and was designed to incorporate the following components:

- Science for the enquiring mind, or pure science, to include the principles, procedures and concepts of the subject as well as its cultural and historical aspects (70%);
- Science for action, or the applications of science, and its interface with technology (22.5%);
- Science which is concerned with issues – political, social and economic – of concern to citizens (7.5%).

There is 30% of the new syllabus devoted to social and applied aspects, which is one of the major changes to the revised curriculum combining the two areas ‘Science for Action’ and ‘Science which deals with issues of concern for students’. A study conducted in 2006 examined the inclusion of the social and applied aspects. This study[5] investigated the implementation of the Science, Technology and Society (STS) of the revised Chemistry curriculum. This study revealed that this new inclusion in the revised 2000 curriculum was not adequately reflected in either state examinations or textbooks. This study also revealed that while the NCCA had stipulated that STS should have a 30% weighting in the curriculum there was inadequate coverage in both the examination papers and textbooks in relation to the STS inclusion.

Along with the aforementioned changes to the layout and content of the 1983 curriculum, the 2000 curriculum has also revised its aims[4]:

- To stimulate and sustain students' interest in, and enjoyment of, chemistry;
- To provide a relevant course for those students who will complete their study of chemistry at this level;
- To provide a foundation course in chemistry for those students who will continue their studies in chemistry or in related subjects;
- To encourage an appreciation of the scientific, social, economic, environmental and technological aspects of chemistry and an understanding of the historical development of chemistry;
- To illustrate generally how humanity has benefited from the study and practice of chemistry;
- To develop an appreciation of scientific method and rational thought;
- To develop skills in laboratory procedures and techniques, carried out with due regard for safety, together with the ability to assess the uses and limitations of these procedures;
- To develop skills of observation, analysis, evaluation, communication and problem solving.

The 2000 curriculum also provided five core objectives as seen in Figure 2.4 for the Higher Level Chemistry Course.

Higher Level Syllabus Objectives

The objectives of the syllabus are:

1. Knowledge

Students should have a knowledge of

- basic chemical terminology, facts, principles and methods
- scientific theories and their limitations
- social, historical, environmental, technological and economic aspects of chemistry.

2. Understanding

Students should understand

- how chemistry relates to everyday life
- scientific information in verbal, graphical and mathematical form
- basic chemical principles
- how chemical problems can be solved
- how the scientific method applies to chemistry.

3. Skills

Students should be able to

- follow instructions given in a suitable form
- perform experiments safely and co-operatively
- select and manipulate suitable apparatus to perform specified tasks
- make accurate observations and measurements
- interpret experimental data and assess the accuracy of experimental results.

4. Competence

Students should be able to

- translate scientific information in verbal, graphical and mathematical form
- organise chemical ideas and statements and write clearly about chemical concepts and theories
- report experimental procedures and results in a concise, accurate and comprehensible manner
- explain both familiar and unfamiliar phenomena by applying known laws and principles
- use chemical facts and principles to make chemical predictions
- perform simple chemical calculations
- identify public issues and misconceptions relating to chemistry and analyse them critically.

5. Attitudes

Students should appreciate

- advances in chemistry and their influence on our lives
- that the understanding of chemistry contributes to the social and economic development of society
- the range of vocational opportunities that use chemistry, and how chemists work.

Figure 2.4 – Stated objectives of the 2000 Higher Level Chemistry Curriculum

The guidelines for the assessment implemented to examine students' completion of the objectives outlined in the curriculum states that "the curriculum will be assessed in relation to its objectives. All material within the curriculum is examinable. Practical work is an integral part of the study of chemistry; it will initially be assessed through the medium of the written examination paper."[4]

Still to date, eight years since the implementation of the 2000 curriculum, the only method that has been employed by the Department of Science and Education to assess students' skills and competence of practical laboratory work is through written examination. It must be stated that this is currently under revision as it has been recognised that this is not the best means of ascertaining students' practical competence.

Written assessment may take many formats, however the type of questions asked in an examination will guide the learning by the student. Assessment drives learning[6], whether summative or formative. Therefore in this study, we wished to determine if the questions asked in the summative Leaving Certificate Chemistry paper are of the lower – order type requiring mainly recall and memorisation to answer them or are of the higher – order (synthesis and evaluation) type where students could show their level of knowledge of the broad area of chemistry. Also, analysis has been carried out to ascertain how successfully the stated objectives in Figure 2.4 have been assessed in the examination.

2.1.2 Use of Bloom's Taxonomy

Any assessment implemented during the course of a module or school year aims to provide feedback to teachers, students, future employers and/or colleges/universities about the abilities that a student possess in order to fulfil a role or an employed position within society[6].

In order to ascertain the level of thinking that students have accomplished during the course of their education, Bloom's Taxonomy has been applied as a schematic which provides educators with one method of classifying this[7]. This hierarchical framework consists of six categories indentified below which can be applied to an examination to test the skills which students possess or to identify the level of question which students can answer, Figure 2.5.

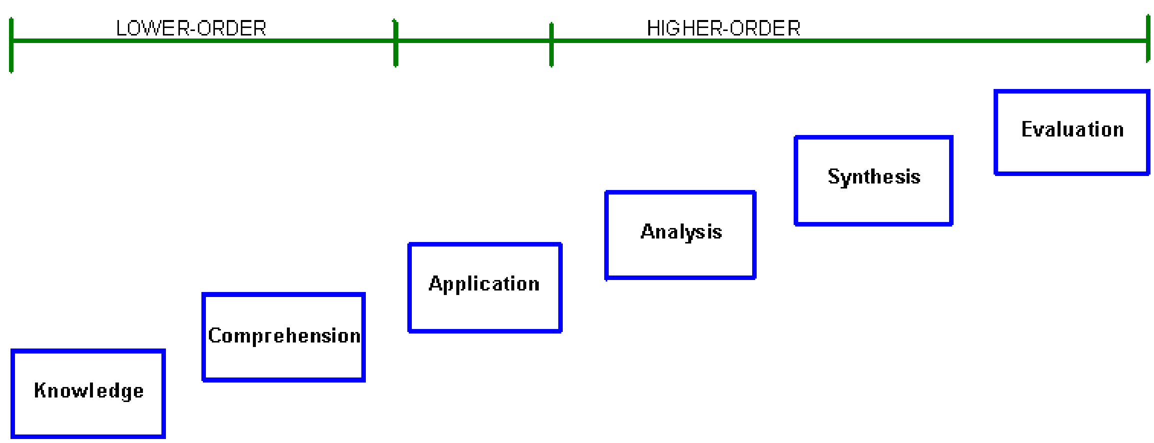

Figure 2.5 – Schematic of Bloom's Taxonomy

Bloom categorises cognitive objectives into six areas of increasing complexity and higher learning skills. These categories can be used to identify the level of questioning employed and thus the type of skill a student must possess in order to correctly answer this question.

The most basic level of Bloom's' categories is **knowledge** which requires recall or the ability to simply state a fact without any real need to understand what it means e.g. definitions in chemistry. **Comprehension** is where students are tested to see if they can go beyond stating simple facts and display that they understand what they are being assessed on.

Application is where students use their accumulated knowledge of concepts to solve problems on an analytical basis. These three questioning types are grouped together as lower order questions. These question types have tended to be the dominate form of examination questions as they are easy to set, answer and grade[8].

The three types of higher order questions require more critical thinking and skill by the examination setter, student and marker. **Analysis** seeks to see if students break down a complex idea into its basic components, evaluate them critically and formulate an answer. **Synthesis** involves the student making predictions or seeking links between different ideas and concepts. The final level of objective identified by Bloom is **evaluation** where the students are required to make judgments about the quality of ideas or problem solutions. It often seeks to see if students can give rational opinions or assessments on controversies that can be justified by concrete evidence or factual information they have accumulated.

Bloom's taxonomy has been applied in a number of educational situations including applications represented by articles and websites describing corrosion training and medical preparation[9]. In almost all circumstances when an instructor wishes to move a group of students through a learning process utilising the organised framework Bloom's taxonomy has proven useful[10].

In one particular application[11], Bloom's taxonomy was used to plan and deliver an integrated English and history course. This taxonomy provided teachers with a new outlook on assessment and enabled them to create assignments and projects that required students to operate at more complex levels of thinking. Another application of Bloom's taxonomy allowed researchers to investigate the different types of questions emphasised in various school curricula[5] and in traditional nationally implemented curricula[12] such as that examined in this study.

Bloom's taxonomy has also been applied to the assessment of students' practical skills in the Leaving Certificate Chemistry course in Ireland. This study[8] determined that the questions employed to assess students' practical skills showed only a very limited number of areas were examined and at the lower level of Bloom's Taxonomy.

However Bloom's taxonomy is one of eleven classification systems which include those proposed by Rosenshine, Dunkin and Biddle and Taba, Gallagher and Carner (as discussed by Gall[13]). It was proposed in the late sixties and also received criticism based on its limitations[13]. Gall states that "if a researcher is interested in more detailed descriptions asked in a specific context, application of Bloom, Gallagher and Carner do not provide this detail."

Some of the limitations suggested by Gall include a cross over of the questioning terms that are used to identify each of the cognitive levels. Due to this cross over some questions can be open in interpretation to each educator which allows for some subjectivity when categorising examination questions. It was suggested that this flaw would cause differences in opinions as to which category certain questions belong to, which could lead to problems when comparing results from different educators or studies.

Despite the limitations as stated by Gall above, it was decided that as a comparison / diagnostic tool, the use of Bloom's Taxonomy for this study was appropriate.
Bloom's six categories of learning skills have been applied to nine years of Leaving Certificate Higher Level Chemistry examination papers in order to identify the level of questioning that has been employed during this summative examination and therefore the level of thinking that is demanded of students completing these examinations.

2.2 Methodology

Analysis on the higher level chemistry papers has been performed in three sections

- Identification of question types using Bloom's taxonomy;
- Determination of the % of each questions type on the examination paper and the corresponding % of marks for each question type;
- Determination of the topics assessed in terms of questions/marks pre time allocated in curriculum.

2.2.1 Identification of % question types and marks allocated

In this section, the Leaving Certificate Chemistry examination papers from 2000 to 2008 have been analysed using the following rubric to classify each individual question according to Bloom's' taxonomy. Depending on the verb used in the question, this identified the learning skill/objective being examined.

Knowledge		**Comprehension**		**Application**	
tell list relate define recall	label select locate find state name	explain estimate interpret outline discuss identify	distinguish predict restate translate describe explain draw	solve show use write demonstrate give	illustrate construct complete examine classify
Analysis		**Synthesis**		**Evaluation**	
analyse distinguish compare contrast investigate categorise	separate calculate diagrams differentiate advertise devise	create invent compose plan construct design	imagine propose formulate compile relate summarise	choose decide debate prioritise critique	verify argue recommend assess rate evaluate

Table 2.1 – Application of Bloom's Taxonomy

The model found in Table 2.1, has been adapted from the form presented by Dalton & Smith[14], as this model was used to identify question types used for primary level classes. Other more general terms have been included (in red) to incorporate similar descriptive verbs found at Leaving Certificate Chemistry level.

(iii) Name a suitable indicator and state the colour change at the end-point of the titration. Why is it necessary to use a buffer solution? (12) K/C

(iv) Name *one* compound that could have been responsible for the temporary hardness, and *one* compound that could have been responsible for the permanent hardness in the water sample. Write an equation for the reaction that took place when the water was boiled. (12) K/C

(v) Using H_2Y^{2-} to represent the EDTA anion and M^{2+} to represent the cation responsible for hardness, the titration reaction may be represented: An

$$H_2Y^{2-} + M^{2+} \longrightarrow MY^{2-} + 2H^+$$

Calculate:

(*a*) the total hardness,

(*b*) the permanent hardness,

(*c*) the temporary hardness, of the water sample, expressing your answers in terms of parts per million (p.p.m.) of calcium carbonate. (18)

Figure 2.6 –Part of a questions showing example of Knowledge, Comprehension and Analysis question types employed in Leaving Certificate examination

In applying the rubric, each sub question was analysed using this rubric e.g. in Figure 2.6 question (iv) has been identified as a knowledge and comprehension question with each part awarded 6 marks. This is as the marks allocated have been divided into equal parts, 6 for the naming of two compounds and 6 for the writing of an equation, according to the marking scheme for this particular year. When the question had been identified the percentage appearance of each question type was calculated as follows.

The number of question types were divided by the total number of questions asked on that given paper e.g. if there were 17 knowledge style questions asked out of a total of 84 questions on a paper then the percentage of knowledge questions is 20.23%. This method of calculation was employed for all questioning types found on the Leaving Certificate Chemistry papers and the results of this analysis are given in section 2.4.1

The higher level Chemistry paper is broken into two sections with Section A dealing with mandatory experiments and Section B dealing with all other theory, experiments and social and applied aspects of chemistry. Section A provides students with the opportunity to answer a minimum of two questions but with the choice of answering three questions. With Section B, students are given eight questions and asked to answer five or six questions depending on the number answered from Section A. In total, students answer eight questions, each accounting for 50 marks, with the entire paper totalling 400 marks.

Following on from the classification of question types according to the rubric contained in Table 2.1, the marks allocated per question type have been determined. As each part of a question was allocated a different number of marks, as can be seen in Figure 2.6, the number of marks per question type was determined and then divided by the total number of marks for the entire paper. The marks allocated for the 11 questions posed in the Leaving Certificate Chemistry paper total 650 marks (see Table 2.5). However students are only required to answer 8 questions which will award a total of 400 marks. So from the analysis if there were 21 analysis questions allocated 167.75 out of 650 marks then the percentage of marks allocated to the analysis questions is 25.81%.

This analysis was performed on the Leaving Certificate Chemistry Examination Papers from 2000 through to 2008, as the study wished to examine the change, if any of the % of questioning types being employed since the change of the higher level curriculum was examined in 2002.As stated previously regarding the limitations to the application of Bloom's Taxonomy there is a level of subjectivity in determining the category that each question fits into, the use of the rubric was given to two co-workers and the results of the application are shown in Table 2.2.

Question type	Person 1 (%)	Person 2 (%)	Person 3 (%)
Knowledge	32.93	35.37	36.59
Comprehension	30.49	34.15	26.83
Application	18.29	14.63	17.07
Analysis	18.29	15.85	13.41
Evaluation	0.00	0.00	1.22
Synthesis	0.00	0.00	4.88

Table 2.2 Application of Rubric

As can be seen the rubric used has allowed for a certain level of discrepancy ± 4% between people perceptions of the level of questions in this particular paper, however the higher percentages are still allocated to those of lower order.

2.2.2 Questions and marks per core topics/sub topics

The higher level Leaving Certificate chemistry curriculum is divided into core topics and two optional topics. Higher level students must study the core in its entirety and are required to choose one of the two optional topics; however this choice is mainly at the discretion of the teacher. Table 2.3 shows the concepts covered in the core and optional topics.

Core Topics	**Optional Topics**
1. Periodic Table 2. Chemical Bonding 3. Stoichiometry, formula and equations 4. Volumetric Analysis 5. Fuels and heats of reaction 6. Rates of Reaction 7. Organic Chemistry 8. Chemical equilibrium 9. Environmental chemistry – Water	1A. Additional Industrial Chemistry 1B. Materials 2A. Atmospheric Chemistry 2B. Additional electrochemistry

Table 2.3 – Core and optional topics on Higher Level Leaving Certificate Chemistry Curriculum

However each of the core topics and optional topics are further divided into sup topics, see Figure 2.3, which for the purpose of my analysis have been identified using the following key (Table 2.4).

Core Topic	Label	Sub Topic	Time allocated (class periods)
Periodic Table	1.1	Periodic Table	3
	1.2	Atomic Structure	6
	1.3	Radioactivity	2
	1.4	Electronic Structure of atoms	11
	1.5	Oxidation and Reduction	7
Chemical bonding	2.1	Chemical compounds	5
	2.2	Ionic bonding	4
	2.3	Covalent bonding	4
	2.4	Electronegativity	2
	2.5	Shapes of molecules and intermolecular forces	5
	2.6	Oxidation numbers	5
Stoichiometry, formula and equations	3.1	States of matter	1
	3.2	Gas Laws	7
	3.3	The mole	9
	3.4	Chemical formulae	6
	3.5	Chemical equations	11
Volumetric Analysis	4.1	Concentrations of solutions	8
	4.2	Acid and Bases	4
	4.3	Volumetric analysis	22
Fuels and heats of reaction	5.1	Sources of Hydrocarbons	1
	5.2	Structure of Aliphatic Hydrocarbons	5
	5.3	Aromatic Hydrocarbons	1
	5.4	Exothermic and endothermic reaction	9
	5.5	Oil refining and its products	4
	5.6	Other Chemical Fuels	3
Rates of reaction	6.1	Reaction rates	3
	6.2	Factors affecting the rate of reaction	8
Organic Chemistry	7.1	Tetrahedral carbon	4
	7.2	Planar carbon	11
	7.3	Organic Chemical Reaction types	21
	7.4	Organic Natural Products	4

Core Topic	Label	Sub Topic	Time allocated (class periods)
	7.5	Chromatography and Instrumentation in Organic Chemistry	3
Chemical equilibrium	8.1	Chemical Equilibrium	8
	8.2	Le Chateliers principle	5
Environmental Chemistry	9.1	pH scale	6
	9.2	Water Hardness	3
	9.3	Water treatment	5
	9.4	Water analysis	11
Optional Topic	**Label**	**Sub Topic**	**Time allocated (class periods)**
Industrial Chemistry	1A.1	General principles of industrial chemistry	3
	1A.2	Case studies	5
Atmospheric Chemistry	1B.1	Oxygen	1
	1B.2	Nitrogen	2
	1B.3	Carbon dioxide	4
	1B.4	Atmospheric pollution	2
	1B.5	The ozone layer	4
Materials	2A.1	Crystals	3
	2A.2	Addition polymers	5
	2A.3	Metals	1
Electrochemistry and extraction of metals	2B.1	The electrochemical series	1
	2B.2	Electrolysis of molten salts	1
	2B.3	Corrosion	2
	2B.4	Strongly electropositive (Na and Al)	4
	2B.5	d-block Metals	4

Table 2.4 – Key for sup topic identification

Core topics and sub topics have been identified and based on the number of class periods allocated to them, analysis has been performed to determine if these topics have been over or under assessed compared to their allocated time in the curriculum.

In order to determine if a topic/sub topic had been over or under assessed the % appearance of a question on that topic was calculated per year from 2002 to 2008. 2000 and 2001 examination papers were not used in this part of the analysis as these were both examined according to the 1983 curriculum.

Each question was classified as dealing with content pertaining to topics/sub topics. The graphs, appearing in section 2.3.2 were calculated as follows; the % questions of topics/subtopics was determined by dividing the number of times a topic had appeared by the total number of questions asked, e.g. if there were 19 questions on volumetric analysis asked in a particular year out of a total of 85 questions asked on the examination in total, then the percentage of questions asked on the volumetric analysis is 22.35%. Then the allocated number of class periods for that topic is divided by the total number of allocated class periods, e.g. for volumetric analysis 34 class periods divided by 258 yields a percentage of 13.18%.

Finally to determine if the topic has been over or under assessed relative to the time allocated to this topic, the % questions is divided by the % time e.g. 22.35%/13.18% = 1.69. If the number is greater than 1, the topic/sub topic is deemed to be over-assessed, while if the number is less than 1, the topic/subtopic is deemed to be under-assessed according to the time allocated.

Along with the % questions given to a certain topic/sub topic, the % marks allocated for a topic/subtopic was also determined. In each Leaving Certificate Chemistry Higher Level paper there are a possible 11 questions and students are required to answer 8 of these 11. The total marks awarded to the students for the completion of these eight questions is 400 marks. However as these papers were analysed based on all possible questions being answered the total number of marks awarded per paper were 650.

The break down of marks is shown in Table 2.5 below.

Question	Number of choices	Marks awarded per choice	Total possible marks for question
1	1	50	50
2	1	50	50
3	1	50	50
4	12	6.25	75
5	1	50	50
6	1	50	50
7	1	50	50
8	1	50	50
9	1	50	50
10	3	25	75
11	4	25	100
		Total marks per paper available	650

Table 2.5 Accounting for 650 possible marks in the Leaving Certificate Chemistry Paper

The number of marks allocated to topic/subtopic was calculated and again divided by the total number of marks for a paper e.g. water analysis (sub topic 9.4) has been awarded 24.25 marks out of 650 for a particular year as explained above, therefore the % of marks allocated to this sub section = 3.73%. Again to determine if a topic/subtopic has been over, or under assessed, the % marks was divided by the % time allocated by the curriculum e.g. 11 classes for water analysis out of 258 classes gives 4.26%, which when divides into the % marks allocated for this subtopic yields 0.88, which in this example shows that this is a lower % of marks compared to the allocated class time.

In this sort of analysis one difficulty is the build up or scaffolding approach of chemical understanding which is required. This analysis has shown that is can be difficult to state precisely that one question belongs solely to a particular subtopic when in fact it also involves one or possibly two other subtopics. This was especially the case in terms of volumetric analysis questions which incorporated the use of students' knowledge of molarity, molecular weights, concentration and balancing of equations, all of which are contained in Section 3, however were identified under the subtopic heading of volumetric analysis Section 4.

2.3 Results & Discussion

This section gives the results of three types of analysis that have been performed on the Leaving Certificate Chemistry Higher Level papers. Only Higher Level papers were considered in this study as the majority of students to take Leaving Certificate Chemistry do so at the higher level e.g. in 2008, 83% of students who took Chemistry at Leaving Certificate did so at higher level. This analysis aims to answer the following questions:

- Does the current assessment employed at Leaving Certificate level incorporate all level of questioning identified by Bloom?

- Are the % marks and % questions awarded to each topic equally represented?

- Are certain topics/ sub topics being over assessed?

- Does the Leaving Certificate assess students' competence of the stated objectives?

As stated in section 2.1.1, the curriculum was changed in 2000 and first examined in 2002. Analysis of question types has been carried out on all examinations from 2000 to 2008 to determine if there was a change in questions type emphasis based on the new curriculum. Analysis concerning the topic and subtopic determination has only been employed on years from 2002 to 2008 as the 2000 curriculum content and suggested time allocation was not applicable to the years examining the 1983 curriculum.

2.3.1 Application of Bloom’s Taxonomy: % questions v % marks

Figures 2.7 - 2.15 show the results of the application of Bloom’s six categories of questioning types to the Leaving Certificate Chemistry papers of 2000 - 2008, which determined the % of questions per question type and the % marks allocated per question type.

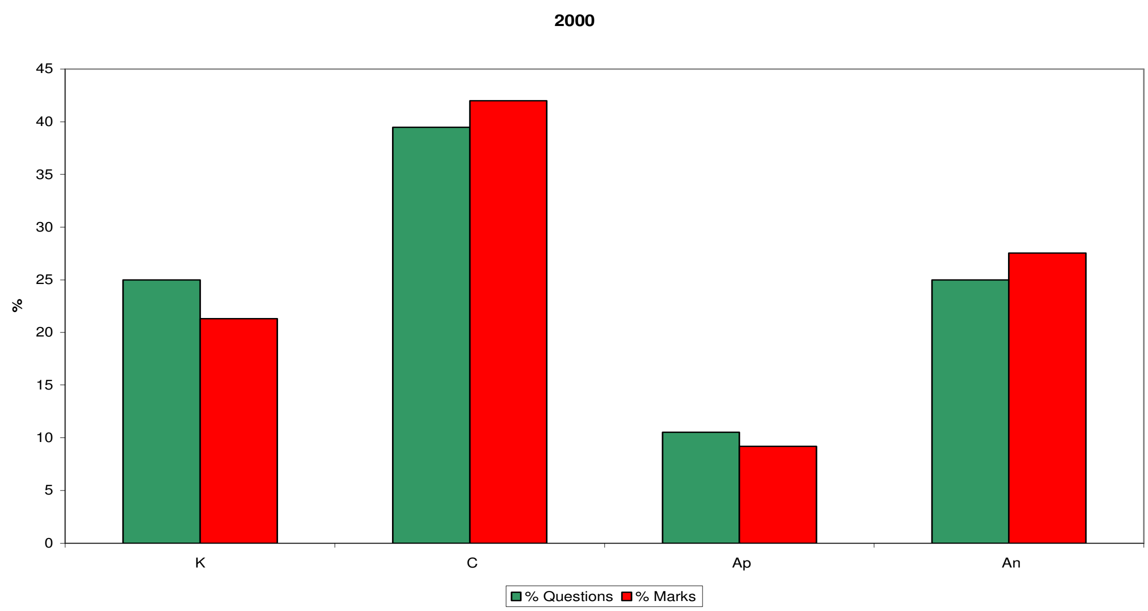

Figure 2.7 – % question type and % marks allocated 2000

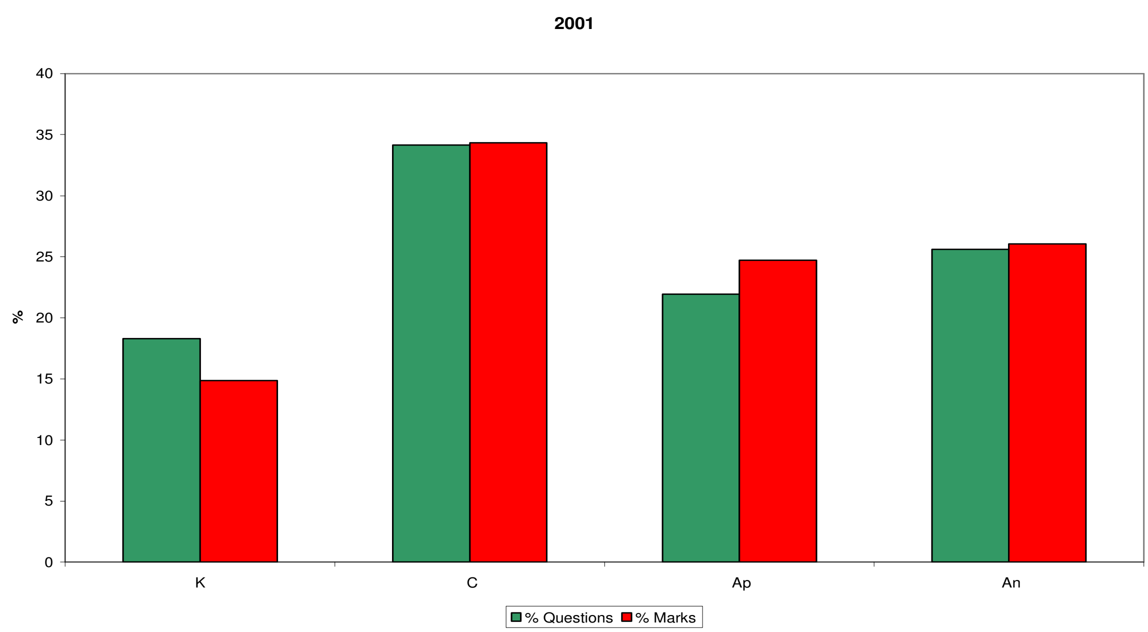

Figure 2.8 – % question type and % marks allocated 2001

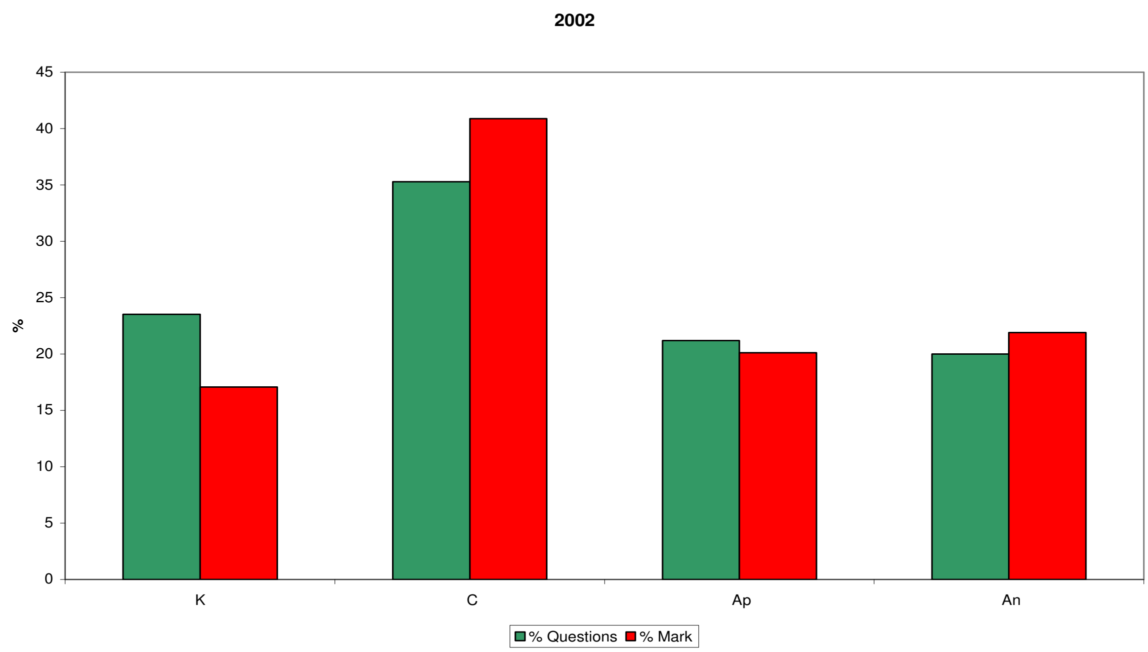

Figure 2.9 – % question type and % marks allocated 2002

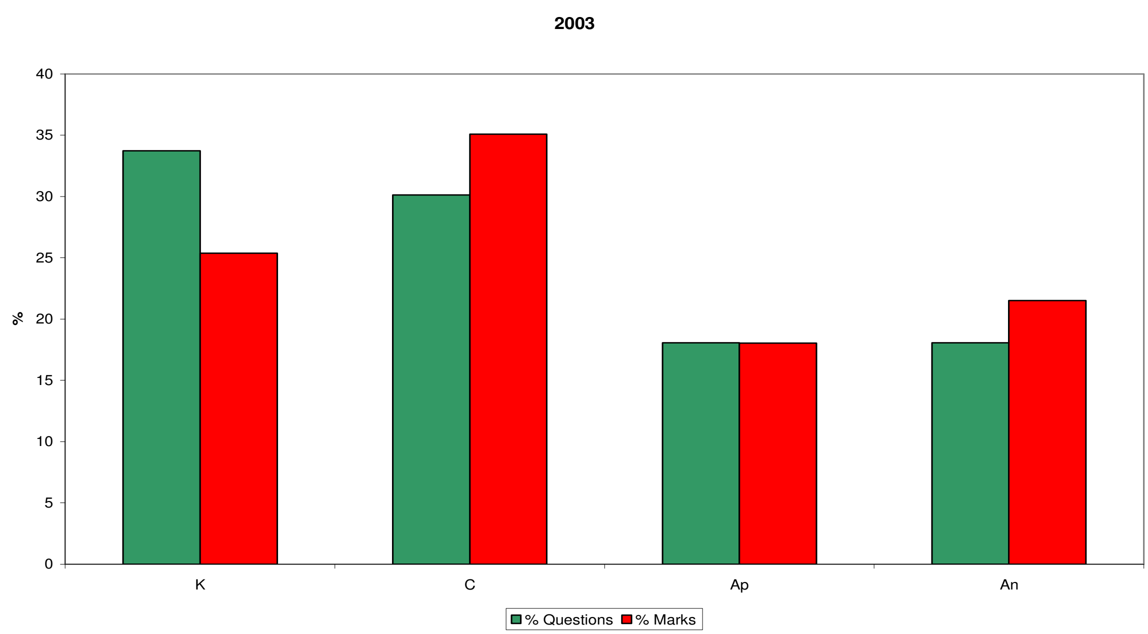

Figure 2.10 – % question type and % marks allocated 2003

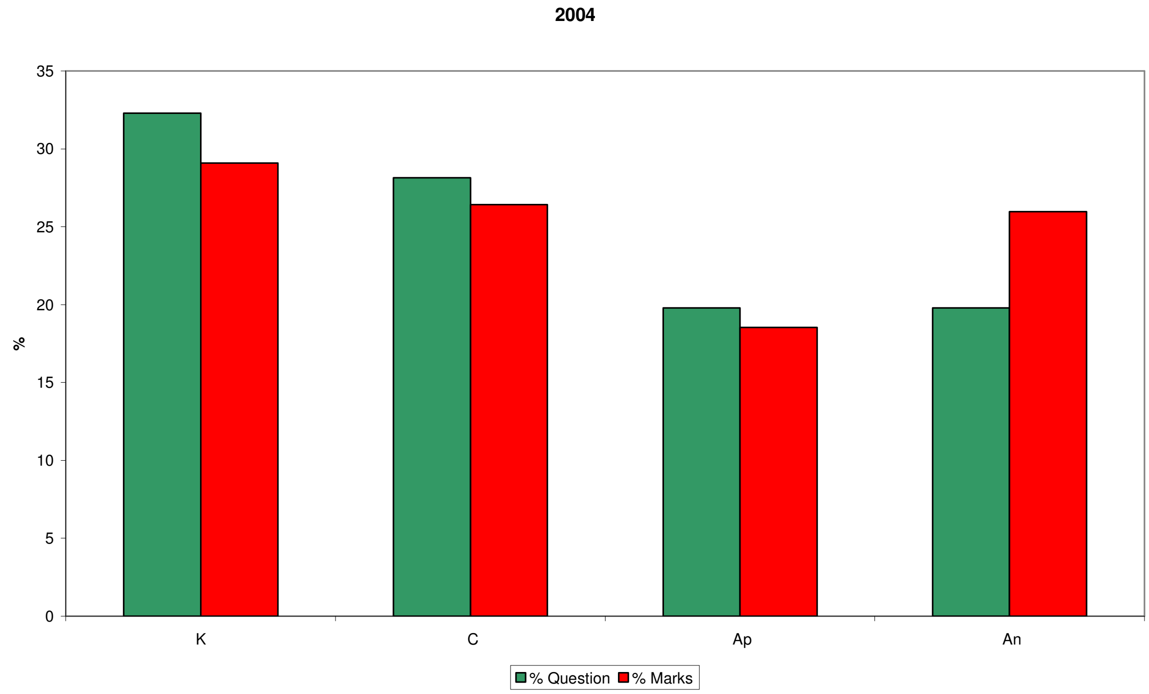

Figure 2.11 – % question type and % marks allocated 2004

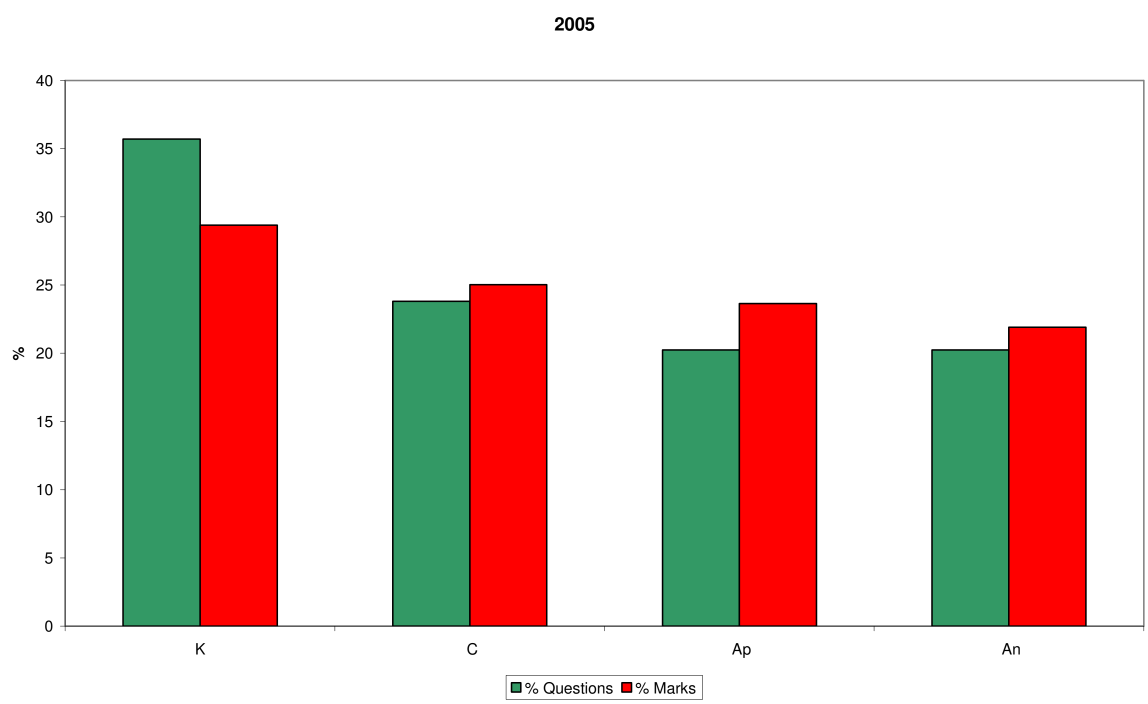

Figure 2.12 – % question type and % marks allocated 2005

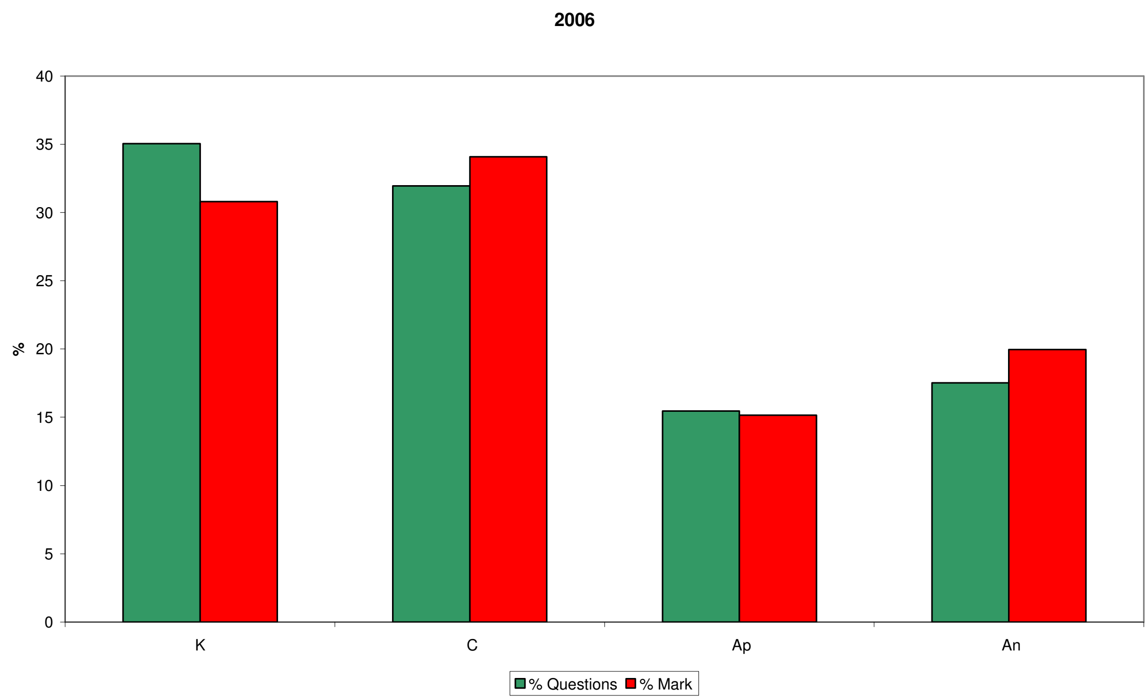

Figure 2.13 – % question type and % marks allocated 2006

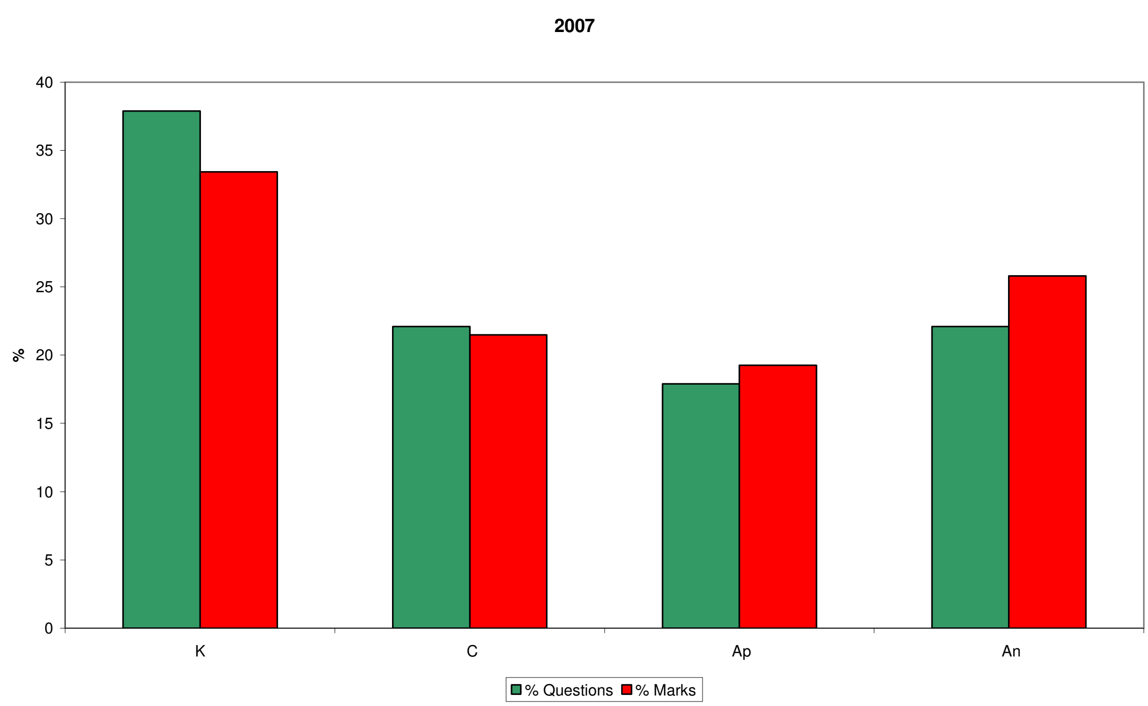

Figure 2.14 – % question type and % marks allocated 2007

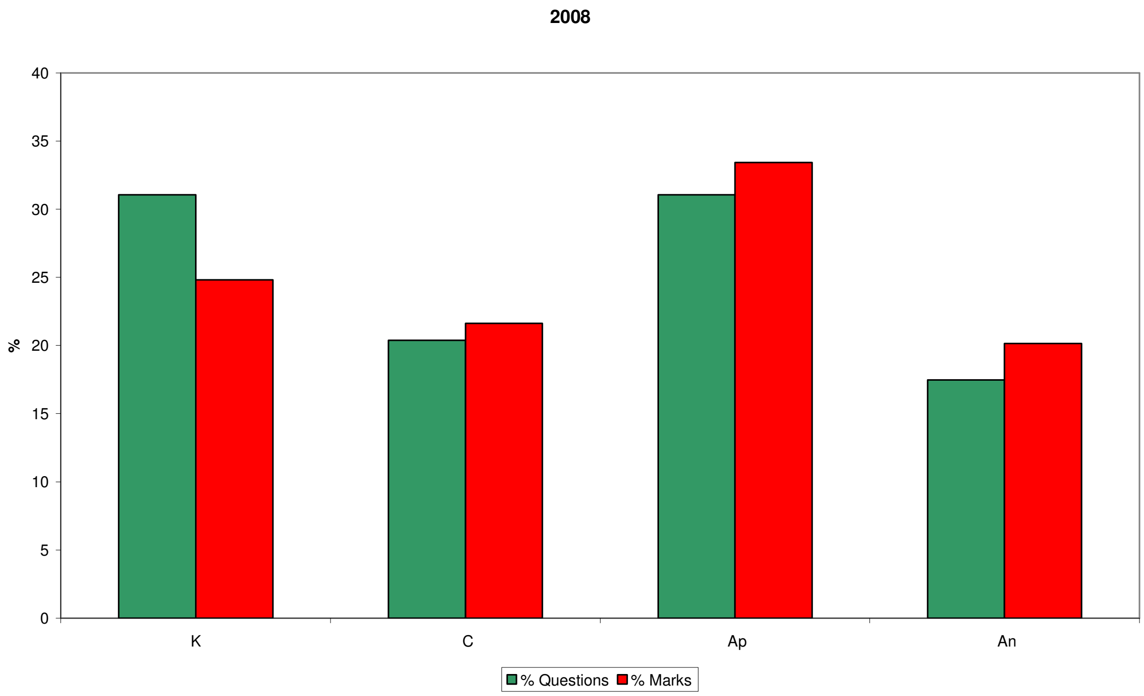

Figure 2.15 – % question type and % marks allocated 2008

From Figures 2.7 - 2.15, a number of trends have been seen in each of the papers:

No questions from Bloom's categories of synthesis or evaluation were identified upon application of the rubric (Table 2.1) in any of the papers analysed. This shows that while students' knowledge, comprehension and application and analysis skills are being examined, with an imbalance shifting towards the lower order questions, students' abilities to complete the top two levels of Bloom's taxonomy are not being examined. While it is not suggested that there should be a shift towards all questions asked being of higher order, it obvious from Figures 2.7 – 2.15 that higher level questions are very poorly represented in the higher level examination papers with a bias towards lower order questioning.

The percentage of marks being awarded to each of the question types is mostly appropriate given the number of questions of that type appearing on a given paper. However there are a number of instances where this was noted not to be the case. Figure 2.9 shows that the percentage marks allocated for knowledge questions was not adequate in comparison to the number of questions that students were asked.

This displays that the knowledge questions were not being greatly rewarded for the completion of these low order question types. Figure 2.10 again presents the imbalance between the marks allocated for the number of questions asked at knowledge level. Students were more appropriately rewarded for their attempts on comprehension, application or analysis questions in this particular year. Figure 2.11 is the first instance where a significant difference is noted in relation to the marks rewarded upon completion of the analysis questions in comparison to the number of questions of this typed being used in 2004. However in 2005 (Figure 2.12) once again the imbalance between the marks allocated for the number of questions asked at knowledge level can be seen. This example of a lower percentage of marks allocated for knowledge type questions is again seen in 2007 (Figure 2.14) and 2008 (Figure 2.15), once again demonstrating the lack of reward that is associated with these questions.

From each of the figures the imbalance between the appearance in lower order and higher order questions is extremely obvious. In the case of Figure 2.7 knowledge, comprehension and application questions encompass 75% of the questions asked and 74% of the marks allocated. The number of and marks allocated to higher level question (analysis only) is very low in this particular year. In 2002, the first year of examination of the new curriculum (Figure 2.9) the lower order question occupy 80% of the questions asked on this, with a fall of 5.6% in the number of higher order questions employed in comparison to 2001. While the new syllabus aimed to provide students with abilities such as those outlined in Figure 2.4, these papers reward students for demonstrating their lower order skills while failing to assess student's abilities to evaluate and synthesis chemical concepts. This trend of employment of lower order questions continues through to 2006 (Figure 2.13) however in 2007 (Figure 2.14) the percentage of questions of analysis type reaches its highest since the introduction of the current curriculum at 22%. Unfortunately this increase was short-lived as in 2008 (Figure 2.15) the percentage of questions fell by 5% from 2007. However the % questions requiring knowledge skills fell to their lowest level since the introduction of the 2000 curriculum to 31%.

From Figures 2.16 and 2.17, the % appearance of each of the question types can be seen from 2000 to 2008.

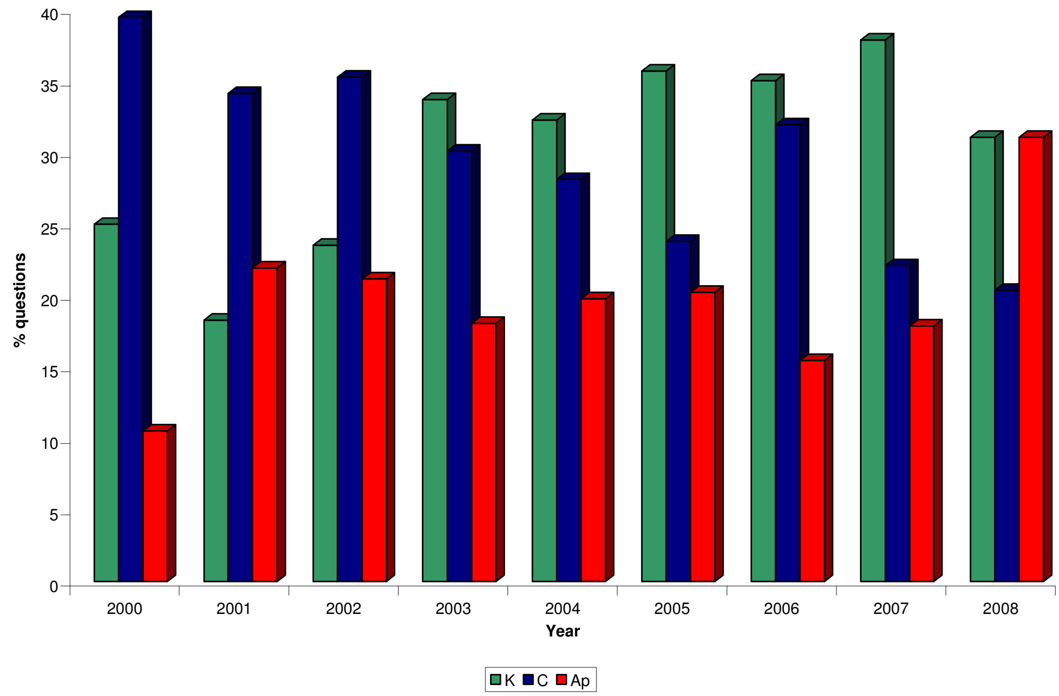

Figure 2.16 – % Lower Order questions 2000 - 2008

As can be seen in Figure 2.16, the % of questions being occupied by lower order varies from 74.4% in 2001 which was the lowest level seen in the nine years of analysis to a high of 82.5% in 2008. The trend that can be seen in relation to the % of knowledge questions being employed in 2000, is that this question type has risen since 2001 with the highest level being observed in 2007 at 37.9%. However as is observed in 2008, there was a drop of 6.8% to the lowest level observed since 2002.

With comprehension questions, there has been a steady decrease in these questions since 2000. However an exception is observed however in 2006 where the % of comprehension rises to 32%, while this decrease in appearance continues in 2007 and 2008, with the lowest % observed in 2008 with 20.4% of the questions being of comprehension style. Application questions which can be seen to start off at a very low level in 2000 have enjoyed a fluctuation between 17 – 20% in appearance since 2002.

However in 2008 the highest level of application question has been seen, which while these questions are still identified as lower order questions they do require a higher learning skill and demand more of students in order to correctly answer them.

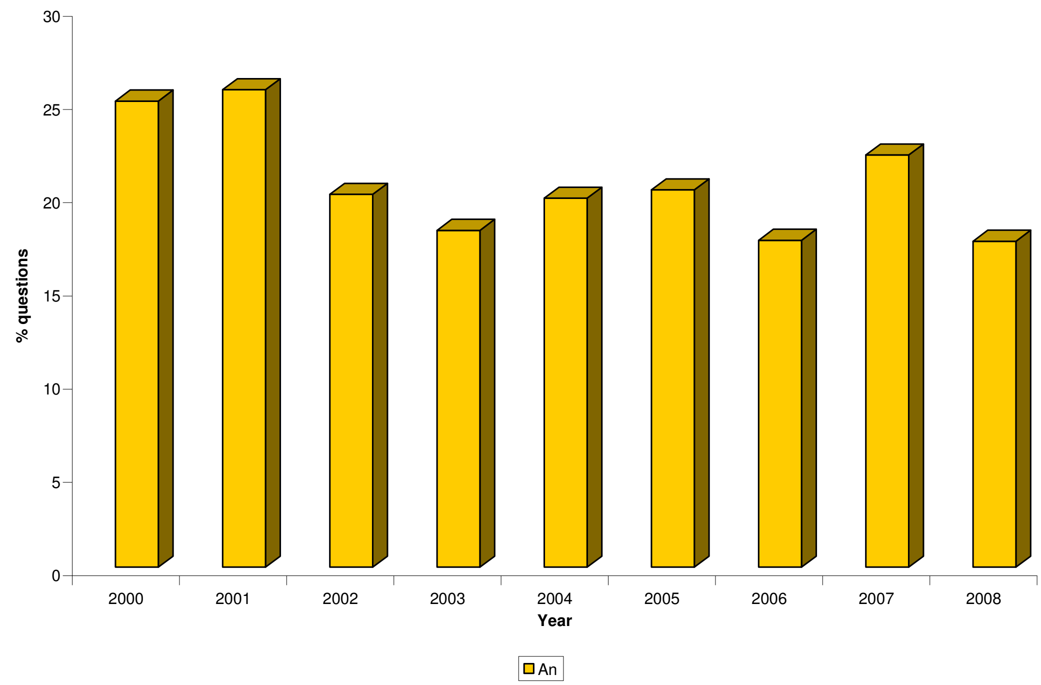

Figure 2.17 – % Higher Order questions 2000 - 2008

Figure 2.17 shows the percentage of application questions that have been seen since 2000 in all analysed papers. As can be seen application question occupy a low percentage of the questions in each of the years examined with the highest percentage observed in 2001 with 25.6% of the paper being analysis questions. The percentage of questions varies between 17-20% with the lowest level observed in 2008 with 17.5% paper being of analysis type questions. It is important to note again that analysis questions were the only type of higher order question identified during this analysed and both evaluation and synthesis have not been seen in any of the years examined.

Figure 2.18 and 2.19, show the % marks allocated to each of the question types since 2000.

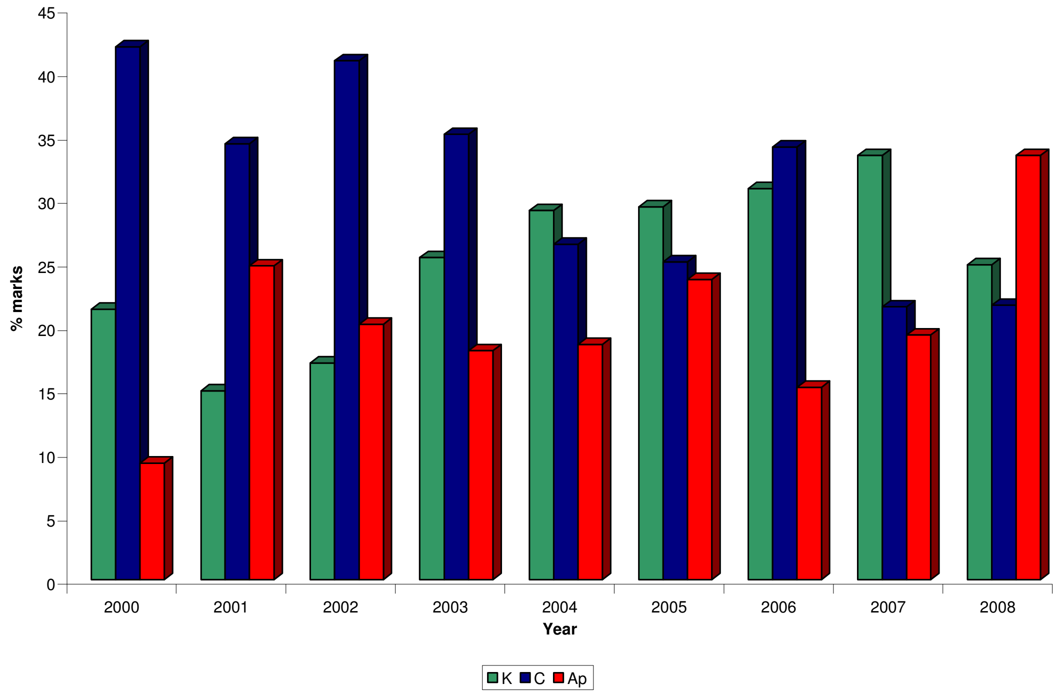

Figure 2.18 – % Lower Order marks 2000 - 2008

Figure 2.18 shows the % of marks being occupied by lower order which is seen to vary from 72.4% in 2000 which was the lowest level seen in the nine years analysed to the highest being 80.0% in 2006. In relation to the percentage of marks allocated for the lowest order of Bloom's taxonomy – knowledge – there has been a steady increase in the percentage awarded for this question type since 2001 with the highest percentage seen in 2007 of 33.4% of marks in 2007 allocated to knowledge questions. In 2008 however this percentage dropped to 24.8% which is the lowest level observed since the first examination of the 2000 curriculum.

Comprehension questions have accounted for as high as 42.00% of the marks in 2000 however proceeded to fall to a low of 25.0% in 2005. In recent years, 2007 and 2008 the percentage of marks that are allocated to comprehension type questions have accounted for approximately 21%, which are the lowest levels seen with a fall of 20% since 2000.

Application questions which have seen a rise in appearance of questions, Figure 2.15, are also seen to have a significant rise of 15.5% between 2000 and 2001. However in 2002 the percentage of marks allocated falls to 20.1% and continues to fall in both 2003 and 2004. A rise is observed in the percentage of marks allocated to application questions in 2006 and 2007 with the highest percentage observed in 2008 when 33.4% of the marks were allocated to application questions. Again even though these questions are still labelled as lower order they do require more thinking and deeper level of understanding that those questions which have been identified as knowledge questions, so this rise in percentage of marks is an improvement on the larger percentages being given to knowledge questions.

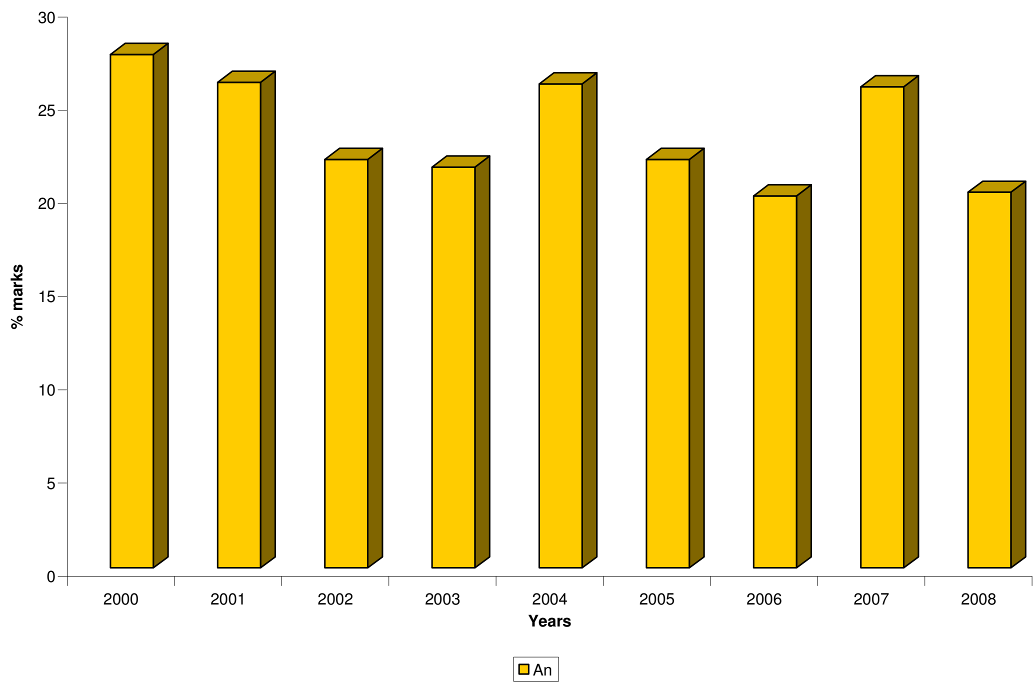

Figure 2.19 – % Higher Order marks 2000 - 2008

Figure 2.19 displays the percentage of marks which have been allocated to those questions deemed to be of analysis level from 2000 to 2008. As seen in this graph the percentage of marks never exceeds 30%, with the highest level observed in 2000, before the examination of the new curriculum.

Since the implementation of the 2000 curriculum the percentage marks awarded to analysis questions has fluctuated between 20 – 25% with the 2004 and 2007 displaying the largest percentage of marks (approximately 26%) for the completion of analysis questions.

In 2008 there was a significant drop in the marks awarded for analysis questions, which mirror those results displayed in Figure 2.16. Again higher order questions are outweighed by those for lower order in both questions asked and marks allocated.

2.3.2 Questions and marks allocated to topics/sub topics

This section deals with the analysis performed on papers from 2002-2008 using the key shown in Table 2.4. For the purposes of this discussion the graphs dealing with core – topic will be displayed and discussed followed by the sub - topic graphs. In each graph the ratio of % questions : % classes allocated and % marks : % classes allocated have been determined i.e. questions/time and marks/time for each core/sub topic. Along with these graphs will be a series of tables depicting the results clearly from each year.

The assessment of core topics from 2002 through to 2008 are discussed in Section 2.3.2.1 and are shown in Figures 2.20 – 2.26. Assessment of sub topics from 2002 to 2008 are shown in Figures 2.27 – 2.33 and are discussed in Section 2.3.2.2. Tables 2.6 and 2.7 indicate whether topics are over or under assessed for each topic while Tables 2.8 and 2.9 show the results for each sub topic.

2.3.2.1 Core topics

Those topics which have been deemed to be under assessed in term of % questions and % marks per allocated class time are found below the x axis, with those deemed to be over - assessed in term of % questions and % marks per allocated class time are found above the x axis.

It is important to note that those topics whose assessment is 0 such as topic 2A in Figure 2.20 have not appeared on that paper and are therefore under - assessed as while they are still allocated a given number of hours in the curriculum have not been questioned at all in that particular year.

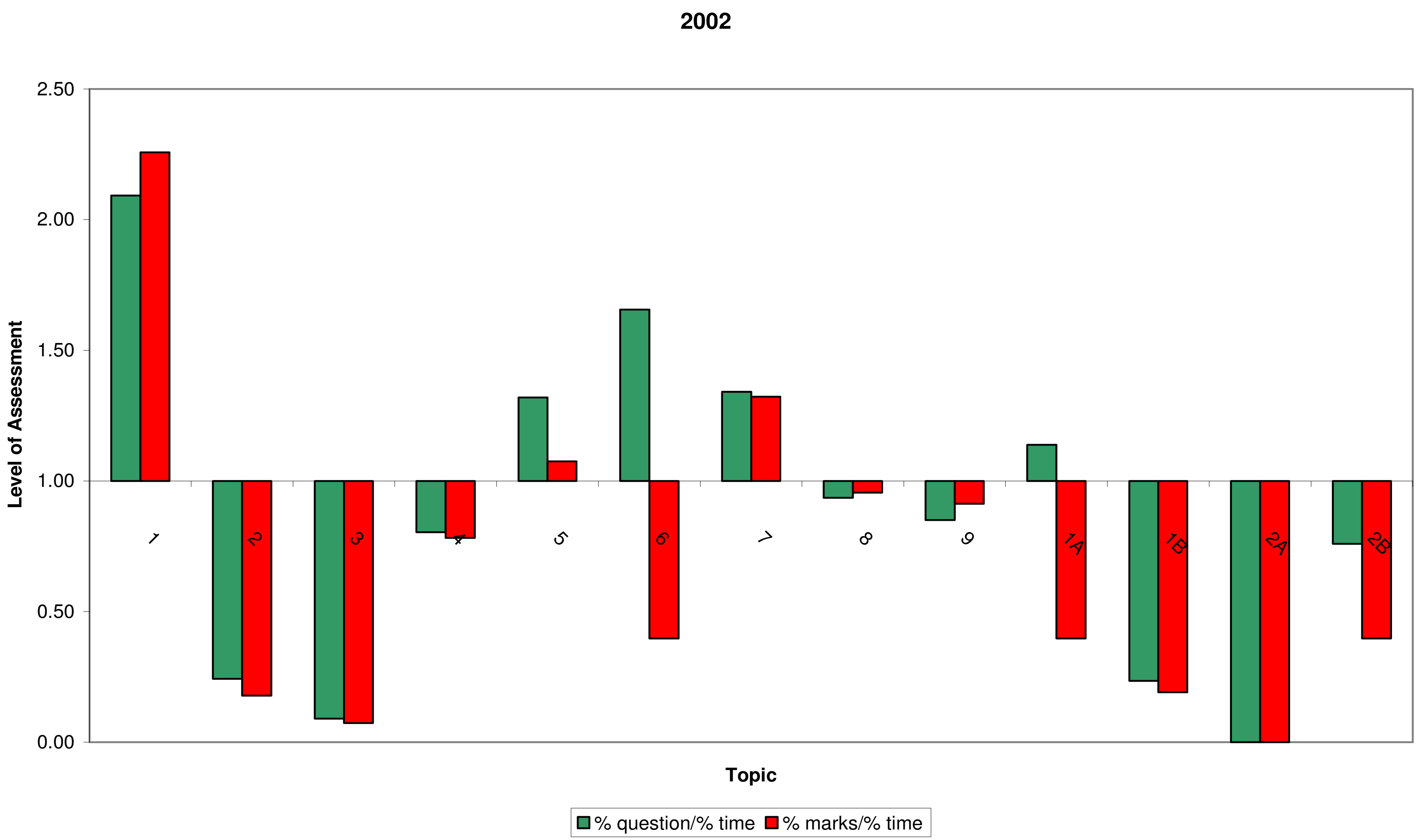

Figure 2.20 – Assessment of core and optional topics in 2002

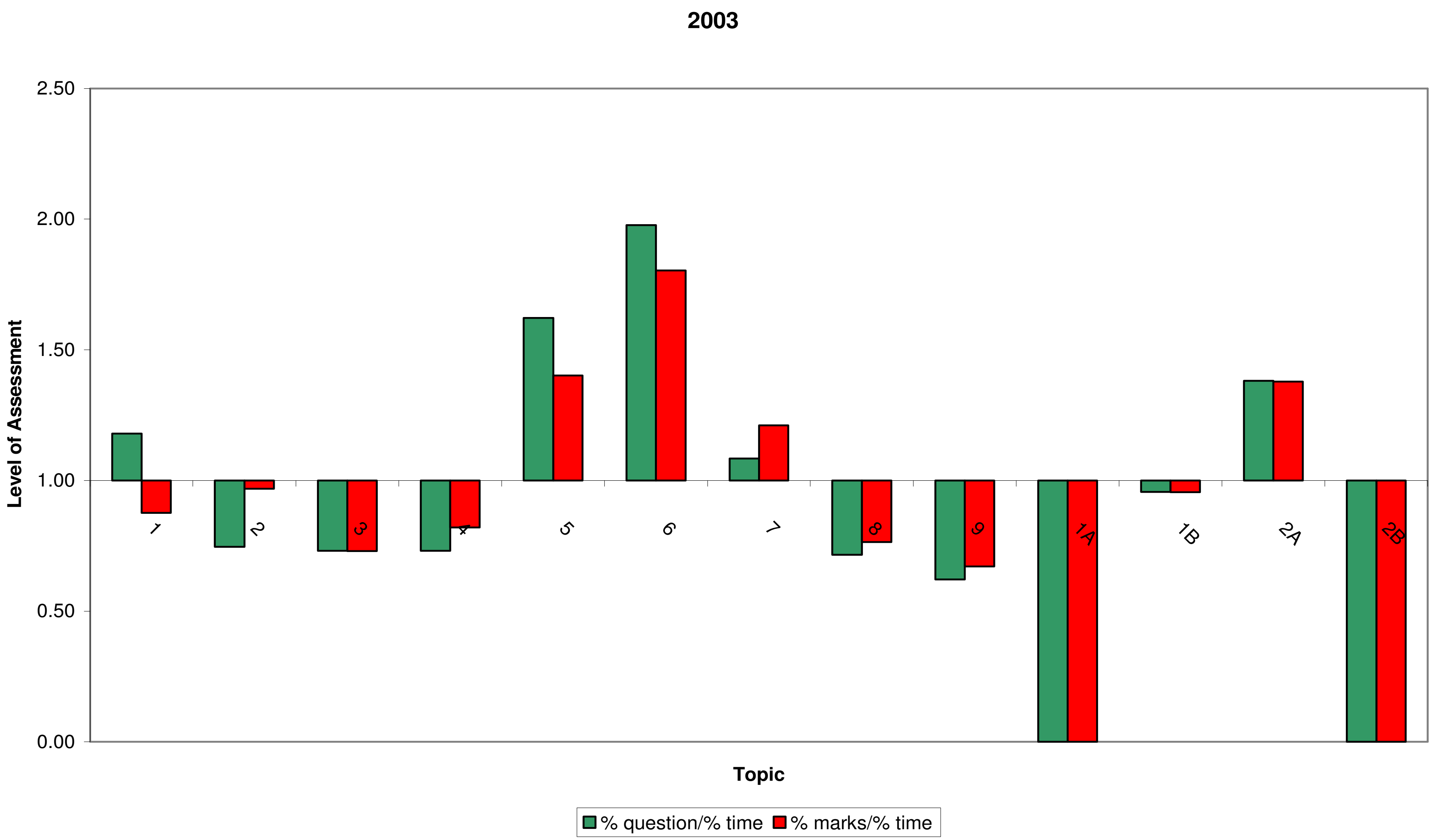

Figure 2.21 – Assessment of core and optional topics in 2003

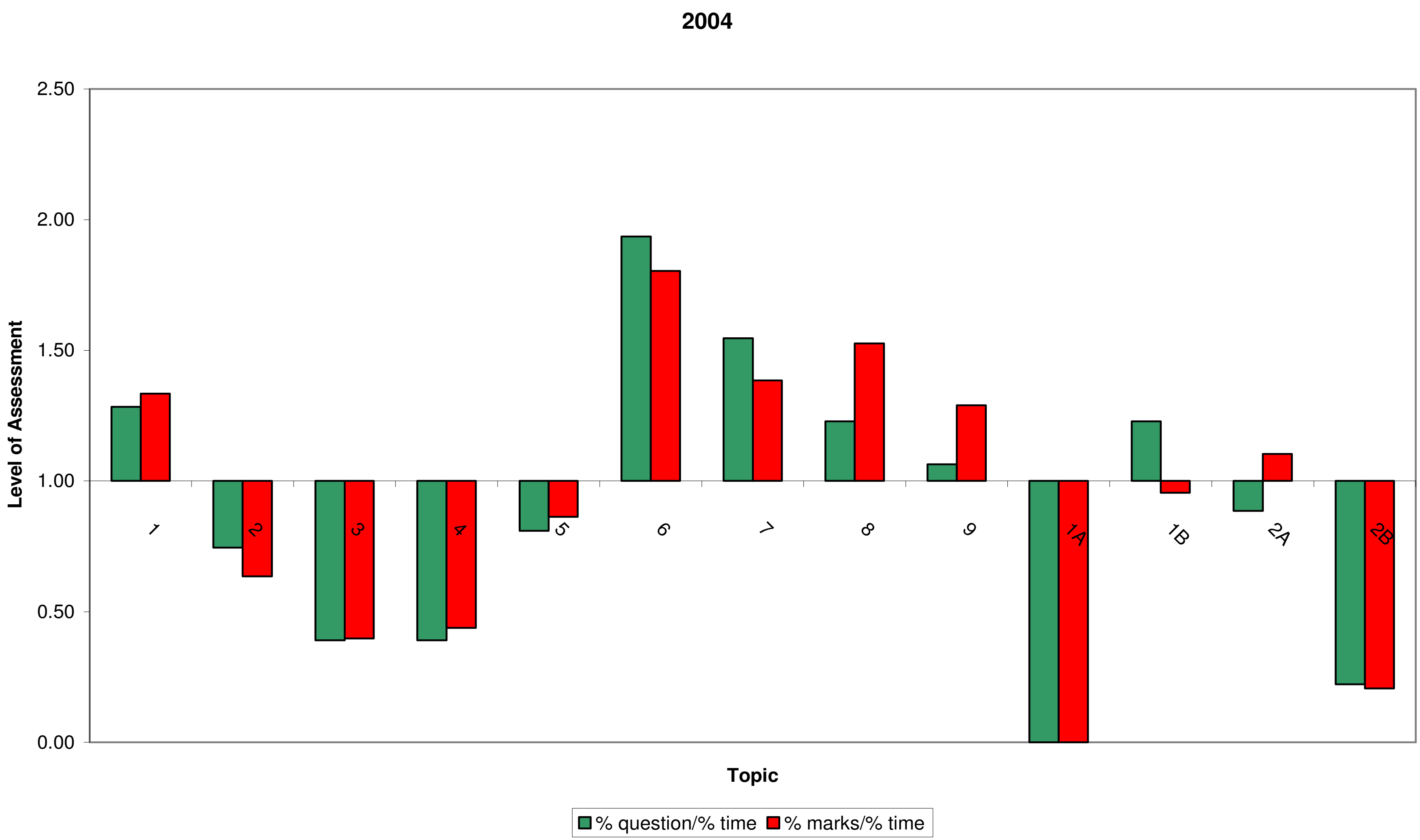

Figure 2.22 – Assessment of core and optional topics in 2004

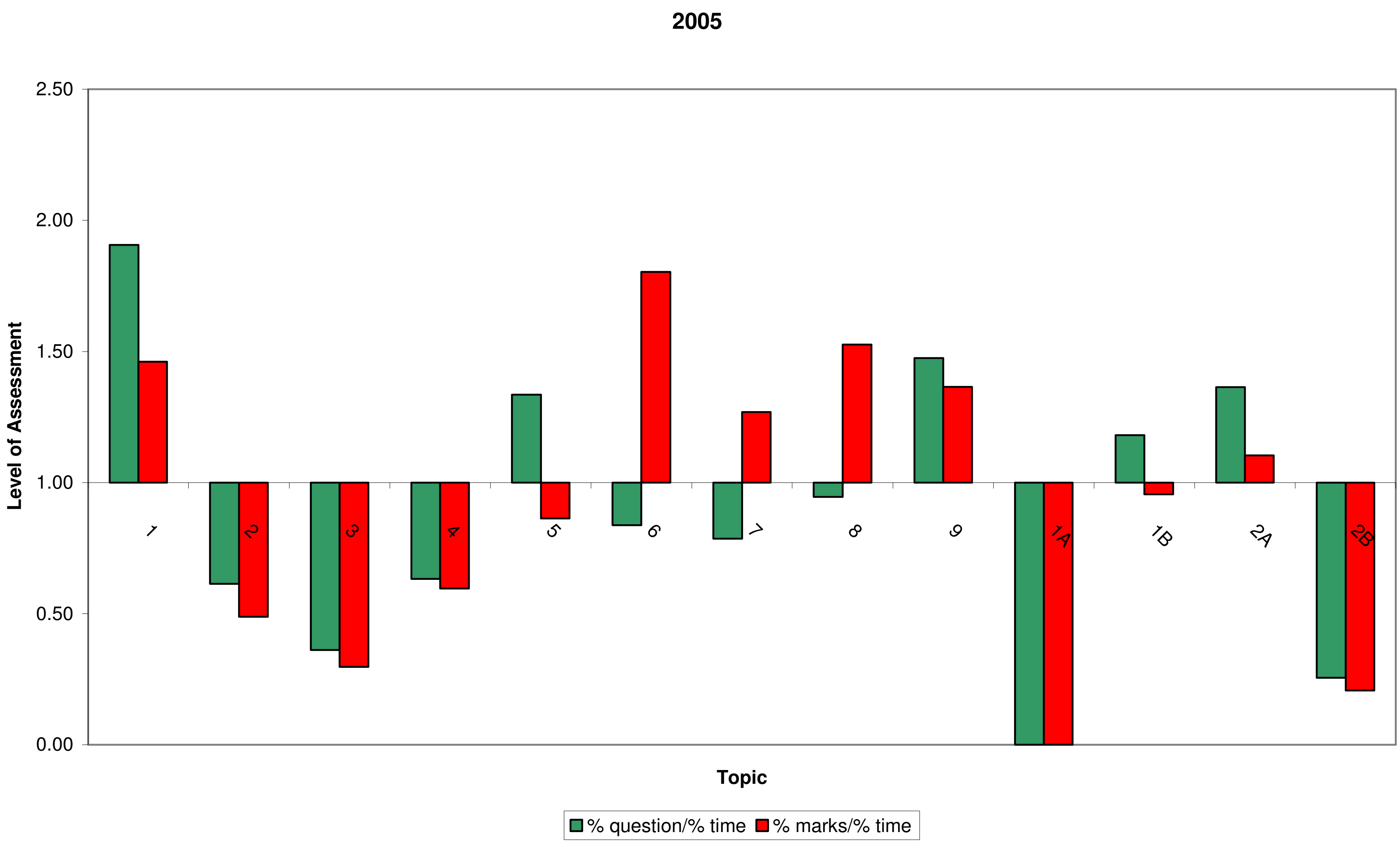

Figure 2.23 – Assessment of core and optional topics in 2005

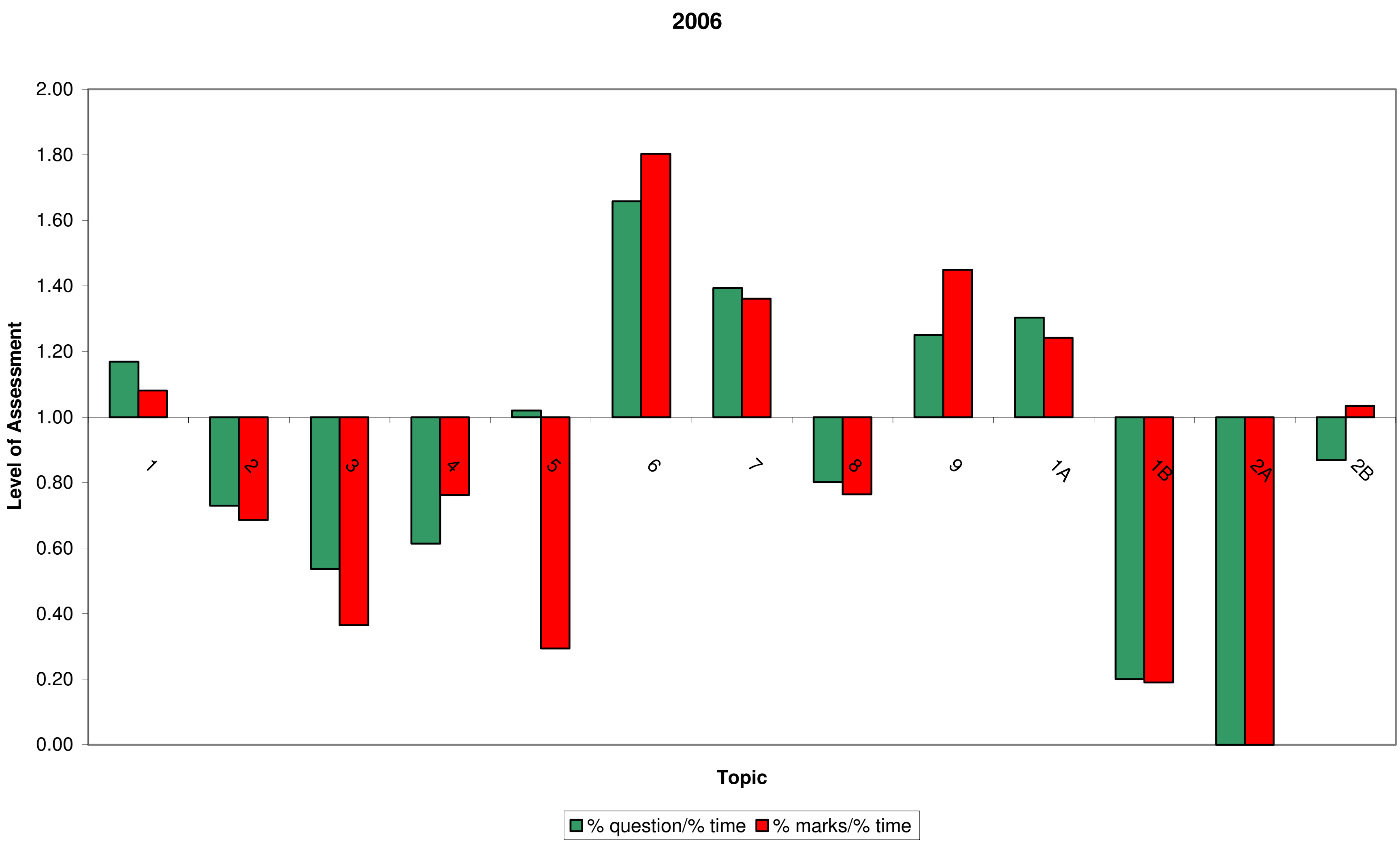

Figure 2.24 – Assessment of core and optional topics in 2006

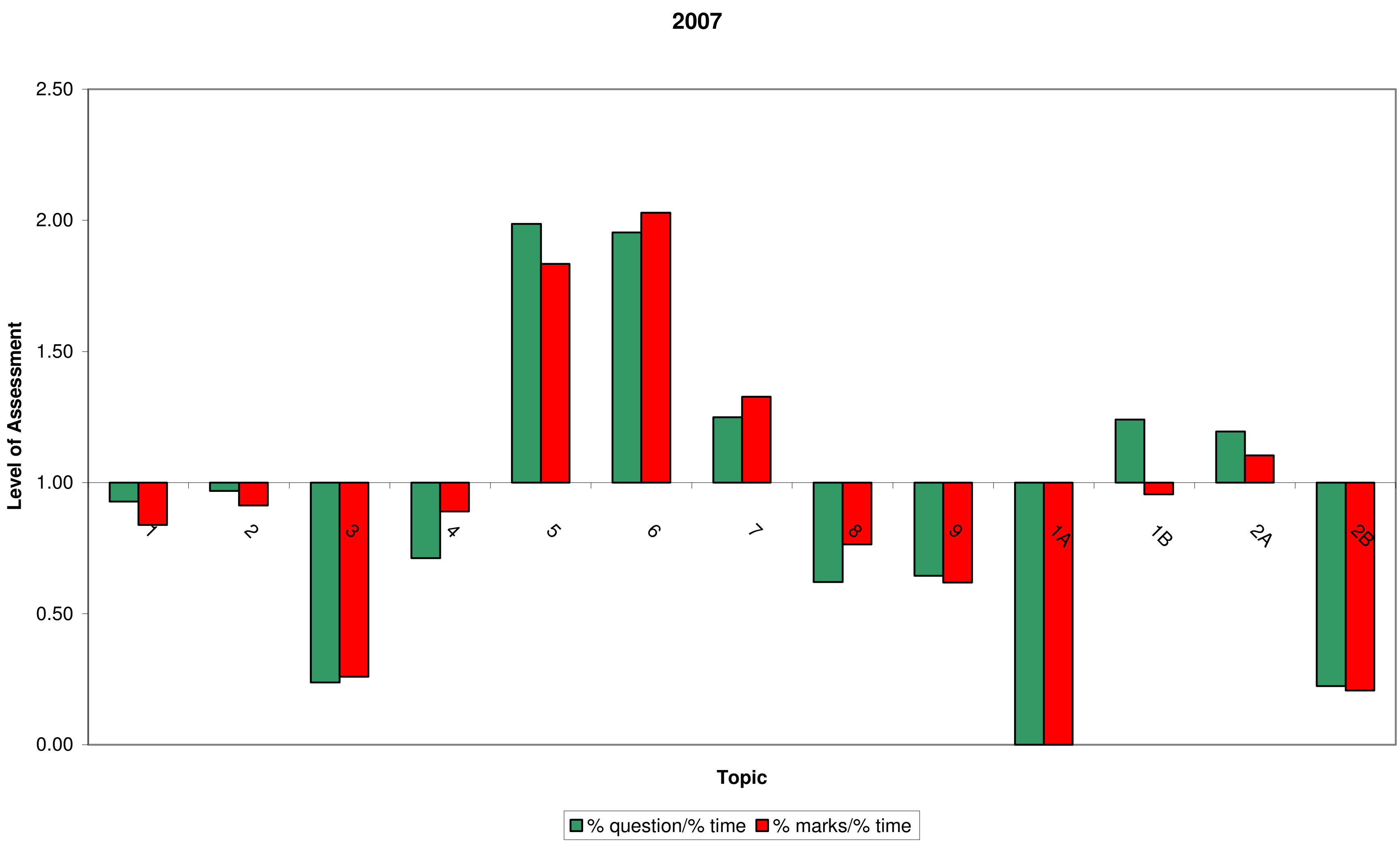

Figure 2.25 – Assessment of core and optional topics in 2007

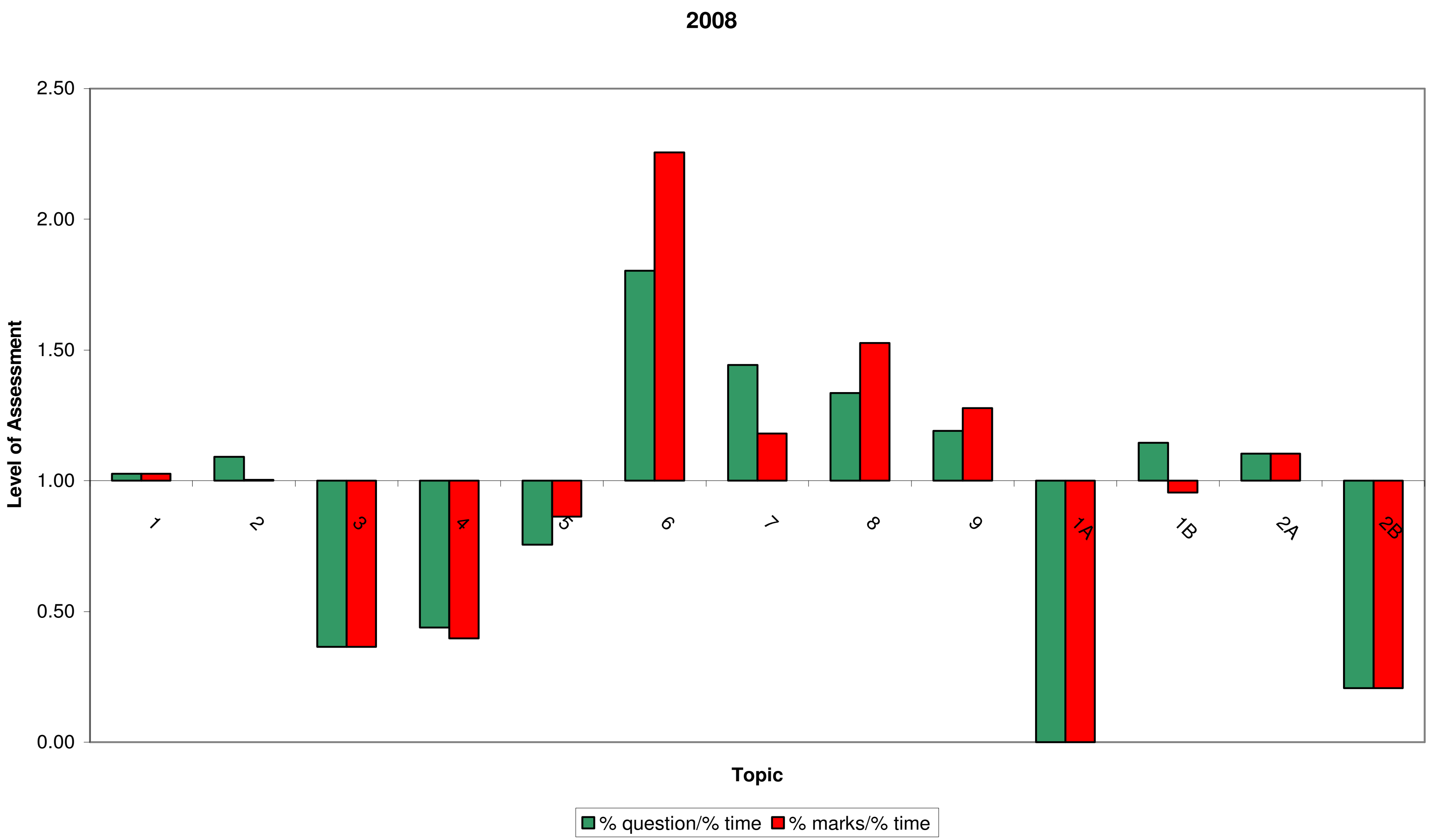

Figure 2.26 – Assessment of core and optional topics in 2008

Topic	2002	2003	2004	2005	2006	2007	2008
1	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Under Assessed	Correctly Assessed
2	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Over Assessed
3	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed
4	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed
5	Over Assessed	Over Assessed	Under Assessed	Over Assessed	Over Assessed	Over Assessed	Under Assessed
6	Over Assessed	Over Assessed	Over Assessed	Under Assessed	Over Assessed	Over Assessed	Over Assessed
7	Over Assessed	Over Assessed	Over Assessed	Under Assessed	Over Assessed	Over Assessed	Over Assessed
8	Under Assessed	Under Assessed	Over Assessed	Under Assessed	Under Assessed	Under Assessed	Over Assessed
9	Under Assessed	Under Assessed	Over Assessed	Over Assessed	Over Assessed	Under Assessed	Over Assessed
1A	Over Assessed	Not Assessed at all	Not Assessed at all	Not Assessed at all	Over Assessed	Not Assessed at all	Not Assessed at all
1B	Over Assessed	Under Assessed	Over Assessed	Over Assessed	Under Assessed	Over Assessed	Over Assessed
2A	Not Assessed at all	Over Assessed	Under Assessed	Over Assessed	Not Assessed at all	Over Assessed	Over Assessed
2B	Under Assessed	Not Assessed at all	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed

Table 2.6 results of Figures 2.20 – 2.26 (% questions/%time)

Topic	2002	2003	2004	2005	2006	2007	2008
1	Over Assessed	Under Assessed	Over Assessed	Over Assessed	Over Assessed	Under Assessed	Correctly Assessed
2	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Correctly Assessed
3	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed
4	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed
5	Over Assessed	Over Assessed	Under Assessed	Under Assessed	Under Assessed	Over Assessed	Under Assessed
6	Under Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed
7	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed	Over Assessed
8	Under Assessed	Under Assessed	Over Assessed	Over Assessed	Under Assessed	Under Assessed	Over Assessed
9	Under Assessed	Under Assessed	Over Assessed	Over Assessed	Over Assessed	Under Assessed	Over Assessed
1A	Under Assessed	Not Assessed at all	Not Assessed at all	Not Assessed at all	Over Assessed	Not Assessed at all	Not Assessed at all
1B	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed	Under Assessed
2A	Not Assessed at all	Over Assessed	Over Assessed	Over Assessed	Not Assessed at all	Over Assessed	Over Assessed
2B	Under Assessed	Not Assessed at all	Under Assessed	Under Assessed	Over Assessed	Under Assessed	Under Assessed

Table 2.7 results of Figures 2.20 – 2.26 (% marks/%time)

As seen in Figure 2.20, topic 1 which deals with the periodic table has been over assessed in both the % questions asked in 2002 and also the % marks allocated. While both topics dealing with chemical bonding (2) and stoichiometry, formula and equations (3) have been under - assessed in both the % questions asked in 2002 and also the % marks allocated. Section 6, which deals with the chemical concept of rates of reaction, shows the greatest imbalance between the ratio of % questions asked per allocated class time, which is shown to have been over assessed and also the % marks allocated per time, been shown to be under assessed. This displays that students are not being rewarded appropriately for the time spent on a given topic by the number of questions asked on a topic and the marks being awarded. The same situation is shown in optional topic 1A, which deals with materials, whereby again the ratio of % questions asked per allocated class time, which is shown to have been over - assessed and also the % marks allocated per time, been shown to be under - assessed.

In Figure 2.21 which displays the results of the analysis performed on the 2003 Chemistry paper, while topic 3 - stoichiometry, formula and equations is shown to be under - assessed both the % questions asked and the % marks allocated are exactly equal. Again this is the case in topic 2A – atmospheric chemistry whereby both the % questions asked and the % marks allocated are exactly equal, while over - assessed. Again topics dealing with the periodic table (1) shows the greatest imbalance between the ratio of % questions asked per allocated class time, which is shown to have been over - assessed and also the % marks allocated per time, been shown to be under - assessed. Topic 2 – chemical bonding show that while the ratio of % questions asked per allocated class time is under - assessed the ratio of % marks allocated per time is close to the x axis so has been slightly under - assessed in 2003. This is also the case for topic 1B – materials which has been slightly under - assessed in terms of both % questions and % marks allocated.

In 2004 (Figure 2.22) topics dealing with the concepts of chemical equilibrium (8) and environmental chemistry (9) show the greatest imbalance between the ratio of questions per allocated class asked and the marks per allocated classes. In both cases the marks per allocated class is greater than the percentage of questions per allocated class. While both are over - assessed, the ratio of % questions to allocated class time is more appropriate in both topics. Also in this year, topic 3 - stoichiometry, formula and equations is once again shown to be under - assessed but both the % questions asked and the % marks allocated are exactly equal, which was also the case in the 2003 paper. Topic 6 rates of reaction has been shown to again be the most over - assessed topic in both terms of % questions per allocated class asked and the % marks per allocated classes.

Figure 2.23 which shows the assessment of % questions per allocated class asked and the % marks per allocated classes for the 2005 paper, continues to display the under - assessment of topics 2, 3, and 4 which has been seen in all previous years in both % questions per allocated class asked and the % marks per allocated classes. This graph also displays the imbalance that appears in 2005 in questions per allocated class and the marks per allocated classes for topics 5, 6, 7 and 8. In the case of rates of reaction (6), organic chemistry (7) and chemical equilibrium (8) the ratio of % questions per allocated class asked has been calculated to be over - assessed while the ratio of % marks per allocated classes is seen to be under - assessed with the greatest imbalance being observed for topic 6. Fuels and heats of reaction (5) however displays the reverse of these three topics with the ratio of % questions per allocated class has been shown to be over - assessed while the ratio of % marks per allocated classes has been under - assessed.

In 2006, Figure 2.24, topic 6 which deals with rates of reaction has been shown once again to be the most over - assessed topic in both terms of questions per allocated class and the marks per allocated classes, which is a repeat of the trend seen in 2004. Fuels and heats of reaction obtained almost a perfect ratio between the questions per time allocated while the ratio of marks per time allocated is seen to be dramatically under - assessed. Once again sections 2, 3 and 4 are all under - assessed in terms of both % questions and % marks per allocated class, which has been displayed in the previous five years.

Figure 2.25 which displays the results of analysis performed on the 2007 paper shows that once again topic 6 which deals with rates of reaction has been shown to be the most over assessed topic in both terms of % questions per allocated class asked and the % marks per allocated classes, along with topic 5. While stoichiometry, formula and equations (3) and volumetric analysis (4) are once again under assessed, topic 2, chemical bonding has moved closer to the x axis displaying that while this topic is still slightly under - assessed the balance between classes allocated to this topic in the curriculum has been nearly achieved in this paper.

In 2008 (Figure 2.26), the trends which have been observed since 2002 continue in that both stoichiometry, formula and equations (3) and volumetric analysis (4) are once again under - assessed, while chemical bonding is seen to been allocated the appropriate marks per allocated class and slightly over - assessed in terms of questions per allocated class. However in the case of the periodic table (1) a balance has been accomplished between the marks per allocated class and questions per allocated class. Again topic 6 has been shown to be the most over - assessed topic in both terms of questions per allocated class asked and the marks per allocated classes.

In each year every topic has been seen to appear whether in an over - assessed or under - assessed capacity apart from the optional topics which would not be expected to appear every year. Analysis has shown that topic 6, rates of reaction has been readily over – assessed in each of the seven years as has topic 7, organic chemistry, however not to the same extent as section 6. Analysis has also shown that some core topics are under - assessed each year with topics 3 and 4, stoichiometry, balancing and equations and volumetric analysis being under - assessed each year in relation to the number of allocated classes in the curriculum.

2.3.2.2 Sub topic analysis

Figures 2.27 - 2.33 show the appearance of sub topics over the years 2002 to 2008. Summary tables of the data are given in Tables 2.8 and 2.9.

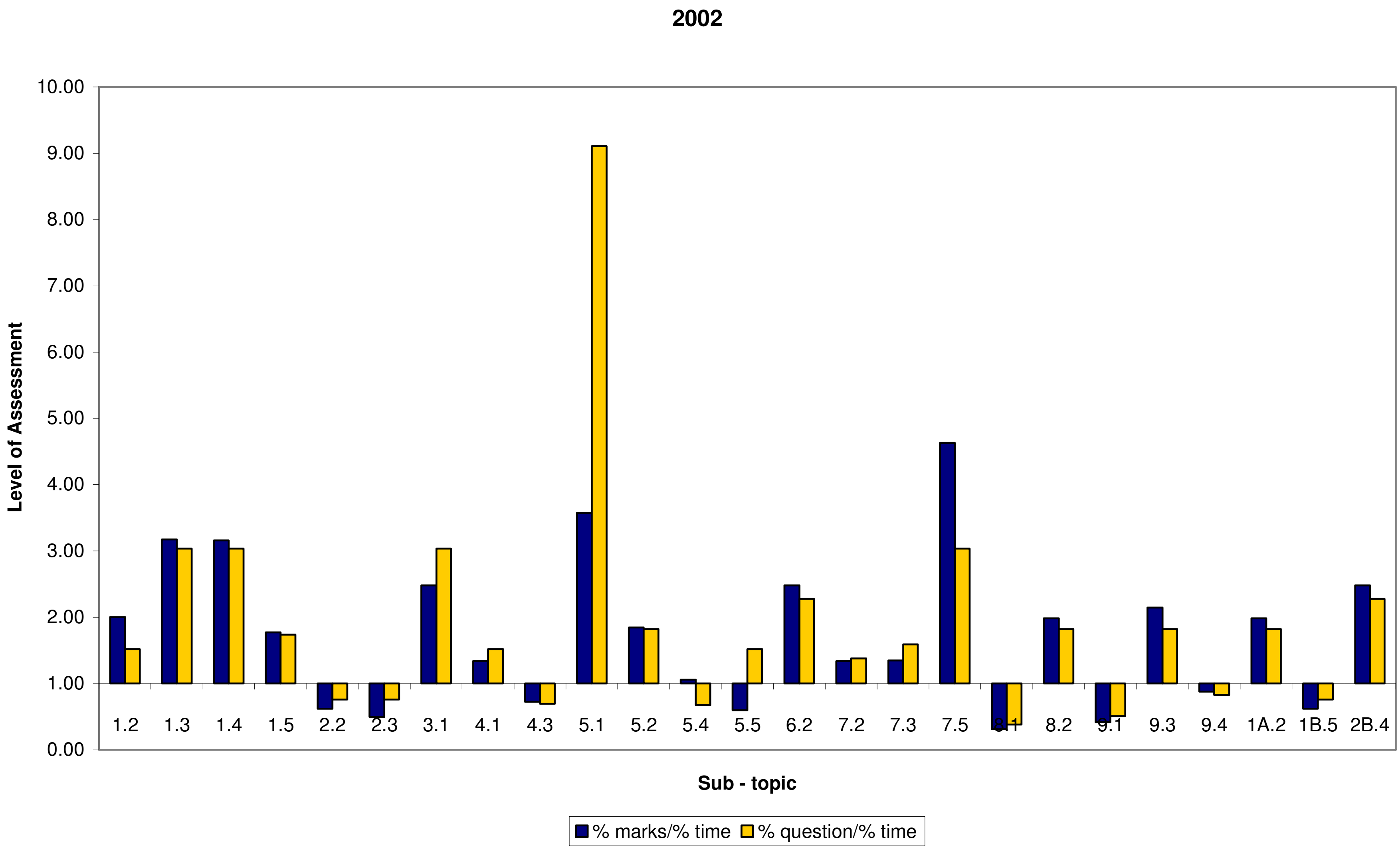

Figure 2.27 – Assessment of sub topics in 2002

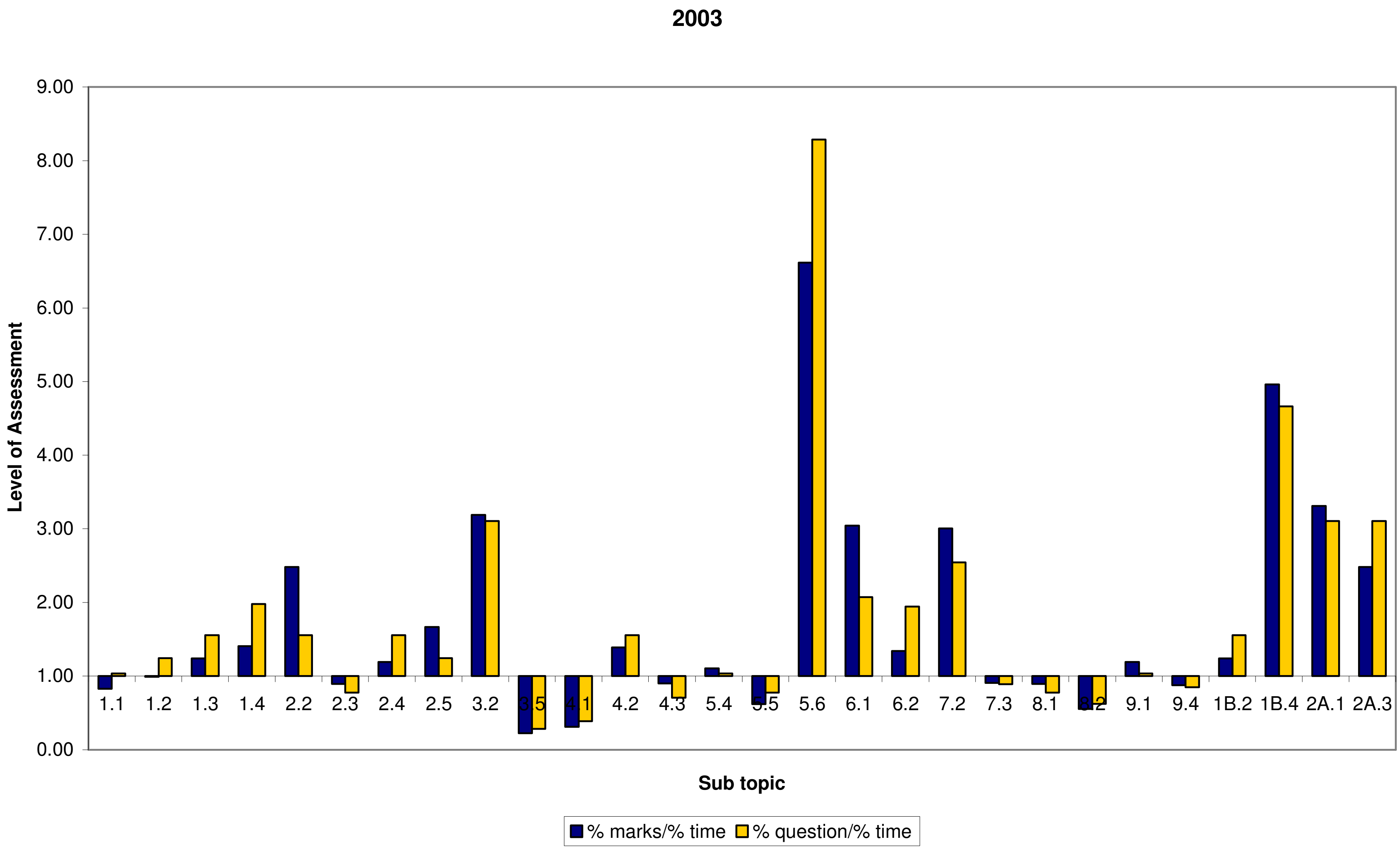

Figure 2.28 – Assessment of sub topics in 2003

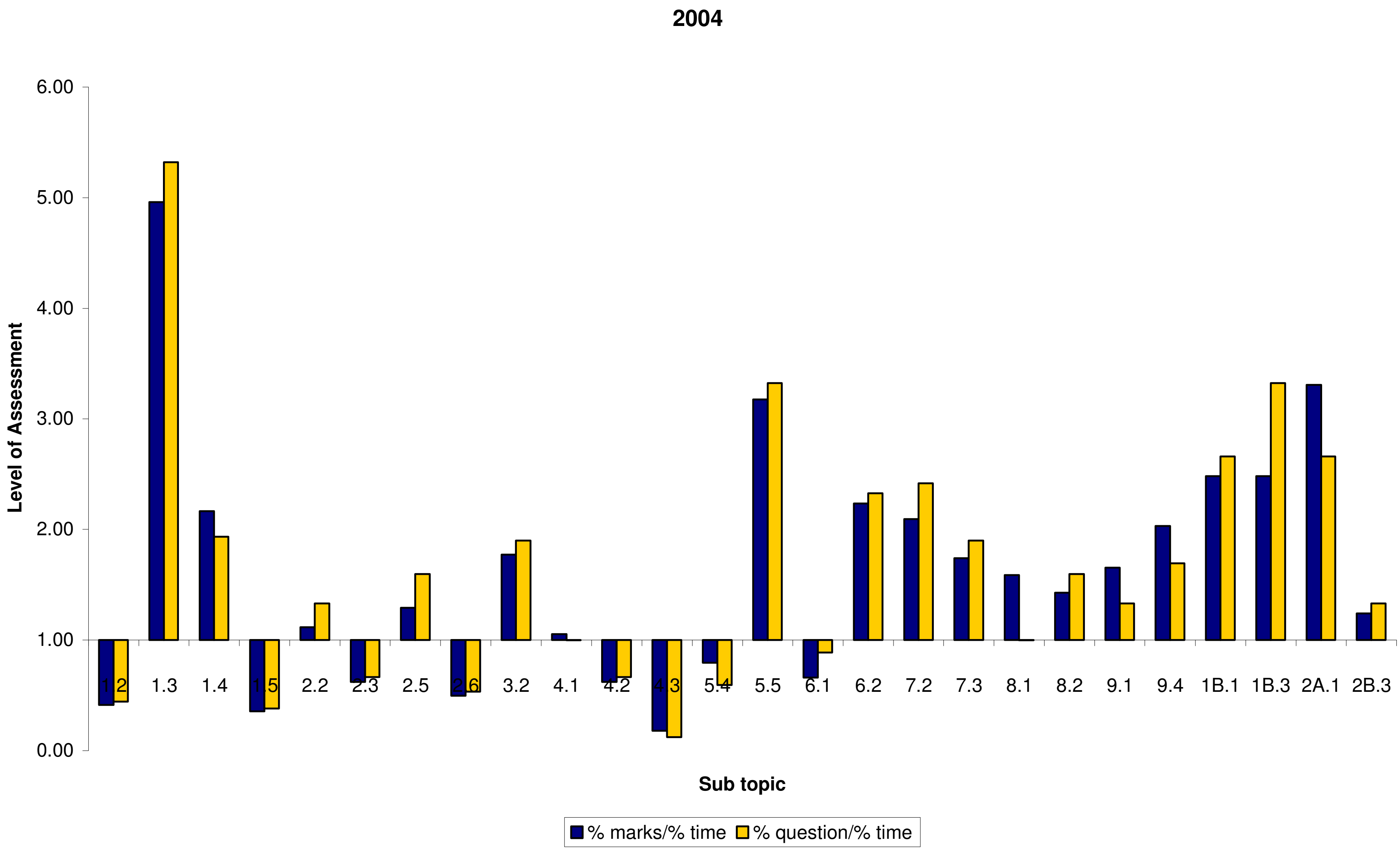

Figure 2.29 – Assessment of sub topics in 2004

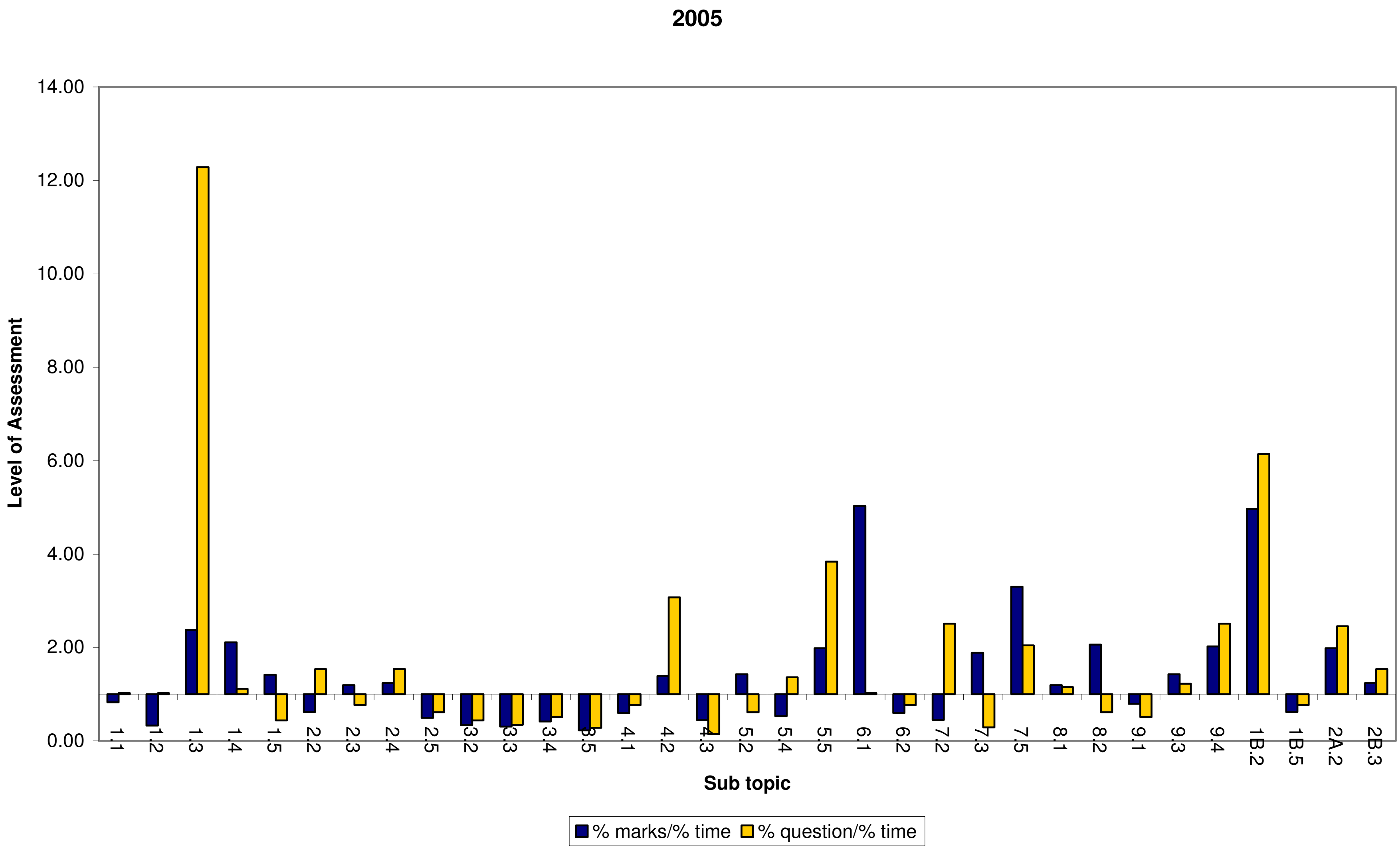

Figure 2.30 – Assessment of sub topics in 2005

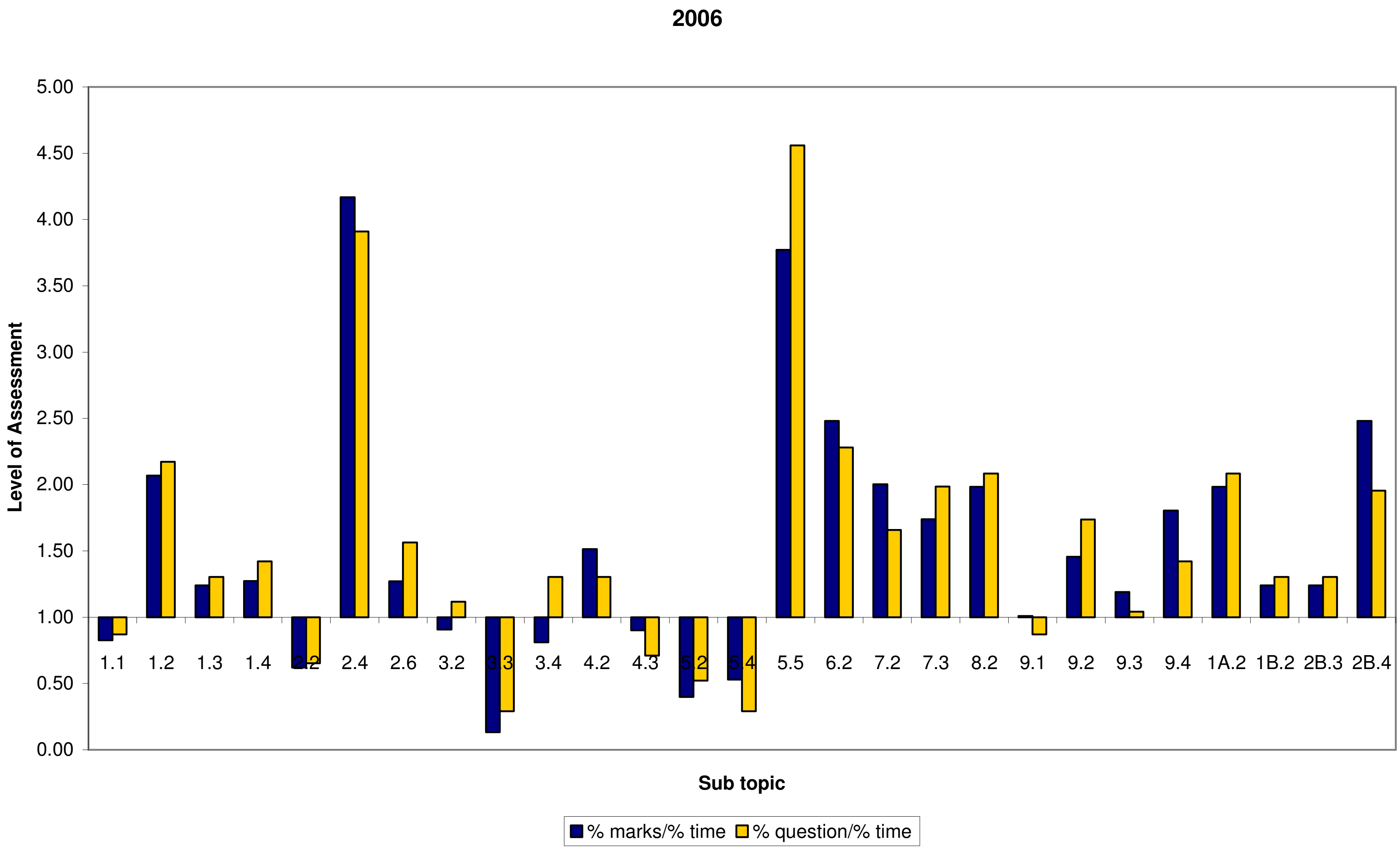

Figure 2.31 – Assessment of sub topics in 2006

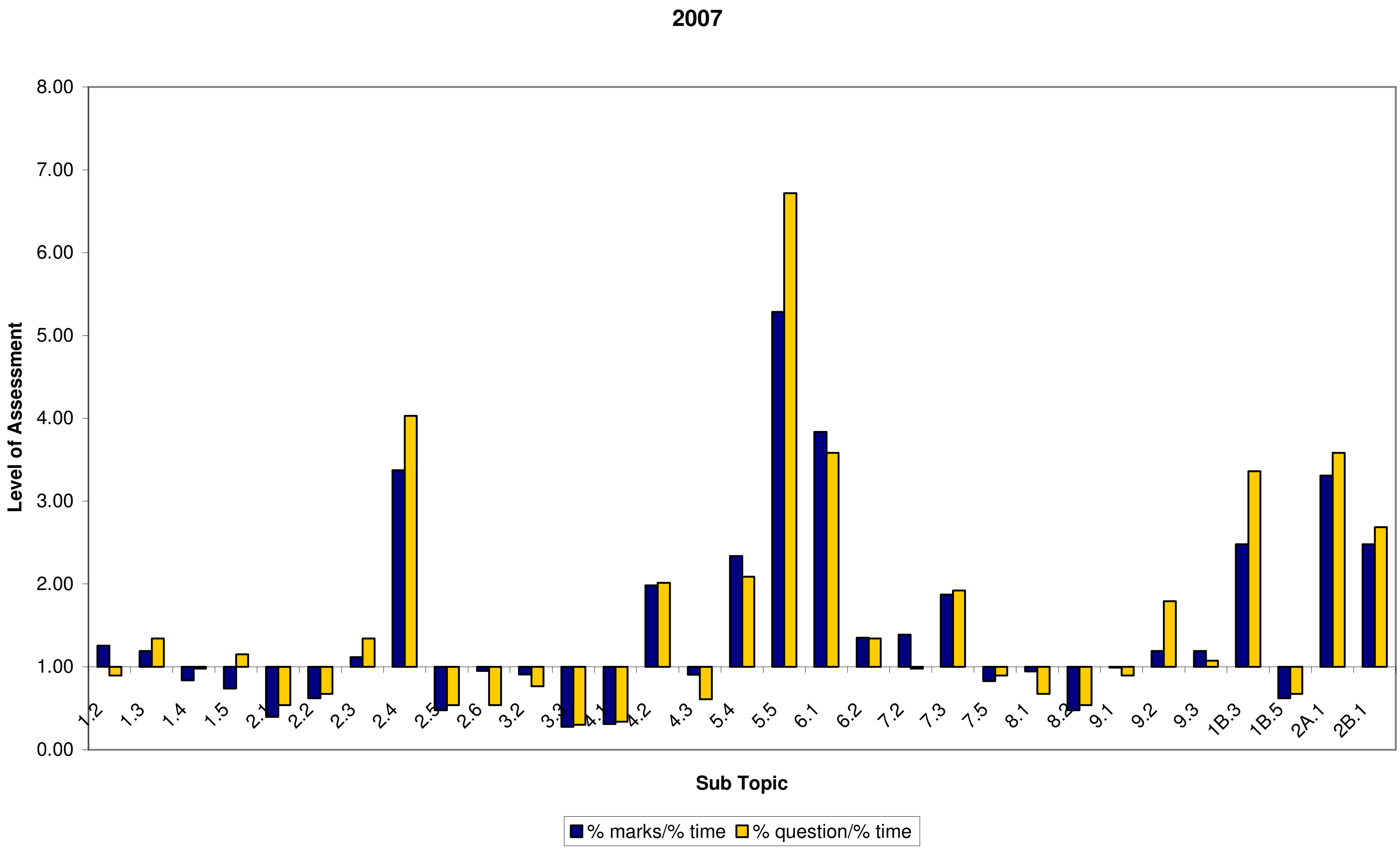

Figure 2.32 – Assessment of sub topics in 2007

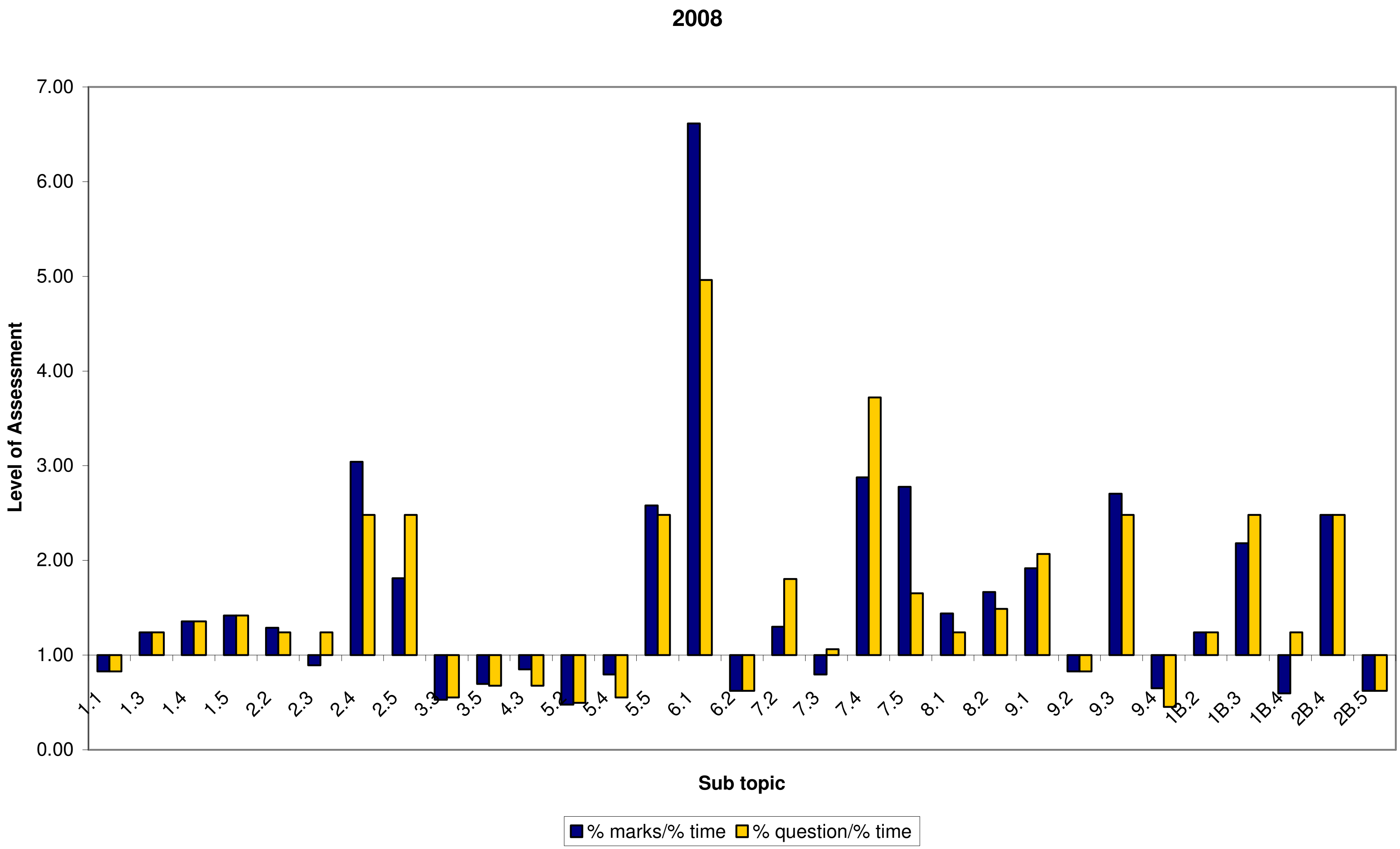

Figure 2.33 – Assessment of sub topics in 2008

Sub topic	2002	2003	2004	2005	2006	2007	2008
1.1	NA	UA	NA	UA	UA	NA	UA
1.2	OA	AA	UA	UA	OA	OA	NA
1.3	OA	OA	OA	OA	OA	OA	OA
1.4	OA	OA	OA	OA	OA	UA	OA
1.5	OA	NA	UA	OA	NA	UA	OA
2.1	NA	NA	NA	NA	NA	UA	NA
2.2	UA	OA	OA	UA	UA	UA	OA
2.3	UA	UA	UA	OA	NA	OA	UA
2.4	NA	OA	NA	OA	OA	OA	OA
2.5	NA	OA	OA	UA	NA	UA	OA
2.6	NA	NA	UA	NA	OA	UA	NA
3.1	OA	NA	NA	NA	NA	NA	NA
3.2	NA	OA	OA	UA	UA	UA	NA
3.3	NA	NA	NA	UA	UA	UA	UA
3.4	NA	NA	NA	UA	UA	NA	NA
3.5	NA	UA	NA	UA	NA	NA	UA
4.1	OA	UA	OA	UA	NA	UA	NA
4.2	NA	OA	UA	OA	OA	OA	NA
4.3	UA	UA	UA	UA	UA	UA	UA
5.1	OA	NA	NA	NA	NA	NA	NA
5.2	OA	NA	NA	OA	UA	NA	UA
5.3	NA	NA	NA	NA	NA	NA	NA
5.4	OA	OA	UA	UA	UA	OA	UA
5.5	UA	UA	OA	OA	OA	OA	OA
5.6	NA	OA	NA	NA	NA	NA	OA
6.1	NA	OA	UA	OA	NA	OA	OA
6.2	OA	OA	OA	UA	OA	OA	UA
7.1	NA	NA	NA	NA	NA	NA	NA
7.2	OA	OA	OA	UA	OA	OA	OA
7.3	OA	UA	OA	OA	OA	OA	UA
7.4	NA	NA	NA	NA	NA	NA	OA
7.5	OA	NA	NA	OA	NA	UA	OA
8.1	UA	UA	OA	OA	NA	UA	OA
8.2	OA	UA	OA	OA	OA	UA	NA
9.1	UA	OA	OA	UA	AA	AA	OA
9.2	NA	NA	NA	NA	OA	OA	UA
9.3	OA	NA	NA	OA	OA	OA	OA
9.4	UA	UA	OA	OA	OA	NA	UA

Table 2.8 Results of Figures 2.27 – 2.33 (% questions/%time)

OA – Over assessed, UA – Under Assessed, NA – Not Assessed, AA – Appropriately Assessed

Sub topic	2002	2003	2004	2005	2006	2007	2008
1A.1	NA	NA	NA	NA	NA	NA	NA
1A.2	OA	NA	NA	NA	OA	NA	NA
1B.1	NA	NA	OA	NA	NA	NA	NA
1B.2	NA	OA	NA	OA	OA	NA	OA
1B.3	NA	NA	OA	NA	NA	OA	OA
1B.4	NA	OA	NA	NA	NA	NA	UA
1B.5	UA	NA	NA	UA	NA	UA	NA
2A.1	NA	OA	OA	NA	NA	OA	NA
2A.2	NA	NA	NA	OA	NA	NA	NA
2A.3	NA	OA	NA	NA	NA	NA	NA
2B.1	NA	NA	NA	NA	NA	OA	NA
2B.2	NA	NA	NA	NA	NA	NA	NA
2B.3	NA	NA	OA	OA	OA	NA	NA
2B.4	OA	NA	NA	NA	OA	NA	OA
2B.5	NA	NA	NA	NA	NA	NA	UA

Table 2.8 cont'd Results of Figures 2.27 – 2.33 (% questions/%time)

OA – Over assessed, UA – Under Assessed, NA – Not Assessed, AA – Appropriately Assessed

Sub topic	2002	2003	2004	2005	2006	2007	2008
1.1	NA	AA	NA	AA	UA	NA	UA
1.2	OA	OA	UA	AA	OA	UA	NA
1.3	OA	OA	OA	OA	OA	OA	OA
1.4	OA	OA	OA	OA	OA	AA	OA
1.5	OA	NA	UA	UA	NA	OA	OA
2.1	NA	NA	NA	NA	NA	UA	NA
2.2	UA	OA	OA	OA	UA	UA	OA
2.3	UA	UA	UA	UA	NA	OA	OA
2.4	NA	OA	NA	OA	OA	OA	OA
2.5	NA	OA	OA	UA	NA	UA	OA
2.6	NA	NA	UA	NA	OA	UA	NA
3.1	OA	NA	NA	NA	NA	NA	NA
3.2	NA	OA	OA	UA	OA	UA	NA
3.3	NA	NA	NA	UA	UA	UA	UA
3.4	NA	NA	NA	UA	OA	NA	NA
3.5	NA	UA	NA	UA	NA	NA	UA
4.1	OA	UA	AA	UA	NA	UA	NA
4.2	NA	OA	UA	OA	OA	OA	NA
4.3	UA	UA	UA	UA	UA	UA	UA

Table 2.9 Results of Figures 2.27 – 2.33 (% marks/%time)

OA – Over assessed, UA – Under Assessed, NA – Not Assessed, AA – Appropriately Assessed

Sub topic	2002	2003	2004	2005	2006	2007	2008
5.1	OA	NA	NA	NA	NA	NA	NA
5.2	OA	NA	NA	UA	UA	NA	UA
5.3	NA	NA	NA	NA	NA	NA	NA
5.4	UA	AA	UA	OA	UA	OA	UA
5.5	OA	UA	OA	OA	OA	OA	OA
5.6	NA	OA	NA	NA	NA	NA	OA
6.1	NA	OA	UA	AA	NA	OA	OA
6.2	OA	OA	OA	UA	OA	OA	UA
7.1	NA	NA	NA	NA	NA	NA	NA
7.2	OA	OA	OA	OA	OA	AA	OA
7.3	OA	UA	OA	UA	OA	OA	AA
7.4	NA	NA	NA	NA	NA	NA	OA
7.5	OA	NA	NA	OA	NA	UA	OA
8.1	UA	UA	AA	OA	NA	UA	OA
8.2	OA	UA	OA	UA	OA	UA	NA
9.1	UA	CA	OA	UA	UA	UA	OA
9.2	NA	NA	NA	OA	OA	OA	UA
9.3	OA	NA	NA	OA	AA	OA	OA
9.4	UA	UA	OA	OA	OA	NA	UA
1A.1	NA	NA	NA	NA	NA	NA	NA
1A.2	OA	NA	NA	NA	OA	NA	NA
1B.1	NA	NA	OA	NA	NA	NA	NA
1B.2	NA	OA	NA	OA	OA	NA	OA
1B.3	NA	NA	OA	NA	NA	OA	OA
1B.4	NA	OA	NA	NA	NA	NA	OA
1B.5	UA	NA	NA	UA	NA	UA	NA
2A.1	NA	OA	OA	NA	NA	OA	NA
2A.2	NA	NA	NA	OA	NA	NA	NA
2A.3	NA	OA	NA	NA	NA	NA	NA
2B.1	NA	NA	NA	NA	NA	OA	NA
2B.2	NA	NA	NA	NA	NA	NA	NA
2B.3	NA	NA	OA	OA	OA	NA	NA
2B.4	OA	NA	NA	NA	OA	NA	OA
2B.5	NA	NA	NA	NA	NA	NA	UA

Table 2.9 cont'd Results of Figures 2.27 – 2.33 (% marks/%time)

OA – Over assessed, UA – Under Assessed, NA – Not Assessed, AA – Appropriately Assessed

While there are 38 core subtopics as stated in the curriculum, there is a variation on the number of sub topics being employed in each of the years analysed where by in 2002 and 2004, 22 core sub topics were examined while in 2005 questions relating to 29 of the core sub topics were asked. The appearance of optional sub topics remains constant at either 4 or 5 of the 14 optional sub topics appearing each year.

In 2002 there were a number of subtopics being both over - assessed, 17 sub topics, and under assessed 9 sub topics (see Figure 2.27). However the sub topic concerning the sources of hydrocarbons has been allocated a high percentage of both questions and marks in relation to the number of classes allocated by the curriculum as it gives the highest peak on this graph, with questions far surpassing the marks. According to this graph and the values obtained, this sub topic is very much over - assessed on this paper in relation to the number of classes allocated. In the same year, chromatography and instrumentation in organic chemistry was the second highest peak on this graph, with the ratio of marks to classes allocated being greater than the ratio of questions to classes allocated. One of the sub topics however, 5.4 shows that exothermic and endothermic reactions were correctly assigned their marks in comparison to the classes allocated however were under - assessed in terms of the questions that should have been asked. In no instance through out the sub topics identified in 2002, did the level of % questions equal the % marks allocated in terms of classes allocated. The closest to this is 1.5 – oxidation and reduction, but while the % questions is almost equal to the % marks allocated, both of these are determined to be over - assessed in comparison to number of allocated classes.

In 2003 the highest peak reached on Figure 2.28, is by the sub section dealing with chemical fuels with again the % of marks allocated being lower than the % questions asked on this sub topic. Also in this year the optional sub topics are showing a larger % appearance and % marks allocation with each of the four identified being over - assessed in comparison to the number of classes allocated. Again sub topic 5.4 shows the closest agreement between % marks and % questions per class allocated, with both values nearing an ideal ratio of 1.

In 2004, sub section 1.3 - radioactivity displays the highest disproportion between % marks and % questions per allocated class, with the optional topics all being shown as over - assessed in both terms of % questions and % marks allocated. This particular year shows the highest number of sub topics being over assessed with 8 subtopics calculated to be under- assessed in both terms of % questions and % marks allocated. Sub topic 5.4, which had demonstrated to be correctly assessed in terms of % questions and % marks allocated in both previous years is seen to be under - assessed in 2004 (Figure 2.29).

The 2005 examination paper (Figure 2.30) displays the most number of sub topics being questioned since the introduction of the 2000 curriculum, and to-date this is still the case with 29 core sub topics and 4 optional sub topics being assessed. Here as in 2004 sub section 1.3 - radioactivity displays the highest disproportion between % marks and % questions per allocated class. Also in this year sub topics; 1.1 - periodic table, 1.2 – atomic structure, 1.5 – oxidation and reduction, 2.2 – ionic bonding, 2.3 – covalent bonding, 5.2 – structure of aliphatic hydrocarbons, 5.4 – exothermic and endothermic reaction, 7.2 – planar carbons, 7.3 – organic chemical reactions and 8.2 – le chateliers principle, all display under - assessment in one of the two variables, % marks per class allocated or % questions per class allocated, while being over - assessed in the other. This shows that there is an unequal distribution in the marks awarded for a given question on a sub topic and students are not receiving apt marks for their work.

In 2006 (Figure 2.31) both sub topics 3.3 – the mole and 5.5 – oil refining were found to be over - assessed in terms of the % marks allocated per class and also % questions appearing per class. Again all of the optional sub topics were over assessed in this year while only two sub topics displayed under - assessment in one of the two variables, % marks per class allocated or % questions per class allocated, while being over - assessed in the other, 3.2 – gas laws and 3.4 – chemical formulae. 2006 also displayed the smallest number of sub topics being under - assessed in terms of % marks per allocated class and % questions per allocated class.

2007 demonstrates the second highest number of core sub topics being employed on the paper – 27. Of these sub topics the largest peaks are shown by sub section 5.5 – oil refining and its products and 2.4 – electronegativity each displaying that the ratio of % marks allocated per class was less than the % questions asked per class in this year. This year also shows a large number of sub topics being under - assessed in terms of both % marks allocated per class and % questions asked per class as 13 sub topics appear below the x axis in Figure 2.32.

Sub topic 6.1 – reaction rates, shows the highest peak in Figure 2.33 with ratio of % marks allocated per class surpassing the ratio of % questions asked per class in this year, 2008. Only two sub topics have shown under - assessment in one of the two variables, % marks per class allocated or % questions per class allocated, while being over - assessed in the other 2.3 – covalent bonding and 7.3 – organic chemical reactions.

2.3.3 Meeting the objectives of the course

In Figure 2.3, the objectives of the 2000 Leaving Certificate Chemistry Course were presented stating the abilities students are expected to display upon completion of the Leaving Certificate examination. In order to be allowed to state whether or not a student possesses such abilities, the role of the examination system is to test these abilities. From the analysis completed on Leaving Certificate papers from 2002 to 2008, the question of whether the objectives of the 2000 curriculum have been met can now be discussed.

Tables 2.10 and 2.11 display the objectives stated in the Leaving Certificate Chemistry curriculum and how the analysis (in bold) has shown how they have been assessed during the course of the Leaving Certificate Chemistry higher level examination.

Knowledge
Are students tested to see if they possess knowledge of basic chemical terminology, facts, principle and methods? **Yes** Are students tested to see if they possess knowledge of scientific theories and their limitations? **Yes** Are students tested to see if they possess knowledge of social, historical, environmental, technological and economic aspects of chemistry? **Yes** **A large % of questions employed at Leaving Certificate level have been shown to be of knowledge type upon the application of Bloom's taxonomy**
Understanding
Are students tested to see if they possess an understanding of how chemistry relates to everyday life? **Yes** Are students tested to see if they possess an understanding of scientific information in verbal, graphical and mathematical form? **No, while students are tested in both graphical and mathematical form no verbal element exists in the current assessment method** Are students tested to see if they possess an understanding of basic chemical principles? **Yes, this objective is very similar to the first knowledge statement** Are students tested to see if they possess an understanding how chemical problems can be solved? **This is quite a difficult objective to agree with as it has not been determined by this study that there are questions which can be termed as problems rather than exercises.** Are students tested to see if they possess an understanding of how the scientific methods apply to chemistry? **Yes application questions which have been identified using Bloom's taxonomy have required students to apply their comprehension of the scientific method to areas of chemistry**

Table 2.10 Assessment of the objectives of the 2000 Chemistry Higher Level

Skills
Are students tested to see if they possess the skills to follow instructions given in a suitable form? **No, students do not complete a practical session as part of their terminal examination and as of yet no form of assessment it performed on their mandatory experiments which are completed during the course of their two years.** Are students tested to see if they possess the skills to perform experiments safely and co-operatively? **No, students do not complete a practical session as part of their terminal examination and as of yet no form of assessment it performed on their mandatory experiments which are completed during the course of their two years.** Are students tested to see if they possess the skills to select and manipulate suitable apparatus to perform specified tasks? **No, students do not complete a practical session as part of their terminal examination and as of yet no form of assessment it performed on their mandatory experiments which are completed during the course of their two years.** Are students tested to see if they possess the skills to interpret experimental data and assess the accuracy of experimental results? **While students have been asked to interpret experimental data, there have been no examples of questioning observed during the course of this analysis which require students to assess the accuracy of experimental results.**
Competence
Are students tested to see if they posses a competence in the ability to translate scientific information in verbal, graphical and mathematical form? **Yes, application questions which have been identified using Bloom's taxonomy have required students to perform such translations in terms of calculations and graphs.** Are students tested to see if they posses a competence in the ability to organise chemical ideas and statements and write clearly about chemical concepts and theories? **No** Are students tested to see if they posses a competence in the ability to report experimental procedures and results in a concise, accurate and comprehensible manner? **No** Are students tested to see if they posses a competence in the ability to explain both familiar and unfamiliar phenomena by applying known laws and principles? **Yes, comprehension questions which have been identified using Bloom's Taxonomy have asked students to utilise basic knowledge of laws and theories to explain phenomena** Are students tested to see if they posses a competence in the ability to use chemical facts and principles to make chemical predications? **No, synthesis questions which require students to predict situations were not identified during the analysis of the papers.** Are students tested to see if they posses a competence in the ability to perform simple chemical calculations? **Yes, these questions were placed in the analysis section of Bloom's taxonomy, which while it possessed a lower percentage on each of the examined papers, were still evident.** Are students tested to see if they posses a competence in the ability to identify public issues and misconceptions relating to chemistry and analyse them critically? **No**
Attitudes
Are students asked their attitudes/opinions in the advances in chemistry and their influence on our life? **No, students are provided with statements and calculations but are not asked to voice their opinion.** Are students asked their attitudes/opinions about what the understanding of chemistry contributes to the social and economic development of society **No, students are provided with statements and calculations but are not asked to voice their opinion.** Are students asked their attitudes/opinions about the range of vocational opportunities that use chemistry and how chemists work **No, students are provided with statements and calculations but are not asked to voice their opinion.**

Table 2.11 – Continuation of assessment of the objectives of the 2000 Chemistry Higher Level curriculum

As can be seen from Tables 2.10 and 2.11, from the twenty three objectives, stated in the curriculum, only eight objectives have been identified by this study as being achieved by the current assessment used at Leaving Certificate level. The objectives under the heading of skills and attitudes are met to the least extent as there is no scope under the current terminal examination for either of these objectives to be met.

Students are not required to express personal opinions about the impact that chemistry has on their lives or society during the course of the examination, and to date no practical element has been incorporated into the final assessment, which would be the only possible way of assessing students' experimental skills which have been outlined in the stated objectives.

2.4 Conclusion

From the application of Bloom's taxonomy to the nine years of examination papers and as was seen in Section 2.3.1, the levels of lower order questions identified in each year in examinations, far surpasses the % of questions and marks allocated to those questions of a higher order.

The lack of the appearance of the higher order questioning types, synthesis and evaluation, has resulted in no marks being allocated for these questioning types. It would be expected that had these styles been employed on the examination that they would merit a greater percentage of the marks allocated. These questions demand a higher level of understanding on the part of the student and this would be reflected in a greater reward for students' attempts to defend their opinions and summations of chemical knowledge. Interestingly with the introduction of the 2000 curriculum which was examined in 2000 and 2001, analysis of both of these years has shown that the inclusion of higher level questions yielded a higher percentage that those years examined under the 2000 curriculum.

While it is not suggested that examinations should on any level only employ higher order questions, it is expected that a balance can be obtained in order to assess all levels of student understanding. Bloom's model of student learning[15] states that students must have a competence in the lower order questions before they can begin to be able to answer the higher order questions. Therefore it stands that in order to give all students an opportunity to obtain some level of completion of the exam, a certain level of the paper should be allocated to lower order question styles. However in order to fully assess the level of understanding that a student has engaged in during their Leaving Certificate years, there must be a full representation of all levels of lower and higher order questioning.

From the analysis performed on the appearance of subtopics in terms of marks allocated and questions asked there was a constant disagreement between these two ratios. During the six years examined there were no cases identified where the ratio of % marks per allocated class exactly matched by the ratio of % questions per allocated class. Some sub topics have appeared in each of the seven years analysed, in either an under - assessed or over - assessed capacity but have appeared each year since 2002.

Among these were: the electronic structure of atoms, oxidation and reduction and factor affecting the rate of reaction, while on the other end of the scale some sub topics have appeared less frequently or not at all. These included sources of hydrocarbons, chemical compounds, tetrahedral carbons and chemical fuels.

However in the case of these subtopics, they have been identified according to the depth of treatment section of the curriculum structure (see Figure 2.3). While some of these sections may include balancing of equations and chemical bonding, which would be considered to be essential components of basic chemistry, have not been identified as separate subtopics. These have been identified as part of the volumetric analysis or organic chemistry section e.g. if a student is asked to balance an organic chemistry equation dealing with the combustion of a hydrocarbon, that has been considered to be part of the organic chemistry sub-topic rather than the application of students' ability to balance an equation which is a different sub-topic.

From the analysis performed on the question/time and mark/time ratio which was a result of the analysis performed in terms of sub topics, some core topics are being over - assessed, especially in the case of rates of reaction which has been observed to be the highest ratio of over - assessment in five out of the seven analysed years. Others topics are being constantly under - assessed in relation to the time that they have been allocated in the new curriculum, with examples of stoichiometry, balancing equations and volumetric analysis. It must be stated however that this analysis shows the imbalance in questions/time to that topic in the curriculum and mark/time allocated to that topic in the curriculum, which shows if a topic is being over or under - assessed in comparison to the time devoted to it in the curriculum.

From this analysis it would be suggested that revisions be made to the employment of questions on the terminal examination to appropriately reflect the amount of time suggested to allocate to that topic/sub – topic. It is only right that if a chemical concept requires twenty two classes to complete that students receive appropriate questions and marks to reflect the effort and time spent learning this concept.

The imbalance which is displayed in Figures 2.20 to 2.33, suggests that a review of both the curriculum and the questions asked of students relating to topics/sub topics needs to be performed by the NCCA and Department of Science and Education to ensure a balance is found between the level of questioning employed in the Leaving Certificate Chemistry examination and the appearance of topics/sub topics.

As can be seen in Section 2.3 the objectives have not been met completely, from those stated in the Chemistry curriculum, except those relating to student knowledge. The area which has shown the greatest lack of assessment is students' display of skills obtained during their completion of the Leaving Certificate course and student attitudes. In no case during the assessment are students required to complete a practical session, as the terminal examination is purely a written examination. It is suggested that the experimentally based questions, which are examined in Section A will draw on student experiences in the laboratory with the completion of their mandatory experiments; however there is no questioning in place to differentiate those students who have completed the experiment and those who have simply memorised the procedure in the text book. Neither are students required to, at any point, express their individual opinions or attitudes towards the impact that chemistry has on their lives or on society but rather are provided with chemical facts. The lack of STS related questions up to 2004 has already been highlighted in the thesis of Jemma Lynch[5] and so has not been focused on in this study.

The curriculum is currently under revision, predominantly looking at the inclusion of a second component to address the underassessment of laboratory work. However, it is suggested from the analysis performed during this study that the level of questioning employed requires attention as well as the reflection of the allocated class period to the number of questions and marks awarded for topics/sub topics in the curriculum.

It is hoped that a revision of the terminal examination with closer attention being paid to the stated objectives outlined by the Leaving Certificate Chemistry curriculum would result in students completing this examination with all of the expected abilities appropriately assessed.

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<u>Chapter 3</u>

Use of Classroom Response Systems for continuous assessment to encourage student engagement

3.1 Introduction

Classroom response systems have been used as a rapid and efficient means of carrying out a method of formative assessment - continuous assessment. This chapter will detail the type of questioning possible and the development of appropriate questions.

3.1.1 Classroom response systems (PADs)

As stated in chapter 1, formative assessment when used appropriately can actively engage students in lecture material which is often seen as abstract and difficult to most students. One of the problems with the introduction of continuous assessment (a form of formative assessment) especially in cases where the cohort is large, approximately 200 students, are the logistics involved in dealing with a large group.

Clickers, personal assessment devices (PADs) and classroom response systems are all names describing the electronic system employed by educators to sample the knowledge of all their students, at any time, without students having to risk embarrassing themselves in front of their peers. A student who is hesitant to raise a hand in response to certain chemical questions may feel no inhibition to responding when using the PADs[1].

As with the introduction of any new technology as an educational tool, the pedagogical reasoning behind their implementation must stand up to scrutiny. Draper[2] sets forward the following arguments for the use of PADs in the classroom, in that they can provide:

- Assessment, both formative and summative;
- Formative feedback on learning;
- Formative feedback on teaching to the lecturer;
- Room for peer assessment;
- The opportunity to build community mutual awareness;
- An opening for experiments using human responses;
- Opportunity to initiate a discussion especially in small groups.

Research has shown that classroom (lecture hall) methods that actively involve students result in substantially greater learning than pure lecturing does.[1,2,3,4,5] Active learning methods may involve working in laboratory settings or on projects, interactive lecture demonstrations or peer discussions during lectures about conceptual questions, which must be types that probe the meaning of a subject, not just the ability to calculate[3].

The PADs system resembles pared-down TV remote control units and they work in the same way. Clickers use infrared or radio-frequency technology to transmit and record student responses to questions. A small, portable receiving station is placed in front of the class to collect and record student responses. Each PAD can be registered to a student and generates a unique identifiable signal.

The system allows for active participation by all students and may provide immediate feed back to the instructor – and the students – about any confusion or misunderstandings of the material being presented, only if appropriate question have been developed to facilitate the identification of these misunderstandings[1].

PADs have been making inroads in universities and colleges in the United States since the late 1990s, as faculty members explored how to increase student interaction[4]. Interaction and feedback are particularly challenging in large lecture environments, where class size limits lecturer - student interaction. PADs can be used to help identify key concepts which students have difficulty in answering and can provide valuable information to the lecturer about how the cohort are engaging with lecture material.

As stated by Douglas Duncan, the sensible use of PADs in class rooms and lectures can aid the educator to[1]:

- Measure what students know before they are taught (pre-assessment);
- Measure student attitudes;
- Find out if students have done their prescribed reading;
- Get students to confront common misconceptions;
- Transform the way that educators perform demonstrations;
- Increase students' retention;

- Test students’ understanding;
- Make some forms of grading and assessment easier;
- Facilitate testing of conceptual understanding – with appropriate questions;
- Facilitate discussion and peer instruction;
- Increase class attendance.

Questions posed during lectures can be used to provide feedback to the learner on how well s/he has understood the material and compare her/his progress with that of other classmates. The performance of the class can provide feedback to the instructor on whether concepts have been understood by the whole class or require further elaboration[5].

The use of PADs as an active learning strategy requires proper planning and time commitment from instructors. The instructor has to spend some time learning to navigate through the software. Some time is also required to create appropriate questions and the participant lists in order to link individual students to their response or in order to track a students’ performance over a semester period[6].

It has been suggested that in any situation where an educator is contemplating using technology in their teaching, the foremost thing that they need to keep in mind is that the technology is only a teaching and learning tool. Learning is enhanced only if the pedagogy, which has been outlined earlier in this chapter in relation to the use of PADs, takes first place and the technology second[5].

Some of the benefits and problems which have been associated with the implementation of the clickers system are stated in Table 3.1[7].

In addition to the stated constraints experienced in Table 3.1 in relation to the usage of PADs the limitation of the types of questioning was also of concern. The main format of questioning employed in any of the previously mentioned studies has been multiple choice questions but, as stated in the literature, they also raise their own concerns and benefits.

<table>
<tr><th>Benefits</th><th>Problems</th></tr>
<tr><td>
• Using handsets is fun and breaks up the lecture;
• Makes lectures more interactive/interesting and involves the whole cohort;
• The anonymity allow students to answer without embarrassing themselves;
• Allows problem areas to be identified;
• Gives a measure of how well the lecturer is putting the ideas across;
• Checks if students are understanding concepts as well as they think they are.
</td><td>
• Setting up and use of handsets take up time in lectures;
• Can distract from the learning point entirely;
• Main focus of lecture seems to be on handset use and not on course content;
• Some students can vote randomly and mislead lecturers;
• Sometimes the lecturer seems to be asking questions just for the sake of it.
</td></tr>
</table>

Table 3.1 Benefits and problems associated with 'clickers' [7]

3.1.2 Multiple Choice Questions

While there are a number of different methods of assessment available to educators, some often choose to rely on simple methods for testing – such as multiple choice questioning – or on the traditional methods of written examinations. Berk quips that the multiple choice questioning format 'holds the world record in categories such as most popular, most unpopular, most used and most misused, most loved and most hated'[8].

The multiple choice questioning format has been criticised almost since the time of its inception. The most formidable challenge perhaps was during the 1990s as an increasing number of educationalists, guided by the constructivist theories proffered by Maron & Saljo[9], Entwistle[10], Biggs[11] and Ramsden[12], argued for teaching and assessment methods that encourage higher order thinking skills.

Multiple choice questions have a reputation of being easy to set, easy to answer and easy to mark and it is recognised there is a danger that they may be all of the above. In their defence however it has been argued that any form of assessment can be designed for a particular level of difficulty[8]. The difficulty level depends upon the nature of the questions asked and also how the multiple choice questions fit into the overall scheme of assessment.

Multiple choice types of assessment have some disadvantages compared to written assessment. Educators cannot be certain if students have demonstrated knowledge levels appropriate to their marks, as guessing and looking for patterns are obvious tactics which can be employed to answer this form of questioning. It has been suggested that the use of multiple choice questions may encourage learning of surface detail rather than a deeper understanding of the under lying concepts[13].

Some students will learn by rote regardless of which assessment format is employed in their learning. The development of appropriate multiple choice questions can be used to distinguish the surface learner from the deeper learner by setting questions which require analysis and application skills.

The element of guess work is a problem that educators also readily associate with multiple choice questions. It has been argued that this is no worse than a student who adopts the 'write-all-you-know' approach to a question for which s/he can generally expect to pick up marks for the correct points the marker has laboriously identified within the largely irrelevant answer[14].

There are various possibilities that have been suggested to coping with the problem of guessing including[15]:

- Use of negative marking to discourage students from equating multiple choice with multiple guesses;
- Adopting mathematical strategies to "normalise" marks achieved;
- Ensuring there are sufficient options for each question and/or raising the overall pass mark for the test to reduce the likelihood of a student passing through chance.

There are a number of advantages associated with the multiple choice questions for their defence as a form of valid assessment. They are objective, so variations in marking due to subjective factors are eliminated and this also makes them easy to mark[16]. They are efficient because questions take less time to complete on the part of the student and therefore it is possible to test a greater range of the curriculum through their employement[15].

Multiple choice questions are versatile and it is only if they are inappropriately used or poorly designed that there is a risk of being too easy or for them to be concentrated on surface level learning.

Poorly designed questions may[17]:

- Give away clues to the answer;
- Fail to test the skills required by the intended learning outcomes;
- Contain obvious wrong answers which can be eliminated by students with only limited knowledge;
- Encourage rote learning;
- Confuse or frustrate students with sound understanding.

Multiple choice questioning is an economical and versatile assessment instrument capable of providing the necessary precision required to measure learning outcomes. Multiple choice questions are capable of being truly effective as long as psychometric editing is performed; however this is essential for all of types of assessment[18].

During the course of their employment in this study, the disadvantages and advantages of multiple choice questioning have been taken into account to ensure that they are used in an appropriate and accessible manner.

The multiple choice format has been used as a form of continuous assessment in this study, where a continuous assessment element was introduced into a physical chemistry lecture and contributed 20% to the end of year examination. Students also completed a written examination at the end of semester and it was hoped that the use of multiple choice questioning in this format will help to encourage student engagement in lecture material and provide feedback to lecturers as to areas of difficulty through appropriate questioning.

Taking into consideration all of the stated advantages and disadvantages of both the ‘clickers (PADs)’ and of multiple choice questions put forward by the literature, it was decided that a continuous assessment element would be implemented into a physical chemistry module within Dublin City University. This continuous assessment element would utilise the multiple choice format and be implemented using the PADs system which was easier when dealing with a large cohort instead of traditional pen and paper assessment and results will be discussed in chapter 3.

While this form of technology has been employed in a lecture environment to introduce formative assessment to 2nd year students, another form of technology will be discussed later, in chapter 4, to show how this was used to implement another formative assessment to 1st year chemistry students.

3.2 Methodology

The continuous assessment (CA) element was introduced to encourage of student engagement and these CA elements involved questions underpinning the core concepts of the physical chemistry module – CS201 Kinetics and Thermodynamics. Results from previous years have shown that students find this module particularly challenging and lecturers have associated student difficulties with student lack of interaction with the course material and their inability to deal with the required mathematical element. The CA element accounted for 20% of the final mark for this particular module. The PADs were used to as the means for conducting the CA element.

This module consisted of twenty-four lectures, twelve lectures based on the core concepts of Kinetics and twelve lectures on Thermodynamics. 126 students from four different programmes (Analytical Science, Biotechnology, Science Education and Chemical & Pharmaceutical Sciences) registered for module CS201, which is a 2nd year undergraduate chemistry module, with an average of 81 students attending the 7 assessment elements.

The questions were developed in collaboration with the two lecturers involved. The core concepts in both Kinetics and Thermodynamics were at the fore-front of the issues which had arisen in previous years. The questions needed to assess students understanding of basic concepts as, with the demanding nature of this subject area, it is essential that students have a grasp of the basic elements before they can progress onto the more complex and advanced concepts.

The PADs used in this particular instance were the Quizdom R4 remotes which are used in conjunction with Microsoft PowerPoint 2003/2007 edition. These remotes operate by infrared technology and receive data from each handheld remote to a parent hub connected to the lecturers' laptop or PC. The lecturer creates their presentation on Microsoft PowerPoint and launches the Quizdom Interactive Quiz on demand. This software along with 200 student hand held remotes can cost in the region of €16,000 in 2006.

The PADs were first employed to assess students' basic mathematical abilities and to shed light on procedures which required more attention from students before attempting the more complicated calculations involved in chemical kinetics and thermodynamics. Students first attempted the questions then were shown the correct answers and were then allowed to retry the questions in an online environment (Moodle) to re-assess themselves. This format was employed for each of the CA elements and students were able to retry each assessment in the online environment for 4 weeks after the end of the semester before their written examination.

Figure 2.1 displays the pattern of use of the PADs within the lecture/module in 2006/2007 semester II.

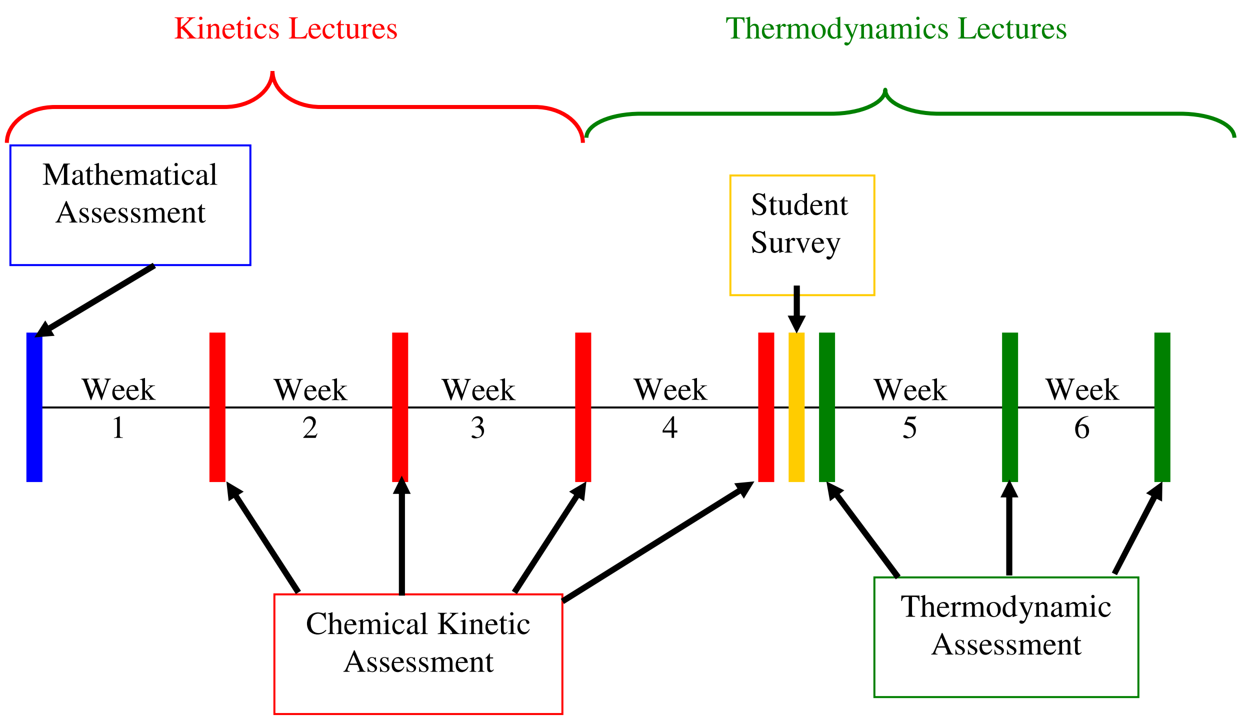

Figure 2.1 Time line of CA elements in CS201

The PADs were used during the final ten- fifteen minutes of the lecture to ask the students approximately five questions based on the concepts covered during the previous lectures. Students were given approximately two – three minutes to answer each question, with additional extra time given when questions involving mathematical calculation had been asked. When collection of data had finished, a histogram would be displayed, showing the number of people who had chosen each multiple answers.

Everyone participating could see the degree of consensus, while knowing themselves their selected answer and so how this compared to the rest of the cohort. Each person's response was anonymous to the rest of the audience, but for the purpose of the assessment the lecturer could track a students' performance based on their allocated eight digit student number which was required to log into the PADs system.

During this module students were also asked to complete a survey in week 6 of the semester, which contained a series of statements about the PADs and continuous assessment element. Students were informed that opinions expressed during this survey were for research purpose only and had no impact on or contribution to their assessment.

3.3 Results & Discussion

The questions which this study aims to answer are:

- Can the PADs be used to help to develop independent learning?

- Can suitable questions be employed to test student abilities in relation to physical chemistry concepts, given the limitations of PADs?

- Can the introduction of PADs be effectively used to engage students in module CS201?

- What are student opinions in relation to the introduction of a continuous assessment element and the tool used to assess them?

3.3.1 Students Mathematical Assessment

At the beginning of lectures for module CS201, students were required to conduct a series of questions involving mathematical techniques. It was hoped that the assessment of students' mathematical abilities would help to identify for both the lectures and students themselves, those who had difficulty with simple calculations, derivations and graphical interpretation.

The PADs were introduced so students would become familiar with how these assessment tools would be incorporated into future lectures. This first introduction allowed students to interact with the lecturer and discussion began among students as to what the correct answers could have been. Students were given adequate time to complete this assessment and, as it would not contribute to the CA element, students were also shown immediately how they and their class mates had performed in this assessment element. Students were able to compare their performance with those of their class mates and identify what mathematical areas were posing problems for the cohort.

Figure 3.2 shows the percentages obtained in the mathematical assessment which involved eight questions on procedures such as indices, deriving, formula manipulation and graphical interpretation. The results displayed show that none of the 79 students completing this assessment correctly answered all of the eight questions. The majority of students correctly answered four of the questions, with only 48.0% of students with more than four correct answers.

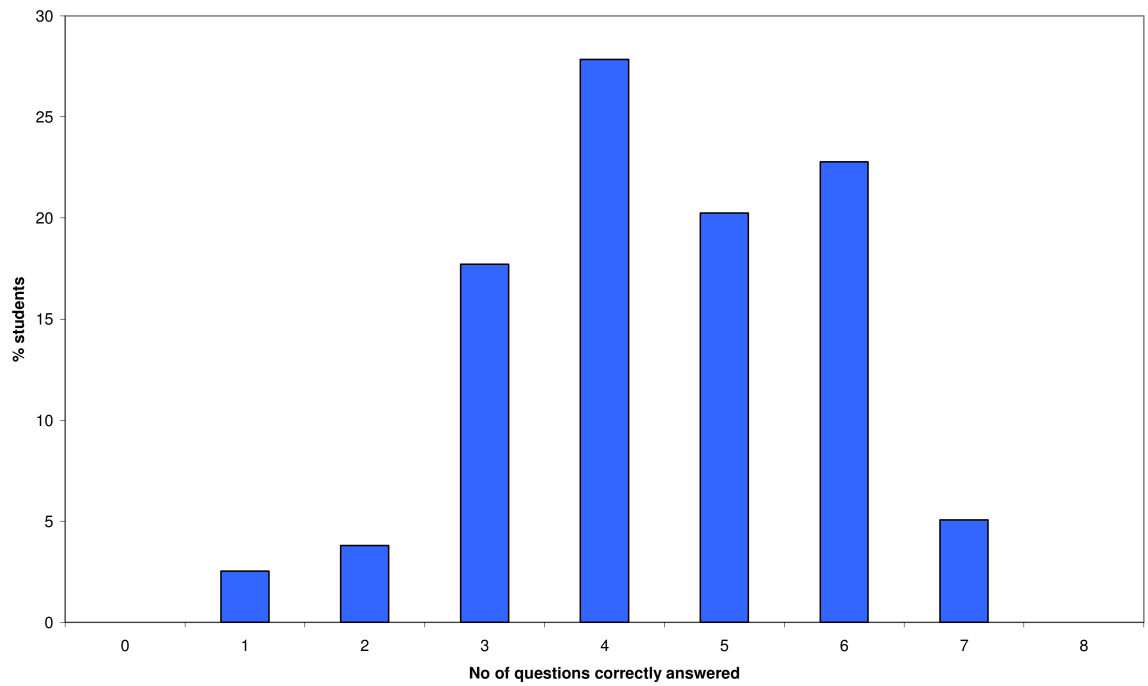

Figure 3.2 – Students' performance on mathematical assessment at beginning of CS201

The question which most students correctly answered involved indices (see appendix B.1, in future text this is noted as B.1), which 93.7% of students correctly answered this question. The question poorly answered, with only 29.1% of students correctly answering, required students to arrange the equation of a line from a given graph (B.7). From the results obtained for questions which required students to perform graphical interpretations were poorly answered with the highest percentage of students correctly answering a graphical interpretation question being 48.1%.

The number of questions correctly answered by student varied from 1 correct to 7 correct however no student incorrectly answered all 8 questions which was somewhat encouraging while on the other end of the scale no student correctly answered all 8 questions either. Among the questions asked of students were indices (B.1), determination of rate (B.2), derivation (B.3), graphical interpretation (B.4, B.6, B.7, and B.8) and formula manipulation (B.5).

From these questions it was determined that while B.1, B.2, and B.3 were answered well by the cohort with 97%, 75% and 87% respectively, there was a noted decrease especially in those questions that required students to perform graphical interpretation. Questions B.4, B.6 and B.7 showed the lowest percentages of this assessment with 39%, 35% and 29% of students selecting the correct answer, with B.7 being the question which the majority of students were unable to answer correctly.

In this question (B.7) students were given a graph with labelled x and y axis and asked to identify the correct equation of the line for this particular graph. The majority of students reverted back to their learned formula of $y = mx + c$, while if they had applied this known formula to the graph itself they would have correctly identified the slope. This shows that while students had learned the correct formula to calculate the equation of a line, they were unable to apply this knowledge to the given graph.

In question 1(B.1), students were asked to identify which mathematical expression was the same as $\sqrt[3]{x}$ from a choice of four possible answers. Only 2 students were unable to correctly identify $x^{1/3}$ as the equivalent, as they chose x^3 demonstrating that they didn't understand the significance of the cubed root. In the second most correctly answered question, (B.3) students were asked to correctly identify the derivative of $3x^4$. 87% of the cohort were able to identify correctly that the derivative was $12x^3$ while the majority of the students incorrectly identified the derivative of $3x^4$ as 12x. Students identifying this answer have correctly multiplied the power by the coefficient of x, however they neglected to subtract one from the original power to leave it x^3.

The purpose of this assessment was to highlight to both students and lecturers, the mathematical abilities of the entire cohort and to help focus attention on the areas which required more consideration on the part of the student. All students were offered the opportunity to re – try the assessment online, in order to re-assess their knowledge out of the lecture environment. 47.6% of the cohort retried this particular mathematics element online. The onus was placed on the students to encourage them to take a more active role in their own learning and to encourage them to engage with the online environment.

3.3.2 Overall Chemical Kinetics Assessment

Figure 3.3 displays students' performance in the four continuous assessment elements which students completed during the course of their module. These elements consisted of a varying number of questions (between five to ten questions), dealing with material that had been covered in previous lectures.

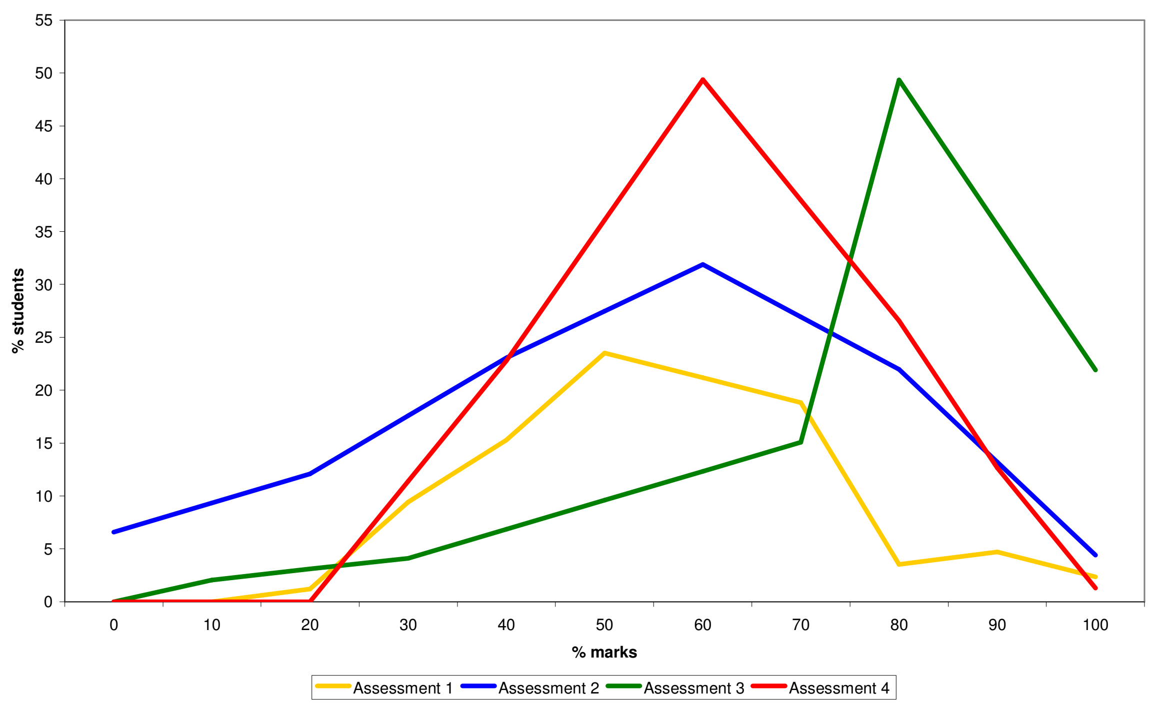

Figure 3.3 - Results of students' performance in four continuous assessments of chemical kinetics material

As it can be seen in Figure 3.3, the percentage of students obtaining one hundred percent in any of the CA elements does not rise above 22%, the highest being in the third assessment module where sixteen students correctly answered all of the questions asked. The largest number of students achieved 50%, in assessment 1, assessment 2 was 60%, assessment 3 was 80% and in assessment 4, the majority of students achieved 40%. A shift can be seen from the implementation of assessment one that students' performance has improved and moved towards the higher end of marks.

Analysis on particular questions has been carried out to determine how students performed on basic chemical kinetics concepts such as: the rate constant *k*, rate equations, factors affecting the rate of reaction and the order of reaction.

For questions involving students understanding of the rate constant B.11, B.14 and B.28 have been analysed. 41 students answered all of these questions which were posed in three separate assessments to assess students understanding of the influence that the rate constant has on the rate of reaction.

	B.11	B.14	B.28
Correct	90.2%	94.6%	100.0%

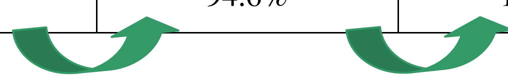

Table 3.2 Student attempts on three rate constant questions

Table 3.2 displays results of the 41 students who attempted all three related questions with 90.2% correctly observing that *k* is related to the speed of a reaction. However 5.4 % of the students who correctly answered B.11 (as displayed by the arrows in Table 3.2) were unable to correctly make the connection that the rate of reaction will increase as the rate constant value increases. In the final question students were asked to determine the dominant product of a reaction based on the rate constant associated with that product. All students who correctly answered question B.14 correctly answered this question also. These students had demonstrated that they have understood the effect that the rate constant *k* has on the rate of reaction.

Table 3.3 shows the questions attempted by 85 students in relations to the rate equation, another basic concept covered during the course of chemical kinetics.

	B.13	B.15	B.17	B.19
Correct	88.2%	42.7%	50.0%	50.0%

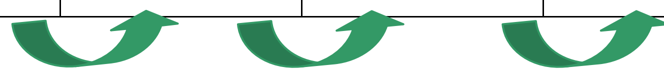

Table 3.3 Student attempts on four rate equation questions

Each of these questions were asked of students during the first CA element, with the first question in this series requiring students to simply state the rate equation which students were introduced to during the course of their initial lectures. This proved to be a simple recall task for the majority of the 85 students asked however 11.8% of the cohort were unable to correctly recall the rate equation. Students were then asked to form a rate equation from given data and a chemical equation. This proved to be beyond the abilities of 57% of students as it was of a higher order than question B.13 and posed more difficult for the majority of students. Question B.17 required students to display an understanding of the process undergone by reactants and products in a reaction. 50% of the students who correctly answered B.15 stated that reactants are used up in a reaction so will have a negative rate while products are formed and will have a positive rate. In the final question, which built upon students understanding of the signs allocated to the reactants and products of a reaction, again 50% of students correctly answering the previous question correctly allocated a negative sign as the reactants are being used up in this reaction. This series of questions has shown that while the majority of students were capable of recalling simple equations, a large problem was encountered by students when required to apply their understanding to the real data.

Table 3.4 displays the results of questions relating to the effect that temperature and pressure will have on the rate of reaction which 68 students answered.

	B.20	B.21	B.22	B.37
Correct	57.4%	48.7%	89.5%	100.0%

Table 3.4 Student attempts on four questions relating to factors affecting the rate of reaction

Students displayed considerable difficulty with understanding of this series of questions as the number of students answering the first question, and of a lower order than those following was just over half of the students who attempted all four questions. Students were required to decide if they would increase or decrease the pressure of a reaction in order to shift the equilibrium to formation of products.

This question required students to apply their knowledge of Le Chateliers principle learnt at both second and tertiary level to a chemical situation; however 42.7% of students were unable to do this. This lack of understanding continued into question B.21 where 51.3% of students who correctly answered the previous question involving the effect of pressure were unable to relate the effect of temperature to a chemical example. While this question was answered poorly by the cohort 89.5% of students who corrected answered that the rate of reaction will increase as the temperature increase, gave the correct reasoning behind their choice. Again in question B.37 all students who were able to correctly give the reasoning behind the relationship between temperature and rate of reaction, correctly stated that an increase in temperature will always increase the rate of reaction. Students have shown a lack of understanding of the factors which affect the rate of reaction which displays that they were not engaged in the course of lectures which covered this topic.

Table 3.5 displays the results of 73 students' answers to a series of four questions involving the relationship between the order of a reaction and the rate of reaction.

	B.18	B.23	B.24	B.25
Correct	41.1%	33.3%	100.0%	80.0%

Table 3.5 Student attempts on four questions relating to the relationship between the order and rate of a reaction

As is seen in Table 3.5 the majority of students could not correctly answer this series of questions involving the order of a reaction concept. Question B.18 which required students to relate a change in concentration to the order of a reaction, was poorly answered by the cohort as 58.9% did not correctly observe that tripling the concentration of a reaction this will have a direct effect on the rate of reaction depending on the order of that reaction. The majority of incorrect answers obtained for this question shows that students made no connection between the effects that the order of a reaction would have on the rate of reaction. Of the 41.1% of the cohort who correctly answered question B.18 only 33.3% of students, correctly assigned the order of reaction to lines observed on a graph. This question then directly linked to an application of students understanding of reaction order in question B.24 where all students who correctly answered the graphical question correctly applied their knowledge to a 'real' situation.

From the analysis of these questions it has been noted that while the majority of students possessed an understanding of the basics of rate equations and rate constant they cannot apply this basic knowledge to more complex and demanding situations. It is also shown from the analysis that the majority of students have had difficulty in understanding the factors which affect the rate of reaction including temperature, pressure and the order of reaction. Students have shown ability in questions which require recall of equations and basic concepts covered in lectures however when required to answer questions demanding application or comprehension students show a distinct lack of follow through. This again displays students lack of engagement with lecture material, which while is more pronounced in the thermodynamics assessment, is still evident in the assessment of chemical kinetic concepts.

3.3.3 Overall results for Thermodynamics Assessment

In Figure 3.4 the results of the three continuous elements are shown, based on the thermodynamics section. These elements consisted of five multiple choice questions based on key concepts involved in the lecture material.

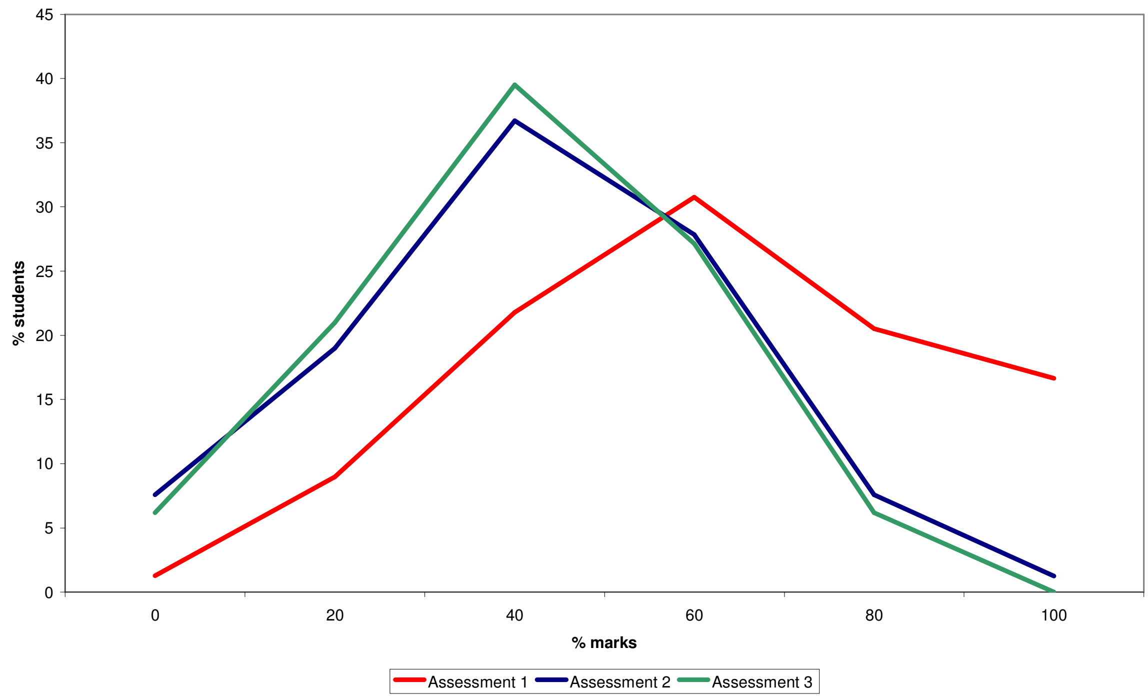

Figure 3.4 - Results of students' performance in three continuous assessments of thermodynamics material

As can be seen in Figure 3.4, the majority of students obtained 40% in assessments, answering two questions of the five asked correctly. The percentage of students obtaining 100% in the continuous assessments fell from the first assessment from 16.7% to 1.3% between the first and second assessments, with no students obtaining one hundred percent in the final assessment.

In the first CA element, students were asked a series of questions dealing with concepts covered in the first four lectures. Some of the questions included in this first assessment were the concepts of enthalpy (B.39, B.42 and B.43) and entropy (B.40 and B.41). B.39 required students to identify the change in enthalpy in a reversible reaction and of the entire cohort, 82% of students correctly identified that in a reversible reaction there is no change in enthalpy.

The next two questions (B.42 and B.43) required students to perform calculations involving enthalpy, similar examples to those which students had completed during the course of the lecture material. 62% of the cohort correctly calculated the value of ΔH for the given reaction in B.41, while 38% were unable to determine the correct value for ΔH for the given reaction. These students did not recognise that the change in heat which occurred depended on the difference between the starting temperature and final temperature of a reaction.

In question B.43 students were required to calculate the ΔH for the given reaction with knowledge of the heats of formation of the reactants involved. Students were expected to apply a mathematical formula, or to use their knowledge of Hess's Law to calculate ΔH. Of the 62% of students who correctly calculated the ΔH for the previous question, 42% of these students correctly identified the value of ΔH. In terms of the entire cohort however 61% of students effectively completed this task, but again 39% were unable to successfully apply their knowledge to this calculation.

Students were also posed two questions dealing with the concept of entropy (B.40 and B.41), in which students were required to apply their understanding of the change undergone in a reversible and an irreversible reaction. In question A.40, 60% of students correctly observed that there is no change in entropy ΔS when the reaction is reversible. Of this percentage, when posed a similar question dealing with the change in entropy ΔS when the reaction is irreversible, 63% of students correctly identified that the change in entropy would be positive and greater than 0. This series of questions has shown approximately 37% of students were unable to correctly identify the change in entropy that occurs during a reversible and an irreversible reaction.

The second assessment (B.44 – B.48) that students completed on thermodynamics required students to demonstrate a further understanding of entropy and enthalpy. In B.46 students were asked to identify from a series of graphs, which reaction would be enthalpically driven. This required students to apply the equation for Gibb's Free Energy, $\Delta G = \Delta H - T\Delta S$, to each of the graphs in order to correctly identify the enthalpically driven reaction. 42% of the cohort correctly observed that in order for the reaction to be enthalpically driven, ΔG will remain negative until the temperature becomes positive and the reaction becomes spontaneous when the temperature of the reaction is greater than 0.

Students also completed a calculation based on the change in entropy which occurs when egg white is denatured (B.47). Students are provided with the require data to complete the calculation but are not given the required formula. From the entire cohort 39% of students correctly identified the change in entropy that occurred during this reaction, using the formula, $\Delta S = \frac{\Delta H\,(kJmol^{-1})}{T(K)}$. A large percentage of the cohort were unable to apply the equation to this situation, which had been encountered during lecture material, with the majority of students stating that the correct answer was none of the choices provided.

In the final assessment, students completed a series of questions which included those based on the concepts of entropy of systems. In B.49 students were posed a question involving the relationship between the entropy of a system and the volume of that system, and how the pressure of the system will affect the value of an equation. 48% of students were able to identify that if the pressure of the system is measured instead of the volume of a system that it will change the sign of the coefficient n in the following equation: $\Delta S_{sys} = nR\ln(X_f/X_i)$. 52% of students were unable to relate the change in variable to the correct effect on the stated equation.

The second question (B.50) examined students understanding of the entropy change which occurs to the surroundings when an exothermic reaction is involved. Students were provided with the formula $\Delta S = q/T$ and were informed that ΔH of the system is greater than zero. 63% of the cohort correctly identified that the entropy of the surroundings will be less than 0 in these given circumstances. The majority of students who incorrectly answered this question assumed that the entropy of the system would be the same as the enthalpy of the system. Once again students were unable to put into context the material which they have encountered during the lectures on thermodynamics.

The majority of students correctly answering three questions per assessment remained quite consistent between assessment elements however, the percentage of students obtaining 0% rose in both the second and third assessment element.

Student averages were lower in the thermodynamic assessments compared to those obtained in the chemical kinetics assessments. In focus group discussion, see Section 3.3.5, students expressed opinions on these results stating that the material covered in lectures did not seem as closely connected to the assessment elements, in Thermodynamics, as those questions asked in terms of chemical kinetics.

3.3.4 Question types – graphical interpretations

During the course of CS201, 29 questions were asked which required students to interpret graphs for both Kinetics (9 questions) and Thermodynamics (10 questions), results of which are seen in Figure 3.5.

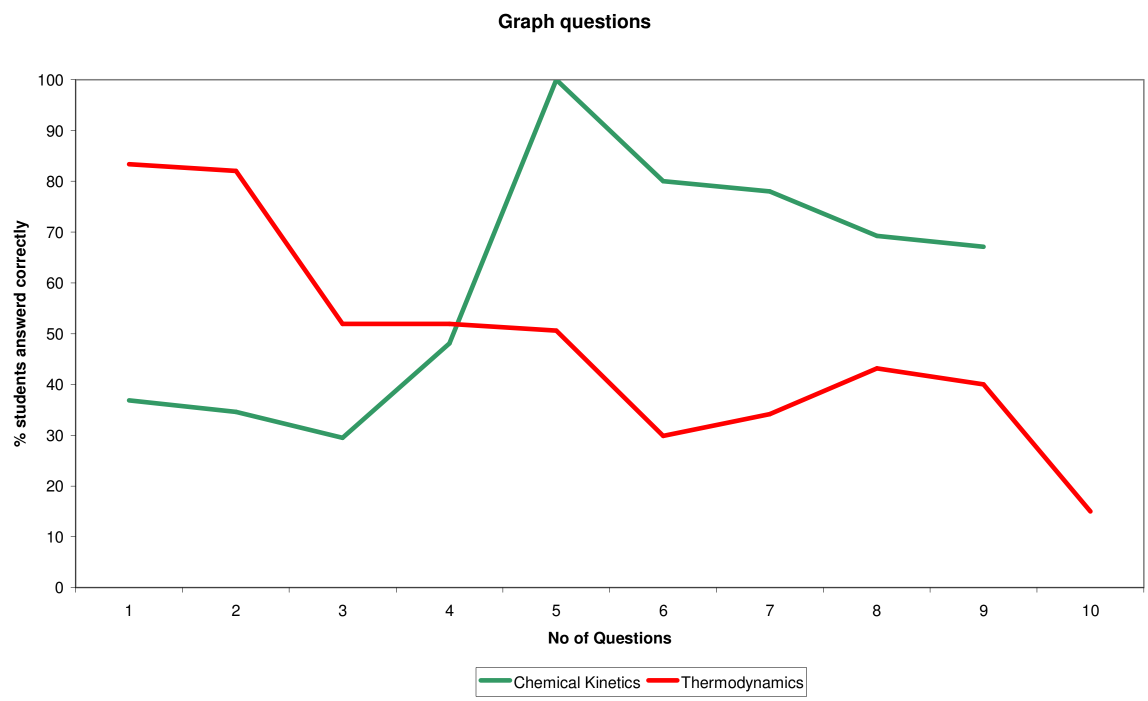

Figure 3.5 – Student attempts on questions involving graphical interpretation.

From the questions set the highest percentage of students giving correct responses for a graphical interpretation was based on kinetics material. For this question (B.9) 100% of students correctly identified the line with the largest rate constant, while the highest percentage of correct responses obtained for a thermodynamically based question was 82.1%.

As displayed in Figure 3.5 student performances greatly increase from the employment of the first graphical interpretations in assessment 1 (B.4, B.5, B.6, B.7, B.8) to the second assessment (B.9, B.10) of chemical kinetic material. However as the assessments progressed it can be seen that number of correct responses obtained by students falls from 80.0% to 67.1% indicating that as the level of complexity increased students were unable to apply their lecture material to these assessment elements.

While one of the reasons for the incorporation of this continuous assessment is to encourage engagement with lecture material, these particular questions display that this was not the case.

In terms of the results obtained in thermodynamic questions which student encountered during the 3 continuous assessment elements performed, 83.3% of students demonstrated a competent understanding of enthalpy (B.39) however when introduced to terms such as reversible (B.40) and irreversible(B.41) in relation to their understanding of entropy, this percentage fell to 52.0%. This inability of 48.1% of students to correct answer questions relating to material covered in lectures continued to be demonstrated, seen in Figure 3.5. This was especially evident in the final assessment which included three questions on graphical elements. It is seen that 43.2% of students correctly identified the diagram which displays how entropy changes in water when heated (B.51) while this % continued to fall to the lowest percentage observed on this question type of 15.00% of students correctly identifying the enthalpy change which occurs when two ideal gases are mixed (B.53).

As was seen in terms of students' inability to relate material covered during chemical kinetics to graphical questions posed during their continuous assessment, similar results are observed with thermodynamic graphs, however somewhat to a greater extent. This lack of engagement has also been expressed by students in both the survey completed and student interviews that were conducted in connection with the implementation of this continuous assessment element.

3.3.5 Student opinions

During the course of module CS201, 79 students where asked to complete a survey in relation to the use of the PADs within the module as an assessment tool and also the questions that were employed to test student understanding, the results of which care summarised below in Table 3.6. A number of students were also interviewed to further investigate student opinion of the introduction of this assessment tool into the module.

Statement	Agree(%)	Don't know (%)	Disagree (%)	Didn't respond (%)
I found the PADs easy to use	95	0	3	2
I took note of all my answers to each of the questions	52	6	39	3
There was enough time to answer all of the questions	71	11	18	0
The questions should be timed	58	1	41	0
The PowerPoint slides were clear and easy to read	90	1	9	0
I found the questions easy to answer	37	19	44	0
There were too many questions	5	4	91	0
I found that the questions required understanding of the material	85	4	10	1
I found that the questions were directly related to the material covered in previous lectures	71	9	16	4
I retried each of the quizzes on Moodle	10	8	82	0
I enjoyed the multiple choice format	92	3	0	5
I would prefer questions that require calculation	13	16	71	0
I guessed half or more of my answers to each quiz	52	9	39	0
I would prefer to prepare my own answers to the questions	16	10	73	1
I would prefer to have had more continuous assessment elements	58	6	33	3
The three continuous assessment elements were well spaced apart from each other	75	8	16	1
The continuous assessment elements are an advantage to my learning	80	11	9	0
I was disappointed with my score in the continuous assessment element	38	25	35	2
I followed the lectures as they progressed	39	18	43	0
I like questions where I could show that I understood concepts.	78	18	4	0
I would recommend that this format is used again for this module next year	92	3	5	0

Table 3.6 Results of student survey in relation to usage of PADs.

The results of these questions, seen in Table 3.6, revealed that the majority of students thought quite positively of this format of assessment while some interesting student opinions were presented during a focus group interview conducted at the end of the entire module.

Some of the positive aspects revealed were, that of the 79 students surveyed:

- 95% found the PADs easy to use;
- 85% found the questions required understanding of the lecture material;
- 92% enjoyed the multiple choice format;
- 44% found the questions challenging;
- 80% considered the CA elements to be an advantage to their learning;
- 78% liked questions where they could show that they understood concepts ;
- 92% would recommend this format being used in the same module next year;
- 71% found that the questions were directly related to material covered in previous lectures;
- 73% preferred to use the multiple choice format to preparing their own answers.

However this survey also revealed some aspects that would require further attention, which included:

- 52% admitted to guessing at least half of their answers;
- 52% neglected to take note of the answers they believed were correct;
- 39% followed lecture material;
- 91% believed that there were too many questions involved in the CA elements;
- 41% stated that the assessment should have a time limit which was in contrast to the 71% who stated that there was enough time to answer the assessment elements;
- 82% were not engaging with CA element in the VLE.

While in this survey, 82% of students stated that they had not retried the assessment elements online, this survey was conducted before students had completed the entire module. From the data obtained from the VLE, of the 126 registered students the percentages that retried the assessments online are presented in table 3.7 below.

Kinetics	**% students completed**	**Thermodynamics**	**% students completed**
Assessment 1	59.5	Assessment 1	52.4
Assessment 2	53.2	Assessment 2	49.2
Assessment 3	50.8	Assessment 3	46.8
Assessment 4	46.8		

Table 3.7- Percentage of students to retried assessment elements online

From Table 3.7 it can be seen that approximately half of those registered students re-attempted the assessment elements in the online environment. These percentages show that students became more involved in their own learning as the module progressed or as the examinations came closer. Students began to engage with the material outside of the lecture; however this may have occurred due to the end of semester exam. This suggests that students were using the assessments as a means of additional revision along with their lecture notes and tutorials. Also from the survey it was revealed that 38% of students were disappointed with their score in the CA element as they believed that they should have achieved better marks. Another point which was revealed during the course of the survey was that only 39% of students admitted to following the lectures as they progressed. This shows that these students were honest in their reflection of participation in their own learning and engagement with lecture material.

Student interviews revealed positive opinions about the implementation of PADs as an assessment tool. Students stated that:

"It was good the way that you could get the feedback and see how other people were doing and compare."

They believed that the PADs assessment was useful in terms of the amount of time required to complete the assessment so it was never tedious. When quizzed on the element of guess work which is introduced with the multiple choice format, these students stated that:

“*the multiple choice format provided the students with a goal to work towards and they could work out their answer towards this goal.”*

However they did admit that when they didn’t understand what was being asked in the question this would be the situation where they would guess their answer. Students were also asked to compare their experience of kinetics and thermodynamic questions. Students stated that

“The thermodynamic questions were generally harder and less obvious. You had to think an awful lot more to interpret the graphs which while it may be getting you thinking, it could be too hard for some people and this is where the guess work could begin.”

“The connection between the kinetics material and assessment element was more obvious than the thermodynamic material. The thermodynamic assessments seemed to be more abstract and unrelated to the lecture material.”

Students also believed that the time restrictions became very obvious in this section as they were trying to interpret the question, work out their answers and their time was already up before they had made a selection. The students interviewed agreed that the CA element helped to cement things in their minds from the week of lectures. They also stated

“The assessment helped to encourage me to read over the lecture material out of lecture time even if it was only glancing over my lecture notes before each assessment.”

Students agreed that they saw the benefits to the introduction to the PADs system, however as questions were generated by two different lecturers, it was obvious to students the extent to which material was being tested, was distinctively different between both sections.

3.4 Conclusion

For this section, it is important to refer back to the question posed at the beginning of Section 3.3. Have each of these questions been answered and to what degree does the analysis support a positive answer in each case?

With the format of 'assess – correct – reassess' which was employed during the course of this module students were offered that opportunity to retry each of the assessments in order to improve their understanding of these basic concepts. 82% of students admitted to not re-attempting the assessments online when asked 6 weeks prior to their end of semester examination. However the results that were obtained from the online data show that the percentage of students attempting to reassess their learning was as high as 50% of the entire 126 students enrolled for this module. Students received no additional percentage contribution from reattempts towards end of year results, however they proceeded to retry the assessment online up until the week before their examination, with some students attempting the assessments more than once. This shows that students may have been using the online material as a revision/practice tool.

From the questions that were used during the course, specific areas of basic concepts were assessed and results revealed that the majority of students had difficulty with the application of basic concepts while they were competent at simple recall. Particular questions were identified in sections 3.3.2 and 3.3.3 as providing students with challenging material while other questions simply required students to recall equations or statements that had been presented during the course of lecture material. The length of time that was allocated to the preparation of these questions however cannot be over stated. It was essential that while these questions appropriately tested students understanding of chemical concepts, they must also provide lecturers with information as to where they are losing students in terms of increasing complexity in lecture material. Lecturers were informed of the areas that were proving to be quite challenging to students such as those identified, e.g. the affect that order has on the rate of reaction, calculations involving Gibb's energy and questions which require the application of knowledge to a graphical interpretation.

The PADs have proven to be an acceptable and appropriate assessment tool to measure the understanding of a large cohort of students in this module; however, the development of appropriate questions is an essential element to their successful incorporation in any module.

During the course of CS201 students completed 7 CA elements – 4 involving chemical kinetic concepts and 3 based on thermodynamic concepts. Each of these assessments tested students' knowledge and application of basic concepts involved in these physical chemistry elements. As seen from the responses of students in terms of each assessment, the majority were unable to correctly answer all questions in chemical kinetics assessments with an average percentage of 62.3% obtained. In the thermodynamics assessment the average percentage obtained by the cohort was 41.0%.

These results support the statements made by students, that they perceived a lack of coherence between the lecture and assessed material in terms of the thermodynamic material. However these results also illustrate that students were not actively engaging with all elements of the lecture material, as all assessed material had been covered within the lecture environment.

Student surveys and opinions have shown that they recognise the advantages of both the PADs and the use of continuous assessment in this particular module. They admitted to finding the questions employed challenging and more closely related to the material in chemical kinetics lectures than that of the thermodynamic lectures. Students stated that they found the PADs easy to use, that they enjoyed the multiple choice format that was used and the majority of students suggested that this format be used again. As the incorporation of multiple choice questions introduces the element of guess work, students were honest as 52% stated that they guessed more than half of their assigned answers. The focus group revealed that students were more inclined to guess their answer if the question was confusing or if they had insufficient time to answer the questions. So while students saw the benefits of the PADs system, they were still critical of certain elements of them.

The PADs system has been successfully implemented in module CS201 as a tool for continuous assessment and the multiple choice format has been embraced by both students and lectures. Key concepts that require more in depth explanation have been identified for both lecturers and students and the online engagement of students has shown that when examinations loom, students take a more active role in their own learning 50% of this cohort applied themselves. While certain issues have been raised from the use of these continuous assessment tools, such as guesswork and lack of engagement with lecture material during the course of the module, the PADs have allowed 50% of students to become more active in their own learning and have provided valuable feedback to lecturers about key areas that most students have difficultly with, long before the end of semester examination.

Valid comparison of final assessment marks with performance in previous years was not possible as the course content, along with assessment formats and the individual lecturers involved differed to previous years. It was considered that too many variables had changed over the years that could contribute to any differences observable and therefore no comparison to previous cohorts has been made.

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Chapter 4

The use of pre and post laboratory tasks to maximise students' laboratory experience – another example of formative assessment.

4.1 Introduction

This chapter deals with the formative assessment method of pre and post laboratory tasks which have been introduced in a virtual learning environment for first year undergraduate chemistry students. These pre laboratory tasks aim to prepare students for their practical session and then the post laboratory tasks present questions to help them to implement what they have learned in the laboratory.

To ensure that the students have carried out that pre and post laboratory tasks they are given a percentage of marks towards their final assessment.

4.1.1 Laboratory work

As stated previously one of the aspects of chemistry which has been deemed to be essential but also one of the most difficult aspects of chemistry to perform assessment appropriately is on students' practical skills. However laboratory work has been identified as on of the most essential parts of undergraduate programmes in chemistry for over the last twenty decades[1]. While it has been agreed that the inclusion of practical work has proven to aid students in their understanding and knowledge of chemistry, the purposes, methodologies and time allocation have been the subject of much debate in recent years[2].

In 1961, Kerr[3] complied a list of the ten aims of practical work which have subsequently been agreed to by the Swain[4], Kempa and Ward[5], Johnstone and Wood[6] and Garnett and Hacklin[7]. This list stated that practical work will:

- Encourage accurate observations and careful recordings;
- Promote simple, common sense, scientific methods of thought;
- Develop manipulate skills;
- Give training in problem solving;
- Fit the requirements of practical exam requirements;

- Elucidate theoretical work so as to aid comprehension;
- Verify facts and principles which have been already taught;
- Be an integral part of the process of finding facts by investigating and arriving at principles;
- Raise and maintain interest in the subject;
- Make phenomena more real through actual experience.

However while the benefits of practical work are many, there are also difficulties associated with the implementation of chemical laboratory work especially when dealing with large numbers. In the case of many undergraduate chemistry courses, the number of students involved in chemical laboratories rarely is below 150. For laboratory work, the pressure of increasing numbers of students coupled with restrictions on people power, materials and equipment and contact hours have been significant[8].

Some of the additional issues which are associated with the integration of practical work in undergraduate chemistry courses include safety issues, staff and demonstrator costs, varying student chemistry experiences and the type of assessment which should be employed in order to correctly reward students for the effort expected of them[9]. However even with the various disadvantages which are related to the employment of practical work, it is still noted that the benefits that are shown from the appropriate use far out weigh these stated issues. The practical laboratory session offers an environment which[10]:

- Allows students to build on their new learning or their prior knowledge;
- Allows learners to handle practical/skill information;
- Facilitates feedback, discussion and reassurance;
- Allows students to apply theory to a practical situation;
- Allows students to make suggestions, propose theories, explore, create and to present their “distilled” knowledge and understanding.

As stated by Bennett[2], methods employed in the practical chemistry laboratory session have come under review in the last few decades. The most predominant form of laboratory which has been used in third level establishments is the expository laboratory – within this learning environment the instructor defines the topic, relates it to previous work and directs students' action. This form of instruction has been criticised for the little emphasis which has been placed on student engagement and thinking as[11]:

- Its 'cookbook' nature emphasises the following of specific procedures to collect data;
- It gives no room for the planning of an experiment;
- It is an ineffective means of building scientific experiments.

Students often learn very little from the time they spend in the laboratory as they may see or make few connections with the appropriate chemistry lecture material. As stated by Rollnick[12], "The separate nature of laboratories and the logistics of offering them to large numbers of students, makes it difficult to ensure that the content being offered in lectures and tutorials relates to the practical work being carried out." Students can feel that they are being treated less as adults in their first year laboratory experiences with the closed, limited nature of the expository lab. They can feel that the assessment does not match their effort or that "the weighting of the assessment will encourage them to cut corners"[13].

Some of the common student opinions/comments which were gathered by Carnduff and Reid about experiences of undergraduate chemistry laboratory sessions included[14]:

- Too long for the marks awarded;
- Just following a recipe;
- Cannot see the point;
- Far too much information;
- Does not help learning.

One of the changes which has been widely accepted by educators is a shift in the emphasis towards students actively engaging in laboratory material in their own time and to encourage student preparation and reading of essential information such as safety requirements for chemicals and equipment being used, formulae and equations required during the course of the experiment, before they enter the laboratory[15,16,17].

It was obvious from this literature that any activity that maximises what students gain from the time that they are actually in the laboratory is worth while. These activities more often require an involvement of students in preparing for their laboratory experience by completing a form of pre-laboratory task which would take on the form of a series of multiple choice questions utilising the benefits as outlined in section 3.1.2.

4.1.2 Pre and Post Laboratory assignments

The use of pre-laboratory tasks/assignments before the laboratory to 'prepare the mind of the learner' is not a new one. Johnstone[8] described the elements of an effective pre-lab exercise as including:

- Revision of theory;
- Re-acquaintance with skills;
- Planning the experiment to some extent;
- Discussion with peers.

When combined with elements of ownership and relevance for the students, the pre-lab can be very effective at preparing the mind of the learner[8]. Also, if students have had direct input into the laboratory experience, for example deciding the procedure or techniques to be employed and have a natural curiosity in the experiments, due to their relation to everyday life for example, they will have a greater motivation and personal interest for actually doing the experiment.

Johnstone *et al.* [17] stated that in relation to the use of pre-labs in physics:

> 'The aim of the pre-labs was to prepare students to take an intelligent interest in the experiment by knowing where they were going, why they were going there and how they were going to get there'.

Sirhan *et al.*[18] comments that pre-lectures in chemistry are "a useful tool in enabling students to make more sense of lectures, the effort being particularly important for students whose background in chemistry is less than adequate". They also note that "students entering a laboratory without some preparation are likely to spend hours in fruitless, routine handle turning and non-learning".

Included in the arguments for incorporating pre – laboratory activity in laboratory sessions put forward by Carnduff and Reid[13], the work that students are expected to perform must:

a.	Ensure that background information is recalled
b.	Connect and revise prior knowledge
c.	Provide some reassurance to the student about their grasp of a topic
d.	Check any procedures that have been read and understood
e.	Practice appropriate data handling, drawings or calculations
f.	Lead the student into thinking about the procedure or concepts
g.	Involve the student in planning
h.	Connect the experiment with other parts of the course
i.	Relate the experiment to the outside world
j.	Improve motivation and invite a prediction or offer a challenge

Table 4.1 Reasons for the use of a pre-laboratory activity[13]

Pre - laboratory activities can stimulate students to think through the laboratory work, with a mind prepared for what will occur during the experimental session[19]. Pre - laboratory work may lead students into thinking about the procedure or concepts and encourage students to connect and revise prior knowledge, thus providing some reassurance about their grasp of the topic being assessed. Pre-laboratory preparation cannot only require students to read their manual before entering the laboratory but must involve students in the planning of their experiment and if possible bridge the gap between experimental theory and practical application.

Overall, pre - laboratory exercises are a simple way of preparing the minds of students to the learning outcomes of the laboratory session and equip students with the required basic material for the completion of the session[20].

However it must be stated that two of the concerns that have been raised of such activities about the employment of the pre – laboratory activity are the length and assessment[13] which are illustrated in Figure 4.1 .

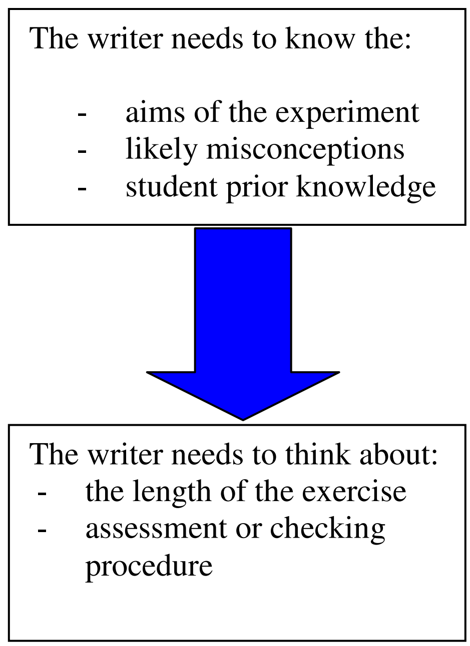


Figure 4.1 Writing pre – laboratory activities (Carnduff & Reid[13])

Once the writer has taken into account the concerns that have been raised when developing appropriate questions for use in the pre – laboratory activity, they can allow for a number of issues to be assessed: the necessary background knowledge to be revisited, experimental techniques to be introduced, significance of experiments and the introduction of important questions that will be addressed during the laboratory session.

Studies that have employed pre – laboratory activities[14,16,17] have provided clear evidence that the learning of students has increased and that their motivation has been enhanced also. In relation to the advantages which have been stated for pre – laboratory activities certain chemistry textbooks have begun to include such activities. “Laboratory experiments for chemistry and the living organism” (1992) Chichester & Wiley and “Laboratory experiments for General Chemistry”(1998) Fort Worth & Saunders are two such examples that have incorporated the pre – laboratory activity into their text books.

It has been stated that in order to provide students with an all encompassing experience for the laboratory session the inclusion of post - lab activities should also be considered[8]. Post laboratory activities are designed to encourage students to reflect on what they have been performing during the laboratory session. It has been suggested that post - laboratory questions should be linked to the pre- laboratory exercises in order to make the laboratory experience more of a complete whole[14]. Post laboratory activities, as stated by Carnduff and Reid[13] should include problems which:

- Interpret students results and observations made during the experimental session;
- Compare student results and observations to those of other classmates and the literature;
- Explore implications and applications of the theory involved;
- Re-examine the procedure used by students and if there are any improvements that could be made;
- Promote discussion between students and tutors.

These pre and post laboratory activities were introduced into a 1st year undergraduate chemistry practical laboratory as a formative assessment method with the aim that the feedback provided to the students by their completion of these tasks, would promote their understanding of the chemical concepts covered in each session. However an appropriate vehicle was required in order to ensure that the utilisation of these additional requirements did not place extra burden on either students or tutors involved.

4.1.3 Online Assessment – Virtual Learning Environment (VLE)

As stated in chapter 3, technology can play an important role in the implementation of formative assessment when chosen appropriately and used effectively. Educational research[21] has shown that traditional teaching methods which are based on large numbers of students do not promote active engagement in the learning process, such that students are passively learning at a moderately shallow level. A suggested solution for this problem, put forward by Gibbs and Simpson[22] is that assessment should be designed that engage students with the learning outcomes of the course without generating large volumes of marking for the lecturer/tutor. As with the implementation of the PADs' as stated in section 3.3 it was envisaged that a technological tool could aid in the introduction of the pre and post laboratory activities into the 1st year undergraduate chemistry laboratory.

However another factor is said to be contributing to the lack of engagement with course material and that is student motivation[23]. Students are becoming increasingly strategic about the length of time, they allocate to their course material with a number of competing demands such as extra curricular activities and part time employment. Due to these restrictions and perceived selectiveness of students, the incorporation of online assessment has been suggested as a solution to student engagement[24].

As reported by Mercer – Chalmers et al[25], VLEs' are a mechanism whereby students can gather the necessary theory and background at their own pace as well as gaining familiarity with necessary ICT and computer skills. In this model of assessment, an approach was incorporated where students were provided with background information and then were required to answer a series of online questions based on the information for the experimental session. Mercer – Chalmers reported that students appreciated being able to access the VLE in their own time and that they were given ample time to complete the given tasks. Students also stated that one of the difficulties which they had to overcome was their individual computer knowledge and experience, however this was gradually solved as students gained the appropriate skills from exposure to the software used.

Nicholls[26] advises that online computer assessment programmes can be written so that:

- Students can work at their own rate and repeat any exercise until they understand the particular lesson involved;
- Students are active by involvement in the learning process is ensured by requiring frequent and creative interaction with the computer;
- Student usage is logged to give the tutor a usage profile for individual students;
- Student competence with specified tasks is tested and automatically marked without recourse to a tutor.

Barajas & Owen[27] complied a list of advantages and disadvantages for both educators and students that should be considered before the implementation of a VLE into a course or module. These are listed in Table 4.2.

	Advantages	**Disadvantages**
Students	• to experience online learning for it's own sake • to access information and assessment • to participate in an alternative learning environment	• lack of technological skills • have had bad experience using new technology and are reluctant to engage in a new form of assessment
Educators	• to experience teaching in a VLE • to offer a new method of learning to students • to reduce their marking of material • to utilize animations and graphical skills	• lack of necessary technological skills • prefer to stick to the method of pen and paper assessment

Table 4.2 Advantages and Disadvantages of VLE's (Barajas & Owen)

First year undergraduate chemistry laboratories have undergone a series of changes over the last number of years within Dublin City University. Pre - laboratory activities involving a selection of written questions and assignments were introduced for a small cohort of students in order their preparation for the laboratory session.

Following from the successful implementation of these pre laboratory exercises, a further study was carried out whereby these activities were performed by the entire first year undergraduate cohort. In addition to the pre - laboratory exercises students were also required to complete a number of questions upon finishing their laboratory session that required information based on their experimental data or the concepts involved in the laboratory.

However, these questions were to be completed during the laboratory session and if there was insufficient time, students did not complete these questions and were not assessed as to their understanding of the concepts covered in the laboratory session. The logistics element that was also posing additional pressure for tutors, as during the laboratory session they would correct student pre - laboratory attempts, laboratory note books and these post - laboratory questions for each individual student.

For the purpose of this project, using the evidence supplied by the literature concerning MCQs, online and formative assessment , it was decided that an online assessment element would be introduced into the practical laboratory module to facilitate the pre and post laboratory activities which would be completed outside of practical laboratory time. This would allow tutors to give feedback to students on their post laboratory assignments outside of laboratory time and allow tutors to concentrate on students performances during the laboratory session. It also ensures that students were not limited by their three hour laboratory sessions to complete these post laboratory questions.

4.2 Methodology

First year undergraduate chemistry students (n = 219) who registered to take chemistry laboratories are heterogeneous in their in both their degree programmes (Analytical Science, Biotechnology, Chemical and Pharmaceutical Science, Common Entry Science, Environmental Science and Health, Genetics and Cell Biology, Science Education and Science International) and in their prior chemistry experience. Some students have studied chemistry to Leaving Certificate level, while other students will have little, Junior Certificate Science or no chemical knowledge. In this particular cohort, 2007/2008 50.7% of students have Leaving Certificate Chemistry while 49.3% have little or no prior chemistry experience.

Students completed one three hour laboratory session each week dealing with a different chemical concept which can be seen in Table 4.3. For each of these laboratory sessions students were required to complete a pre – laboratory quiz in preparation for their practical session. The questions involved in these online quizzes required students to have basic knowledge of terminology, chemical techniques, simple calculations, chemical formulas, equations and some times safety aspects related to the experiment to be completed. These questions were designed to ensure that students were prepared on a basic level for the concepts that would be covered in the practical session.

Students were required to log on to the VLE called Moodle to answer the pre laboratory quiz where they could download the word document containing the pre – laboratory quiz for the forthcoming laboratory session, if they wished to complete the quiz before submitting their answers online. Students were given access to the pre-laboratory tasks for a particular experiment for approximately one week before they entered the laboratory session. They were allowed to complete their quiz at any time within that week, any number of times, however only a students' first attempt was awarded marks.

Upon submission of their attempt to the quiz students were given immediate feedback as to how they scored on that particular quiz. They were able to see the questions that they had answered correctly and more importantly those that were answered incorrectly. They were not given the correct answers to those questions that they had answered incorrectly. As stated previously however, it was the students' first attempt mark that counted towards their continuous assessment.

In semester one, students were required to complete ten pre laboratory online assessments, with 7 – 16 questions depending on the laboratory session. In semester two, students' completed nine online assessments again with a varying number of questions per pre laboratory quiz. Student scores per question were downloaded after each quiz to ascertain the basic knowledge of students.

	Semester I		**Semester II**
1.1	Introduction to chemistry laboratory	2.1	Investigation of water hardness using EDTA titration
1.2	What's in a mole?	2.2	Analysis of rubex by back titration
1.3	Concentrate, concentrate, concentrate	2.3	Microscale determination of dissociation constant of a weak acid
1.4	Is a salt soluble or not?	2.4	Spectroscopic determination of an equilibrium constant
1.5	Forensic Analysis	2.5	Microscale solid-liquid extraction of trimystrin from nutmeg
1.6	Acids, bases, indicators and pH	2.6	"Selggog Abbey" EPA Water Problem
1.7	What concentration is it?	2.7	Laboratory examination and student presentations
	Laboratory examination	2.8	Dehydration of 4-methylpentan-2-ol and isolation of the products by distillation
1.8	Calorimetric determination of enthalpies	2.10	Microscale synthesis of acetylsalicyclic acid (Aspirin)
1.9	Devise an experiment	2.11	Microscale hydrolysis of trimyristin
1.10	Determination of the ideal gas constant	21.12	Qualitative determination of organic functional groups
1.11	Identification of the stoichiometry of a metal – ligand complex		

Table 4.3 First year undergraduate chemistry laboratory sessions

In the case of the post laboratory session, questions were uploaded onto the VLE on Friday afternoon, when all three laboratory groups had completed their respective laboratory sessions. The post laboratory assignment consisted of two to three questions relating to the experimental practical session performed by students, usually asking students to evaluate their experimental results in comparison to literature or to apply understanding gained during the laboratory experience to more 'real' situations. These questions were designed in order to assess the level of engagement and level of understanding that students acquired during the course of their practical laboratory.

Students submitted their answers to the post laboratory questions in word format before the next laboratory session for marking by their laboratory tutor. This tutor was assigned to students for the entire semester of the laboratory sessions and was provided with a solutions/marking sheet to ensure uniformity in marking standards. Students were given a mark out of ten from their tutors and were also provided with some general feedback about their performance in the task, as to where they may have lost marks or some encouragement if they have shown an improvement; an example of which is shown below.

'Hey Sarah, good work! Be sure and show any formulas you use so you can show where figures are coming from, and don't forget the units of measurement!! Be careful using the capital m, i.e. 0.06M means there is 0.06moles /L, it does not indicate the no. of moles.'

The typical routine implemented in the laboratory session, can be seen in Figure 4.2.

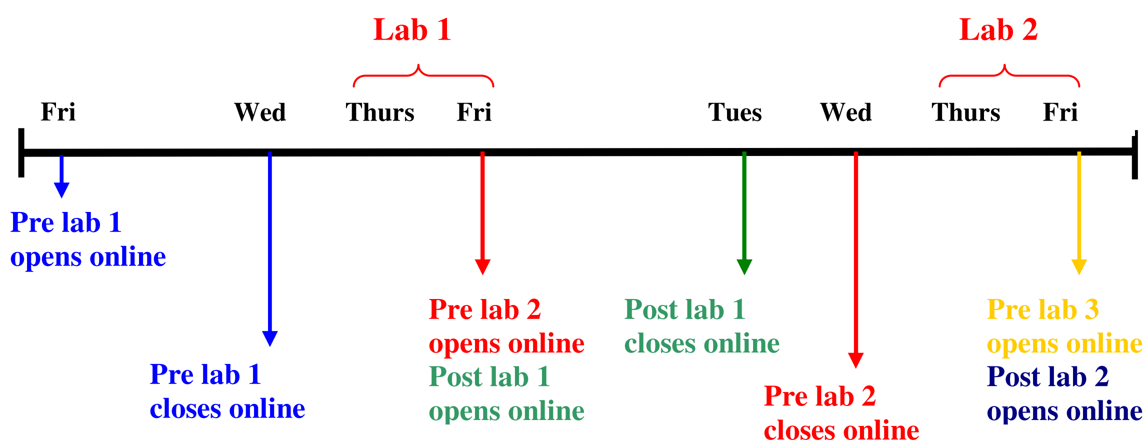


Figure 4.2 Typical weekly assessment in undergraduate chemistry laboratory module

Students were required to ensure that both their post and pre laboratory tasks were submitted to the online environment on the Tuesday and Wednesday respectively before entering their next laboratory session. As the post laboratory mark was allocated by their tutor sufficient time was given for correction so that students could receive feedback on their attempt in the following laboratory.

4.3 Results & Discussion

The questions that this study has aimed to answer are:

- Does the implementation of pre and post laboratory tasks influences student learning?

- Does a student's prior chemistry experience determine their success in pre and post laboratory activities?

- What are the opinions of students, who have had no experience of a VLE or pre and post – laboratory activities prior to this of their introduction?

4.3.1 Students performance in pre and post laboratories

In this section two results will be presented

- Correlation between students' results in pre and post laboratory activities;
- Paired t tests on students' performances.

Pearsons correlation coefficient investigates if there is a relationship between two or more variables showing if there is positive, negative or no association. A positive association would mean that high values in one variable are correlated with high values in the other variable. Values ranging from –1 to +1 are obtained indicating the strength and direction of the association. The closer the value of the sample correlation coefficient is to +1, the stronger the positive association, and vice versa for a negative association.

Using Statistical Program for Scientific Statistics (SPSS) the significance of the Pearsons' coefficient has also been calculated with a value below 0.05 meaning that there is a statistically significant difference at 95% confidence, whereas if the significance is greater than 0.05, then the means are not significantly different.

In order to calculate the correlation coefficient the following formula was applied:

$$r = \frac{1}{n-1} \sum \left(\frac{X - \overline{X}}{s_X} \right) \left(\frac{Y - \overline{Y}}{s_Y} \right)$$

Where $\overline{X}$ is the mean of the x variable

$\overline{Y}$ is the mean of the y variable

S_x is the standard deviation of the x variables

S_y is the standard deviation of the y variables

n is the number of pairs

Table 4.4 shows the Person's correlation coefficient for students percentage in pre and post laboratory tasks in semester I. For the purpose of comparison those students who did not complete both pre and post laboratory tasks for a particular laboratory were discounted as no correlation could be obtained.

Laboratory		**Pearson's Correlation Coefficient**	**Significance**
1.2	N=165	0.090	0.250
1.3	N=175	0.306	0.000
1.4	N=179	0.085	0.259
1.5	N=163	0.316	0.000
1.6	N=163	0.134	0.087
1.7	N=175	0.123	0.106
1.8	N=144	0.014	0.869
1.9	N=133	0.262	0.002
1.10	N=149	0.030	0.712
1.11	N=133	0.182	0.036

Table 4.4 Pearson's correlation coefficients for student marks in semester one pre and post laboratory activities

In Table 4.4, the correlation between students performance in pre and post laboratory tasks for semester I have been displayed with laboratory 1.3, 1.5 and 1.9 showing particular interesting results. Each of these laboratories have shown a stronger positive correlation between students performance in pre and post laboratory tasks, which is supported by a significance value of 0.000. It must be stated that while these correlations are stronger and more significant than other laboratories conducted in semester I, the correlations are quite weak in terms of the correlation value which is only considered significant if above 0.60.

This positive correlation shows that students' performance in their pre laboratory activities was related to their percentage in their post laboratory task, i.e. a student who obtained a high percentage in the pre laboratory quiz for 1.5 also scored well in the post laboratory questions for this laboratory. However these correlations are not as strong, as the average percentages obtained by students (shown in Table 4.5) were higher in pre laboratory tasks than in their post laboratory tasks.

It was not expected that there would be a particularly strong correlation between students performance in the pre and post laboratory tasks. This was due to the nature of the questions being asked in these two different assessments; however it would have been expected that had students readily engaged with material before and during the laboratory session that they would be better equipped to deal with the more challenging and complex questions asked in their post laboratory task.

Table 4.5 shows the persons correlation for student's percentages in pre and post laboratory tasks in semester II.

Laboratory		Pearson's Correlation Coefficient	Significance
2.1	N=158	0.222	0.005
2.2	N=135	0.097	0.263
2.3	N=122	0.412	0.000
2.4	N=116	0.064	0.493
2.5	N=122	-0.043	0.641
2.8	N=118	0.198	0.031
2.10	N=86	0.022	0.839
2.11	N=137	0.172	0.044
2.12	N=92	0.106	0.313

Table 4.5 Coefficient values for student marks in semester two pre and post lab activities

In Table 4.5 only two laboratories show a significant correlation between students' performance in pre and post laboratory tasks 2.1 and 2.3. As in the case with those pre and post laboratories identified in Table 4.4, in these two laboratories positive correlation between students percentage for each of these pre and post laboratory tasks, which is supported by a significance value of 0.000 and in the case of 2.1 a significance of 0.005.

The correlation value seen for laboratory 2.3 is the highest significant correlation obtained for the pre and post laboratory tasks which involved determination of the dissociation constant of a weak acid. Once again it must be stated that these correlations, for laboratories 2.1 and 2.3, are quite weak as they are not higher than 0.60.

It can also be seen that the number of students completing both pre and post laboratory activities in semester two has decreased compared to those completing activities in semester one. The average number of students completing activities in semester one was 158 which fell to an average of 121 students in semester two. The most significant drop in submission of work occurred in semester two with laboratories 2.10 (N= 86 students) and

2.12 (N= 92 students), both of which were performed by students in the last two weeks of the semester.

Towards the end of the semester, particularly during the final two weeks, the number of students attending laboratories began to drop and as the final submission of post laboratory tasks was out of semester time, the number of students submitting work was particularly low. It is also thought that as students had been informed of their average laboratory mark for semester two, they may have decided that they could afford to not submit these final two tasks, while some may also have had to deal with a multitude of deadlines which always accumulate at the end of each semester.

While Pearson's correlation coefficient has shown a relationship between students' performance in their pre and post laboratory tasks, a paired t test has been performed on each of the tasks set for semester 1 and 2 laboratory tasks. This test shows the difference between the percentage means of the pre and post tests and the significance of these differences. For the purposes of this assessment, only students who completed both pre and post tasks for each laboratory session have been included.

The formula for calculating the t-value is given below.

$$t = \frac{d}{\sigma\sqrt{n}}$$

where *d* the mean of the differences between the means
σ the standard deviation
n the number of matched/paired samples

Using SPSS, the paired t test also gives a value for significance. If the significance, *p*, is below 0.05, then there is a significant difference at 95% confidence, whereas if $p>0.05$, then the means are not significantly different.

Laboratory		Mean of pre task (%)	Mean of post task (%)	t value	Significance
1.2	N=165	67.55	58.70	-4.124	0.000
1.3	N=175	76.76	74.75	-1.039	0.300
1.4	N=179	73.23	83.07	+6.201	0.000
1.5	N=163	73.77	63.40	-5.384	0.000
1.6	N=163	80.56	63.66	-8.231	0.000
1.7	N=175	69.52	68.13	0.738	0.462
1.8	N=144	56.94	65.75	+5.046	0.000
1.9	N=133	83.80	62.25	-9.584	0.000
1.10	N=149	73.63	64.33	-3.410	0.001
1.11	N=133	81.31	69.77	-4.468	0.000

Table 4.6 t values for pre and post laboratory tasks in semester one

As seen in Table 4.6 the average percentage obtained by students for pre laboratory tasks was significantly greater than that for the post laboratory tasks in six of the laboratories carried out in semester one (1.2, 1.5, 1.6, 1.9, 1.10, 1.11). This supports the argument put forward previously that it was not expected that there would be a mirroring percentage obtained for both tasks, as the pre laboratory task contained simple, basic, leading questions aimed at providing students with adequate preparation for the practical session, while post laboratory questions were designed to challenge students understanding of chemical reactions and concepts.

However analysis revealed that four experiments were the exception to this trend in semester one, with both laboratories 1.4 and 1.8 showing a significant improvement in the mean obtained for the post laboratory tasks and laboratories 1.3 and 1.7 showing no significant difference between the mean values obtained for both tasks.

For these four exceptions the pre, post and in laboratory tasks have been identified in order to ascertain if there is was a large degree of linking between the activities that students were asked to complete in these three tasks, as they displayed different results in comparison to other laboratories. This linking assessment may provide reasoning for students performing better in these cases than in other laboratories.

In the case of laboratory session 1.3 – which dealt with the concept of molarity and concentration, Figure 4.3 displays the pre, post and in laboratory tasks that students were required to complete.

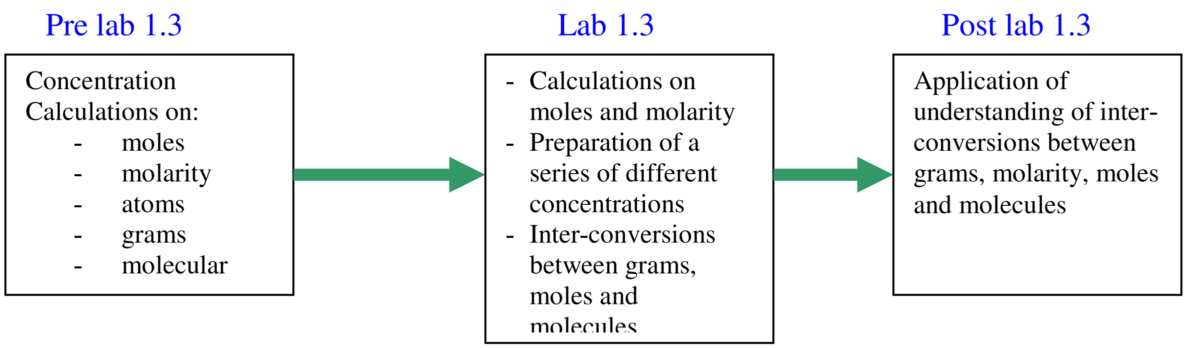


Figure 4.3 Linking of material covered in laboratory 1.3

As can be seen in Figure 4.3 the tasks that were required of students in all three laboratory tasks are closely related. Each element was concerned with students' abilities to perform calculations and inter-conversions related to the mole concept and molarity.

There was a steady progression from the preparatory calculations expected of students in the pre laboratory activity (appendix C.1, noted as C.1 in further text) and the more challenging calculations that required application of students' understanding gained during their laboratory experience in the post laboratory activity (C.2). These links and progression within the three elements involved in this laboratory have allowed students to engage with the concept of molarity, which is shown by no decrease in the mean percentage obtained by students in the post laboratory task.

Figure 4.4 displays the pre, post and in – laboratory tasks that students were required to complete in laboratory 1.4 which introduced students to anions and solubility rules.

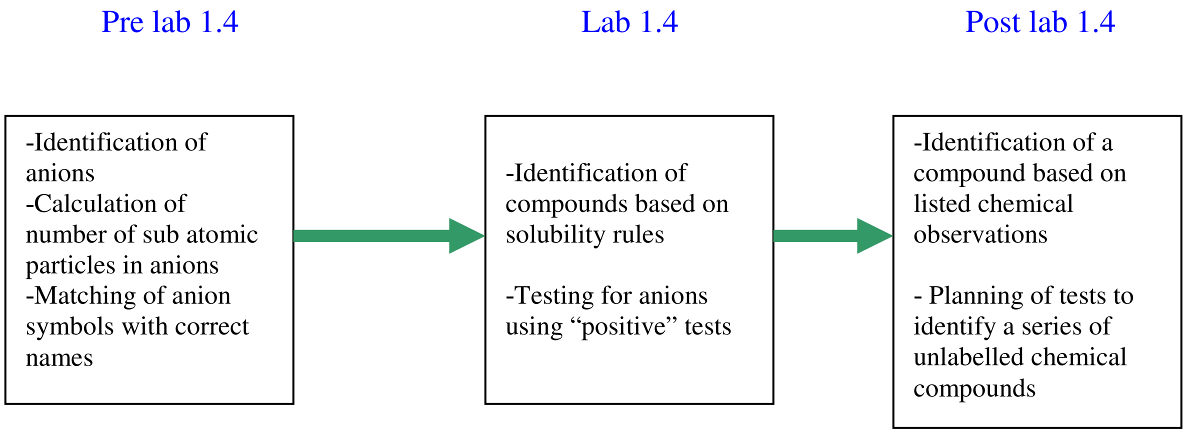


Figure 4.4 Linking of material covered in laboratory 1.4

The results obtained in Table 4.6 show that there was no significant difference between the average percentages obtained in the pre (C.3) and post laboratory activities (C.4) for laboratory 1.4. As the post laboratory activities were designed to challenge and to test students knowledge from their in – laboratory experience, in this example students are showing that the clear linking of material is allowing them to apply their understanding to these more complex problems.

Figure 4.5 displays the pre, post and in – laboratory tasks that students were required to complete for laboratory 1.7 involved students applying their understanding of molarity to a chemical titration.

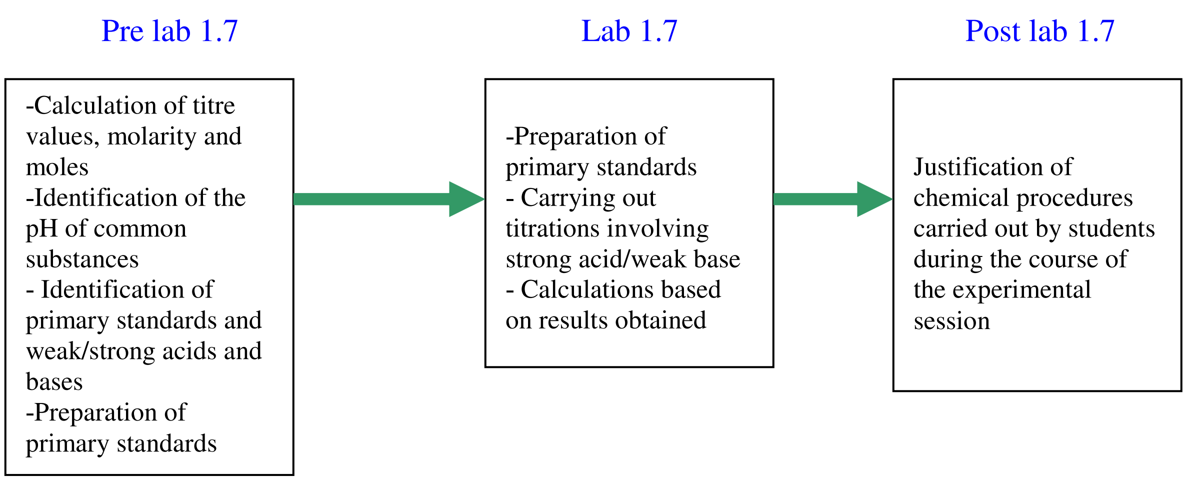


Figure 4.5 Linking of material covered in laboratory 1.7

In this laboratory session the tasks that students were required to complete in each of the pre, post and in laboratory elements were closely linked providing a scaffold approach to students understanding. Students demonstrated an understanding of the material involved in this laboratory session by obtaining similar average percentages in both their post laboratory activity (C.6) and pre laboratory attempts (C.5). As in laboratory 1.3, students have shown a significant level of engagement with laboratory material and the concepts involved than in other laboratories in semester one such as 1.5 and 1.6.

Laboratory 1.8 which dealt with the concept of heats of reaction displayed similar results, seen in Table 4.6, to those obtained for laboratory 1.3 and Figure 4.6 shows the tasks that students completed during the three laboratory elements for this practical session.

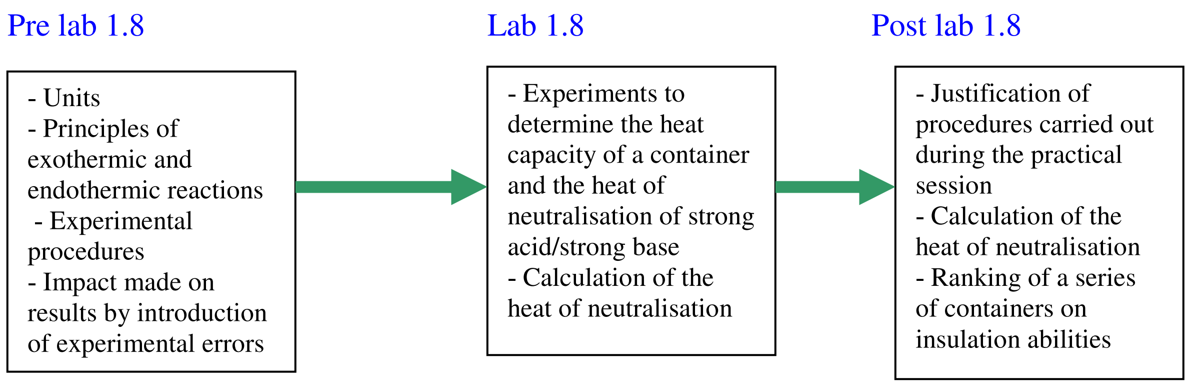


Figure 4.6 Linking of material covered in lab 1.8

There was an increase in student averages for post laboratory questions (C.8) compared to those obtained for pre laboratory questions (C.7), once again showing that students are engaged in these laboratory concepts. Figure 4.6 demonstrates the linking of material between all three elements involved in laboratory 1.8 and the increase in student averages for post laboratory questions, which have been seen to be challenging by students (see section 4.3.5) is possibly due to the tasks completed by students in both pre and in laboratory elements.

Those instances where students have shown dis-improvement in their average percentage obtained for post laboratory tasks may have been due to the lack of linkage between the three elements of the laboratory or also may be accounted for by the lack of engagement by students when presented with the more challenging questions of the post laboratory task.

Table 4.7 shows the t values obtained for the second semester by the same group of undergraduate chemistry students, whose results have demonstrated the same trend as those seen in Table 4.6. As stated before the initial figures which stand out in the second semester is the significant drop in numbers of students submitting attempts for both pre and post laboratory activities.

Laboratory		**Mean of pre task (%)**	**Mean of post task (%)**	**t value**	**Significance**
2.1	N=158	85.23	60.89	-14.294	0.000
2.2	N=135	87.16	60.59	-13.605	0.000
2.3	N=122	67.59	63.98	-1.672	0.097
2.4	N=116	84.34	57.41	-10.843	0.000
2.5	N=122	85.62	58.98	-13.310	0.000
2.8	N=118	85.47	56.36	-14.204	0.000
2.10	N=86	75.12	61.63	-4.769	0.000
2.11	N=137	82.58	60.15	-12.066	0.000
2.12	N=92	78.73	73.01	-1.944	0.055

Table 4.7 t values for pre and post laboratory tasks in semester 2

As in semester one (Table 4.6), the majority of laboratories have displayed a significant decrease in the average percentages obtained by students for their attempts in post laboratory activities compared to those obtained for pre laboratory activities. While it was not expected that students would obtain equal averages on both pre and post activities, due to the different levels of learning that are required for the successful completion of both, there was a significant decrease in the average in all but two laboratories performed in semester two: 2.3 and 2.12. In both of these cases analysis has shown that there is no significant difference in averages obtained for both pre and post laboratory activities, which again can be attributed to the degree of linkage found between the pre, post and in – laboratory elements.

Figure 4.7 displays the three laboratory elements and the tasks which students completed during each element for laboratory 2.3 while Figure 4.8 displays the same information for laboratory 2.12.

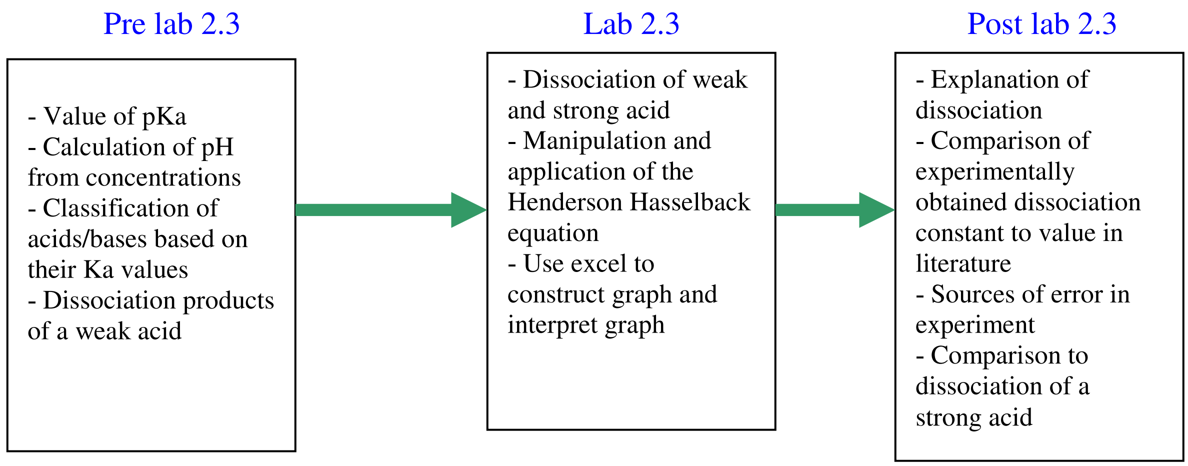


Figure 4.7 Linking of material covered in lab 2.3

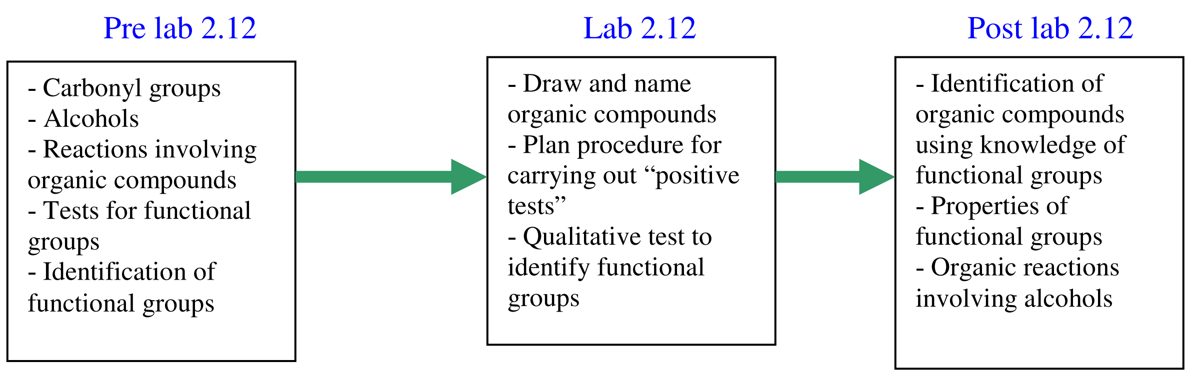


Figure 4.8 Linking of material covered in lab 2.12

As in those examples seen in semester one (Figures 4.3 - 4.6) these laboratory elements are displaying a high degree of linking between all of the tasks required of students. In both laboratories 2.3 (C.9,C.10) and 2.12 (C.11, C.12), students are performing equally well on pre and post laboratory tasks, showing an engagement and understanding of the material covered in these particular laboratories.

Analysis has shown that students are obtaining a lower percentage in the majority of post laboratory activities in comparison to the average percentage obtained for their pre laboratory task. While linking has been attributed to an increase or similar percentage obtained in six cases of both semesters 1 and 2, the correlation and t values have shown that the majority of students are not displaying the same level of engagement in their post laboratory activities that would be expected from the high percentages which have been displayed for their attempts in pre laboratory activities in both Tables 4.4 and 4.5. Due to the challenging nature of the post laboratory questions, which students were required to complete for each laboratory, a similar or increase in percentage shows that students have engaged more in the chemical material and have confidently applied their knowledge to these application questions successfully in six cases.

4.3.2 Correlation of overall pre and post laboratory results

For this section the Pearson coefficient was calculated for the correlation between students average percentage obtained for:

- Pre and post laboratory tasks for semester 1
- Pre and post laboratory tasks for semester 2
- Pre laboratory tasks for both semesters
- Post laboratory assignments for both semesters

Test		Pearsons correlation coefficient
Semester 1	Pre laboratory assignment/ Post laboratory assignment	0.702
Semester 2	Pre laboratory assignment/ Post laboratory assignment	0.702
	Pre laboratory assignment (Sem I)/ Pre laboratory assignment(Sem II)	0.700
	Post laboratory assignment (Sem I)/ Post laboratory assignment(Sem II)	0.651

Table 4.8 Pearsons correlationcoefficient

As can been seen, in Table 4.8 all of the coefficient values obtained are above 0.600 and are therefore significant.

It must be noted that the coefficients that were obtained in these correlations were close to +1 showing a positive association which means that high values in one variable are correlated with high values in the other variable and matching association with low percentages. As these coefficients were not negative values, it demonstrates that students who obtained high values in their pre laboratory task also performed well in their post laboratory task.

The correlation value obtained for the relationship between student average pre and post laboratory tasks in both semesters shows that students who obtained average high percentages in their pre laboratory task obtained an average high percentage in their respective post laboratory assignments. Vice versa those students who performed poorly in the pre laboratory quiz showed weakness also in the completion of their post laboratory activities.

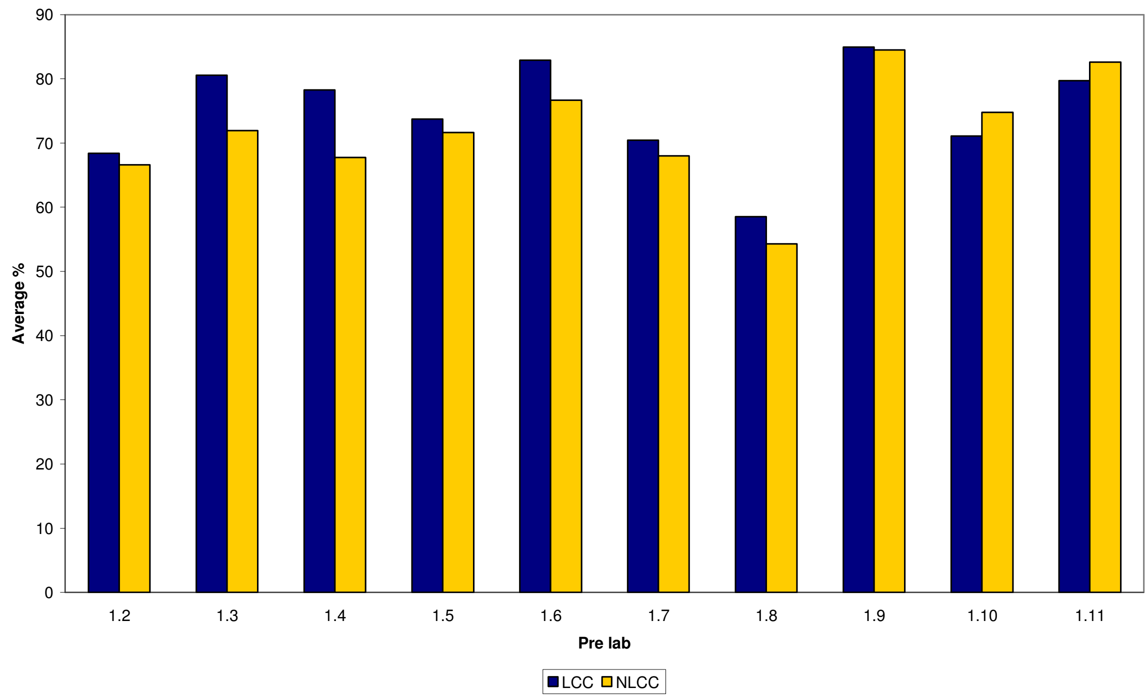
A correlation between student performances in semesters 1 and 2 in terms of pre laboratory quizzes show that students who performed well in semester I also performed well in semester II. Results were similar for student performances in semesters I and II with pre laboratory quizzes, which revealed students who performed well in semester I also performed well in semester II.

It has been shown in section 4.3.1 that there was not a very strong correlation between students performance in individual laboratory tasks, however as seen in Table 4.6 the average percentages of students in both pre and post laboratory have a strong correlation in both semester 1 and 2.

4.3.3 Students pre and post laboratory task and prior chemistry experience

In this section average percentages obtained by students for individual pre and post laboratory tasks are displayed and are separated based on students' prior Leaving Certificate Chemistry background, those who have Leaving Certificate Chemistry (LCC) and those who do not (NLCC)

Figure 4.9 shows the average percentage obtained for pre laboratory tasks in semester one with standard deviations along with t values displayed below.



	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11
LCC (Average%)	68.4	80.6	78.3	73.8	82.9	70.4	58.5	85.0	71.1	79.7
σ	12.7	13.7	15.5	20.9	17.6	18.6	11.4	15.7	24.4	20.7
NLCC (Average%)	66.6	71.9	67.7	71.6	76.7	68.0	54.3	84.5	74.8	82.6
σ	15.7	21.0	19.7	23.9	21.4	20.1	14.8	18.4	24.7	22.4
t – values	0.86	3.39	4.04	0.66	2.20	0.86	2.20	0.18	-1.00	-0.92

Figure 4.9 Average % score by students on pre laboratory semester 1

Firstly from Figure 4.9 it can be seen that on average both LCC and NLCC students were performing particularly well on all semester 1 pre laboratory tasks with average scores in excess of 50%. This shows that students are not only attempting the preparatory tasks before completing their practical sessions but also they have a basic knowledge of the concepts to be covered in the laboratory.

The averages overall obtained by NLCC students were only marginally lower than those obtained by LCC students showing that the questions being used were not over challenging even to those who had little or no chemistry knowledge. These questions, as stated previously in section 4.2 were designed to be basic and straightforward yet helping to introduce students to terminology and simple chemistry that they should be aware of before attempting the laboratory session. As can be also be seen in Figure 4.9, LCC students were still challenged by these questions, even when they may have encountered the majority of these concepts at Leaving Certificate level.

The standard deviation values also displayed in Figure 4.9, show that the percentages obtained by NLCC students were considerably larger in range than those of LCC students. As observed particularly for laboratory 1.3, the standard deviation value obtained for LCC was 13.7 while for non NLCC students was 21.00, displaying that the percentages obtained by NLCC students were of greater distance from the mean, both higher and lower, than those obtained by LCC students.

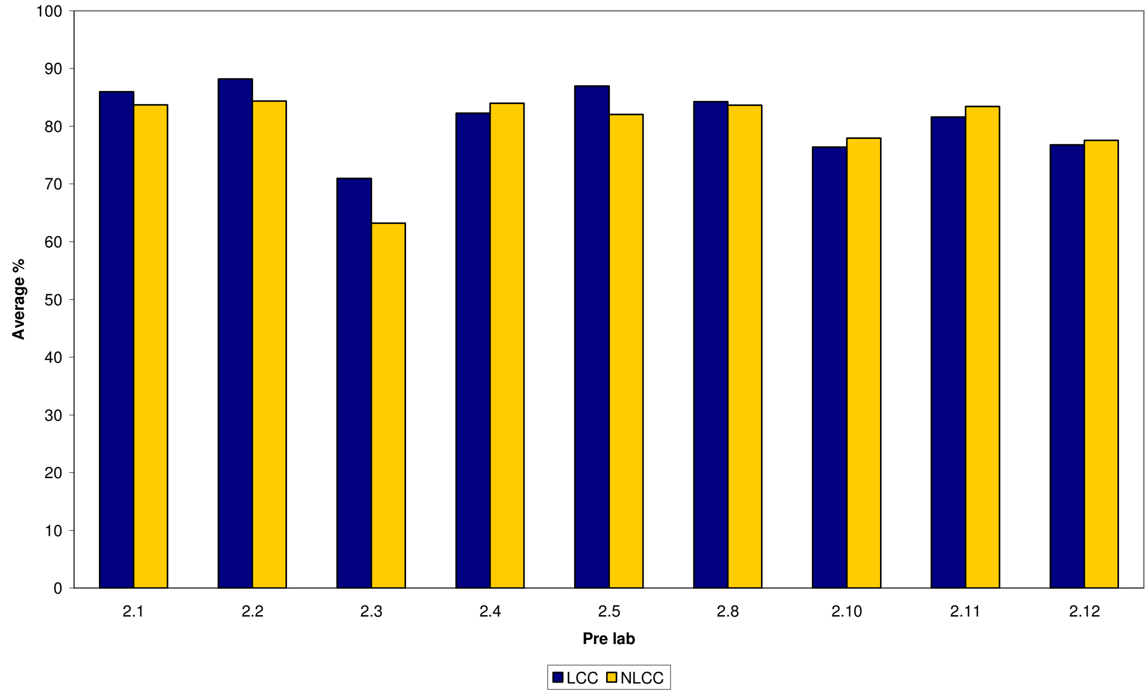
The t values, which are displayed at the bottom of Figure 4.9 are only considered significant when the t -value is above 1.96 to account for a 95% confidence interval (Statistics for Dummies). Therefore the pre laboratory quizzes were LCC students preformed significantly better than their NLCC counterparts were 1.3, 1.4, 1.6 and 1.8. These pre laboratory tasks involved molarity, solubility rules, titrations and the calculation of heats of neutralisation. As would be expected for questions dealing with mole and molarity, LCC students performed better than those students with no chemistry background. These LCC students would have been exposed to the concepts and calculations involved in their prior LCC studies.

The NLCC students have not been introduced to these terms and calculations prior to this practical laboratory and, as is known by educators world – wide, this is one of the most difficult concepts to all chemistry students, not only at third level.

In the case of laboratory 1.8, this was the lowest average percentage observed for both NLCC and LCC students in semester 1. This pre laboratory (C.7) dealt with the concept of heats of reaction and neutralisation which proved to be quite challenging to students. In particular the question relating the impact that error has on the calculation of ΔH (C.7.6) proved to be quite difficult for both sets of students as this question was answered badly which accounted for 50% of the marks awarded for this particular pre laboratory task.

Laboratory 1.9, which dealt with the concept of gas laws, was the task in which students scored most highly in, with LCC students obtaining an average of 84.98% and NLCC students obtaining 84.5% on average. This task (C.13) involved a series of questions relating to the concepts of Boyles, Charles and Gay – Lussac's laws which students would be investigating during the course of laboratory 1.9, along with temperature conversions and gas volumes.

Figure 4.10 shows the average percentage obtained in semester 2 pre laboratory quizzes. Initially it can be observed that the percentages obtained by both NLCC and LCC students are higher than those in semester 1 with six of the nine quizzes showing averages of over 80% for both sets of students(2.1, 2.2, 2.4, 2.5, 2.8, 2.11). Also the standard deviation values for both LCC and NLCC students have dropped, showing that while the percentages obtained by students still differ from the mean, these differences are not as far from the mean as those seen in semester 1.



	2.1	2.2	2.3	2.4	2.5	2.8	2.10	2.11	2.12
LCC (Average%)	85.9	88.2	71.0	82.3	87.0	84.3	76.4	81.6	76.8
σ	15.4	14.5	20.3	19.3	14.0	14.1	15.2	15.1	20.9
NLCC (Average%)	83.7	84.4	63.2	84.0	82.0	83.7	78.0	83.5	77.6
σ	17.0	15.0	20.4	19.1	15.7	15.0	17.2	16.5	19.1
t	0.91	1.70	2.49	-0.58	2.22	0.28	-0.57	-0.74	-0.24

Figure 4.10 Average % score by students on pre laboratory semester 2 quizzes

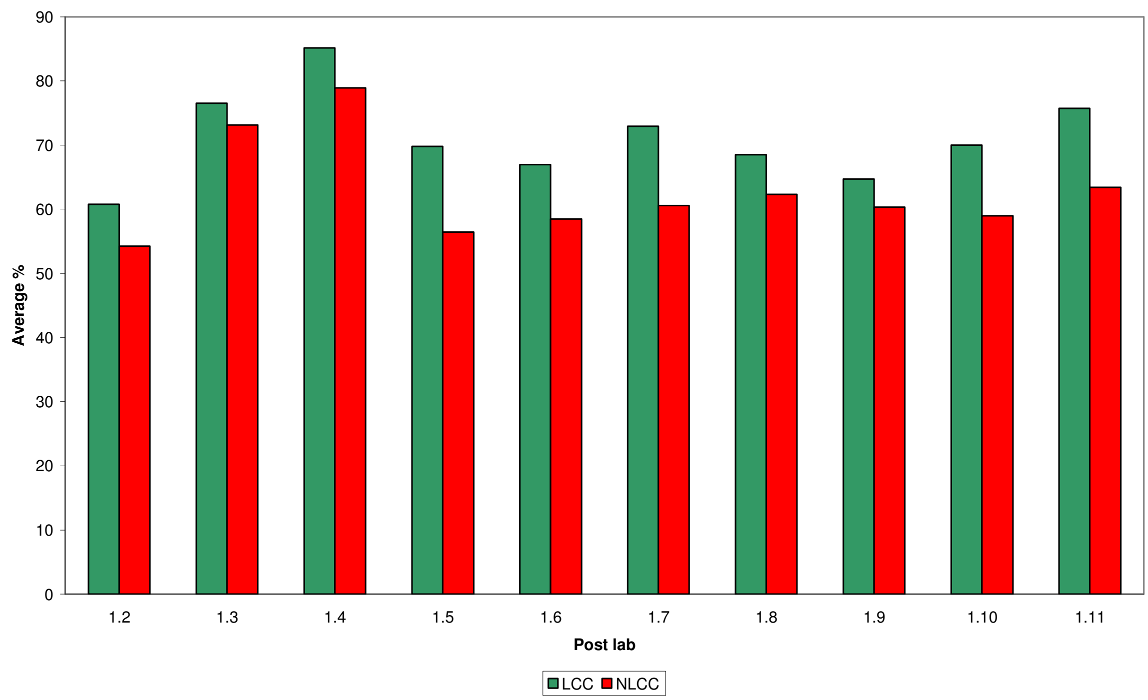
In semester 2, NLCC students have raised their average marks in all of the pre laboratory quizzes in comparison to their scores in semester 1 while LCC students maintain a high grade once again in semester 2. The averages obtained never drop below 50% in either case for the LCC or NLCC students, who are both displaying an increase in preparedness for the concepts involved in semester 2 laboratories.

No laboratory stands out in semester 2 as having a higher average as in semester 1, as six pre laboratory quizzes have averages of over 80%. However laboratory 2.3 (C.9) has proven to be quite challenging to both NLCC and LCC students, with an average obtained of 63.2% and 71.0% respectively. As determined from the t value obtained this is the only pre laboratory quiz which can be compare directly as the t value obtained is over 1.96. Here LCC students have performed significantly better than their NLCC counterparts with an average of 6% difference between the two cohorts. These questions were used in order to prepare students for the experimental session to determine the dissociation constant of a weak acid.

Students were required to calculate the pH of a series of acids and bases (C.9.3) from their $[H^+]$ and also to classify an acid/base as weak or strong based on their K_a value (C.9.4) as two of the questions in this pre laboratory task. As both questions were allocated 38.5% of the total percentage for this task and as they proved to be quite challenging to both sets of students, this accounts for the lower average percentages obtained by NLCC and LCC students.

In both semesters NLCC students have shown a strong chemical ability as the average obtained across the two semesters never dropped below 50%. This also provides evidence that the level of chemistry which was expected from students in order to adequately prepare for their laboratory session was appropriate for those students with little or no chemical experience. However the pre laboratory tasks still proved to be challenging for LCC students as while their scores also never dropped below 50% there was no one week in either semester where the average obtained climbed over 90%. As these students have completed chemistry to Leaving Certificate Level it would be expected that the average marks obtained could reach 100% as the questions posed required basic chemical knowledge.

Figure 4.11 shows the average percentage obtained in semester 1 post laboratory assignments by both NLCC and LCC students.



	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11
LCC (Average%)	60.8	76.5	85.1	69.8	66.9	73.0	68.5	64.7	70.0	75.7
σ	25.9	24.4	13.6	21.3	20.0	17.7	16.9	24.0	23.6	21.8
NLCC (Average%)	54.2	73.2	78.9	56.4	58.5	66.5	62.3	60.3	59.0	63.4
σ	25.0	26.2	14.8	18.2	21.4	21.6	16.1	24.4	22.4	26.5
t	1.01	0.40	0.78	2.09	1.28	1.93	0.82	0.57	1.58	1.50

Figure 4.11 Average % score by students on post laboratory tasks semester 1

In comparison to those results shown in Figure 4.9, showing student averages obtained for pre laboratory tasks, it can be seen that the averages obtained by both cohorts of students in the post laboratory tasks in semester 1 are lower.

Once again both LCC and NLCC students are displaying some engagement with the material assessed in the post laboratory tasks as both cohorts obtained averages greater than 50%, similar as in the pre laboratory tasks of semesters 1 and 2.

In relation to the performance of LCC students, the impact that prior chemical knowledge has on students' scores in post laboratory activities is more evident than in pre laboratory tasks, as the averages obtained by both LCC and NLCC students are substantially lower than what they obtained in their attempts in both pre laboratory tasks for semesters 1 and 2, however the drop in percentage is greater for the NLCC students.

Post laboratories 1.5 and 1.7 are the only two post laboratory assignments were the results obtained by NLCC and LCC students show a significant difference. While 1.7 has a t value of less than 1.96 this is to a 90% confidence interval rather than a 95% confidence interval as with 1.5. In post laboratory 1.5 students were required to complete a series of questions based on the solubility rules they had investigated during their laboratory session. In post laboratory 1.7 students were tested on their ability to perform a titration calculation which was hoped to build on their experience of calculations during the laboratory session. LCC students would be expected to have somewhat of an advantage on their NLCC counterparts as they would have had some experience in the completion of these calculations, balancing of equations and ion formation as they are an integral part of the Leaving Certificate Chemistry course.

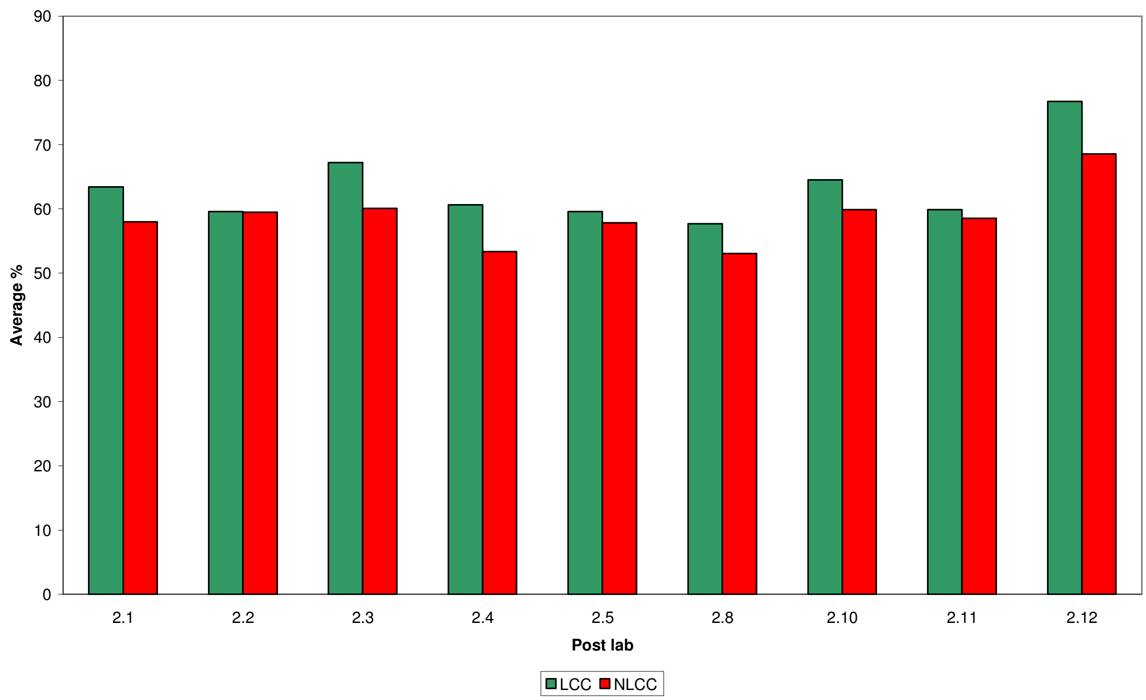
As seen in Figure 4.10, laboratory 1.4 (C.4) shows the highest average percentage obtained by both LCC and NLCC students while post laboratory task 1.2 (F.13) proved to be the most challenging of the ten tasks in semester 1. Section 4.2.1 discussed the linkage that was seen between the in-laboratory session and the questions asked of students in their post laboratory activity. It is thought that this high degree of linkage proved to engage students in their post laboratory questions and accounts for the high level of achievement that has been seen in the average percentage obtained for this laboratory.

The laboratory 1.2 dealing with the mole has been seen to be quite challenging to both LCC and NLCC students. This concept was relatively new to NLCC students and proved to be quite difficult which accounts for their low average percentage.

This post laboratory question built upon calculations performed in the laboratory session but demanded more understanding and ability from students than those calculations previously experienced.

LCC students however had covered the concept of the mole during their Leaving Certificate studies and while they performed better than their NLCC class mates, proved to not have a sufficient understanding and engagement with this concept to maintain their strong average percentage for this task.

Figure 4.12 shows the average percentage obtained in semester II post laboratory assignments



	2.1	2.2	2.3	2.4	2.5	2.6	2.8	2.10	2.11
LCC (Average%)	63.4	59.6	67.2	60.6	59.6	57.7	64.5	59.9	76.7
σ	22.5	20.7	22.7	23.3	18.8	23.2	19.6	20.6	22.0
NLCC (Average%)	58.0	59.5	60.1	53.3	57.0	53.0	59.0	58.5	68.6
σ	16.6	20.6	26.0	20.2	16.7	20.7	19.1	17.5	23.4
t	0.80	0.01	0.91	1.02	0.23	0.64	0.51	0.19	0.80

Figure 4.12 Average % score by students on post laboratory tasks semester 2

It is obvious in comparison to those average percentages observed in Figure 4.11 that neither group of students are engaging with the material to the same extent as in semester 1 and that the post laboratory tasks are proving to be quite challenging for all. The percentages obtained by LCC have dropped significantly in comparison to those they achieved in semester 1, the average percentage obtained by LCC students has fallen from 71.1% in semester 1 to 63.2% in semester 2. In comparison to this the average by NLCC students has fallen from 62.7% semester 1 to 58.7% in semester 2. This also may be accounted for by the fall in number of students completing post laboratory tasks as seen in Table 4.5 in section 4.2.1.

The post laboratory task in which students obtained the highest average percentage was laboratory 2.12 (C.12), which was shown in section 4.2.1 to have a high degree of linkage between the laboratory tasks and the post laboratory questions.

However in semester 2 there was no particular post laboratory task which has shown to have been particularly difficult for either LCC or NLCC students as none of the nine post laboratory percentages achieved by either cohort have shown significance over 1.96. The associated standard deviations have shown that in post laboratory activities, standard deviations are greater for the LCC cohort in seven of the post laboratory tasks than for the LCC cohort.

In summary, both sets of students have performed well on pre laboratory tasks in both semester 1 and 2 with an increase in the average percentages evident in semester 2. However in the case of the post laboratory tasks, a sharp fall in the average percentages obtained by both NLCC and LCC cohorts has shown that the questions involved in these laboratories have proven more challenging to students and may indicate reduced engagement by students. It must be noted that there was also a change in academic staff running the laboratory session for semester 1 to semester 2 and the effect of this (if any) is difficult to quantify.

4.3.4 Student survey results – pre and post laboratory opinions

In the final week of both semesters I and II, students completed a questionnaire relating to their experience within the first year laboratory sessions. The questionnaire dealt with a range of topics, however in relation to this study the experiences with the pre and post – laboratory activities were selected out for analysis. Results are shown in Table 4.9.

Semester I (N=187)		**Semester II (N = 167)**	
Question	Agree (%)	Question	Agree (%)
I found the pre – lab quiz beneficial	89.3	I found the pre – lab quiz beneficial	99.2
If I properly prepared for the lab there was enough time to complete all of the tasks	67.4	If I properly prepared for the lab there was enough time to complete all of the tasks	74.9
I felt that the pre – laboratory quiz prepared me for carrying out the experiment	80.8	I felt that the pre – laboratory quiz prepared me for carrying out the experiment	83.8
My marks for the pre – laboratory quiz reflected the effort that I put in	57.8	My marks for the pre – laboratory quiz reflected the effort that I put in	70.1
I downloaded the pre – laboratory quiz as a word document before attempting the quiz online	79.3	I downloaded the pre – laboratory quiz as a word document before attempting the quiz online	65.3
I was well prepared for the experiment that I was to carry out each week	61.0	I was well prepared for the experiment that I was to carry out each week	53.9

Table 4.9 Student opinions on Pre – laboratory tasks

The majority of the students agreed in both semesters that if they properly prepared for the laboratory they had adequate time to complete all tasks in their experimental session. Part of the preparation that students were required to do was to complete were the pre laboratory activities, which over 80% of students agreed helped them prepare for the laboratory session. Over half of the students in the first semester stated that their marks for the pre – lab quiz did reflect their effort while this number rose in the second semester.

This statement was particularly encouraging as the average percentage of marks achieved by students in the second semester for their pre laboratory tasks rose, see Figure 4.9, which meant that students were trying harder in the second semester or that the pre laboratory quizzes were easier, or that they became more efficient at working together in completing them.

The fact that <60% of the students in semester I were happy that their marks in pre laboratory quizzes reflected the effort that they had put in, suggests that the students had put significant effort into completing the pre laboratory quiz.

As stated before the pre laboratory quizzes were available to download by students in order to allow them to prepare their answers offline if they wished. Students only received a grade for their first submitted attempt, so downloading the quiz before completion would show that students were planning ahead and taking an active role in their assessment.

However fewer students downloaded the pre laboratory quiz in the second semester. This could be due to a number of factors, e.g. students more comfortable with technology, working together at PC, etc. Students also felt less prepared for their laboratory session. It is interesting to note that, in semester II, almost all of students found the pre laboratory quiz beneficial and majority feel it had prepared then for the laboratory session, only approximately half of them were well prepared.

Comments from students on pre laboratory quizzes, collected during the course of the questionnaire are given in Table 4.10.

Comments from semester 1
'I could have spent more time on my pre lab tasks' *'I really enjoyed the quizzes and felt that they focused my attention on the basics for the lab session'* *'Devote more time to working on my pre-lab and reading up on my experiment'* *'I should have done more research & looked up the answers to the pre – lab questions I didn't know'*
Comments from semester 2
I didn't enjoy the pre lab tasks as I felt that I wasn't rewarded for the effort I put in.' *'Pre and post labs were easier to do as we were more used to them after semester 1'*

Table 4.10 - Individual student opinions expressed on pre laboratory quizzes

As can be seen from comments in Table 4.10, students began in semester 2 to take responsibility for their own preparation and recognised the impact that the pre – laboratory had on their performance and preparation for the laboratory. While some students stated that they were overwhelmed with the tasks that they were asked to complete for the lab session, they recognised that the more effort put into the pre laboratory tasks, the more prepared they were for the experimental session.

Table 4.11 summaries student opinions of post laboratory tasks.

Semester I (N=187)		**Semester II (N = 167)**	
Question	Agree (%)	Question	Agree (%)
The post – laboratory activities made me think about what I had completed in the laboratory	84.0	The post – laboratory activities made me think about what I had completed in the laboratory	73.1
I found the post – laboratory activities challenging but doable	69.0	I found the post – laboratory activities challenging but doable	80.8
I found the calculations involved in the post – laboratory doable	11.8	I found the calculations involved in the post – laboratory doable	12.6
		I found the Moodle environment easy to use for this module	91.6
		The volume of "out of lab" work was manageable	58.7

Table 4.11 Student opinions on post – laboratory activities and Moodle

From Table 4.11, it is seen that a large percentage of the cohort agreed that the post laboratory activities were directly linked to the material covered in the experimental session. However this percentage drops in relation to semester 2, which is also reflected with a rise in student agreement that the post laboratory activities are challenging. This was also supported by Figure 4.8, which displays the falling percentages obtained by students for post laboratory attempts in semester 2, compared to those average percentages for semester 1 in Figure 4.9.

On student opinions of the calculation element of the post laboratory activities, it is very evident that this is the aspect of the chemistry which they find difficult, with less than 12 % of students in semester 1, agreeing that the calculations were doable with a small increase to less than 13 % in semester 2 .

However this was not a problem exclusively associated with post laboratory activities as 70% of students surveyed in semester 2 expressed that one of the main difficulties that they had in terms of the entire lab session was their ability to perform the required calculations. This was also supported by students expressing a wish to have more tutorials which dealt with calculations for both lecture and laboratory material.

In relation to students' opinions on the post laboratory assignments, the following opinions (Table 4.12) were presented when students were asked if they would change anything for the following year.

Challenging post laboratory activities
The post lab are a bit complicated and could be easier' *'…… some post lab questions were too hard for people who haven't done chemistry'* *'More time to do the post lab assignment as they are quite challenging'* *'I think that there should be more help available for the post lab questions as they are difficult!'*

Time issues
'More time to do the pre and post labs before they close on Moodle'
General feedback
'I began to get more confident about my completion of the post laboratory and understand what I was doing' *'The feedback on my post – lab was more informative compared to Semester I'*

Table 4.12 - Individual student suggestions of changes to laboratories

Student comments suggest that they are having difficulty with their time management in terms of completion of their "out of lab" work, however this is a personal issue that students must be aware of when meeting deadlines, during the course of all their undergraduate modules. Students did however raise the concern that the post – laboratory activities were especially challenging to those students who had not completed chemistry for the Leaving Certificate. Some students however, did state that they felt more confident with the attempts at the post laboratory activity as the semester progressed, while they didn't feel that the activities were any less challenging as the semester continued.

In terms of students' opinions of using the VLE, the majority of students stated that they found the online element easy to use. This analysis shows that with repeated implementation and correct instruction, students of all levels of computer experience: mature students to those coming straight from secondary schools, have grasped the necessary skills to upload, download documents and perform online activities.

4.4 Conclusion

The implementation of pre and post laboratory activities is not a new concept and has been shown in the literature to benefit student learning in the laboratory context.

The VLE has proven to be a useful and easy tool with which to provide students, tutors and academic staff with feedback on students' performance both prior to and after the laboratory session. Students received immediate feedback on basic pre – laboratory questions while tutors and academics were able to identify problem areas that could be dealt with in either group tutorial or on a one to one basis within the laboratory session. The marking of the post laboratory activities allowed tutors to provide their students with guidance and appropriate feedback on their attempts. Students could discuss their marks with their tutor and also could self assess their post laboratory attempt once provided with appropriate feedback, which allowed them to see where problems had arisen.

As students were allocated a given percentage of their overall laboratory work for the completion of their pre and post laboratory activities, their interaction with the online material was not an issue until the last few weeks of each semester, Table 4.6, where student number began to fall, with the lowest percentage of students observed in the final week of semester 2 with 40.8% of the cohort completing both the pre and post laboratory tasks.

Students have expressed their opinions in terms of the pre and post laboratories and the effect that they have had on students in - laboratory experiences. Students have stated that they found that the pre laboratory quiz helped to focus their learning on the principles involved in their laboratory session, and that it also helped in their preparation for the laboratory tasks. Students also stated that they found the majority of post laboratory assignments challenging but doable, the averages seen in section 4.2.3 and 4.2.1 show that the post laboratory tasks were more challenging for students in semester 2. Students did also express some issues with the time limits that were allocated for the completion of the post laboratory activities and that the level of post – laboratory assignments could be made easier in future.

Results have shown that students saw the benefits of their pre laboratory quizzes and their average scores reflected this enthusiasm, with an increase in student averages between semester 1 and semester 2. The results shown in section 4.2.3 display that the level of questioning chosen for these pre laboratory quizzes allowed even those with little or no chemistry experience to adequately prepare for their practical element as high averages were achieved by both LCC and NLCC students.

Students' results in relation to their attempts on post laboratory activities showed that a large percentage of students found the questions difficult and were not engaging with the material covered in the majority of laboratory sessions in both semesters 1 and 2. It also was seen in both student surveys and in average percentages that the post laboratory questions in semester 2 proved to be more challenging to the students than those in semester 1. It was also seen from the correlation and t values, that there was a degree of linkage between four experiments in semester 1 and two experiments in semester 2 which allowed students to clearly relate all material covered in the pre, post and in laboratory tasks. This linkage, when evident to students, allowed them to build upon their knowledge and to successfully apply their understanding to the more complex questions of the post laboratory session. When this linkage was not obvious to students and their understanding was not as clearly questioned, student engagement with the post laboratory questions resulted in a fall in percentage obtained, in comparison to their obtained average for the pre laboratory task for the same experimental session.

Students did express during the course of the laboratory evaluation surveys, that they found the calculation aspect of the laboratory sessions, pre and post assignments quite difficult. This is not, an aspect that is only seen in the chemical laboratory environment, it is evident in all elements of the chemistry modules. While students have the required mathematical ability, based on the entry requirements for each of the chemistry courses, they are unable to apply their knowledge of mathematical procedures and techniques to chemical situations.

It has been observed from the numbers of students completing both pre and post laboratory tasks, and from the opinions extracted from student questionnaires, that the online assessment element is a successful method of assessing students understanding both before and after a practical session.

Students have noted the positive impact that the pre laboratory quizzes have had on their preparation for laboratory sessions, and that the post laboratory questions made them think about the concepts covered in laboratories.

However results have shown that unless there is a strong linkage between the three elements that students are required to complete in their practical laboratory experience, pre, in and post laboratory tasks, they display a lack of engagement with the post laboratory material. While the linkage of material used in pre, post and in laboratory elements may be very obvious to academics and tutors it may not be as evident to undergraduate students. In order to ensure that the success demonstrated in six of the nineteen analysed laboratory sessions is promoted, further work needs to be done on those questions employed to prepare and assess students' chemical knowledge both prior and after the laboratory session. Once this linkage of material is evident to students in pre, post and in – laboratory tasks it would be hoped that a positive correlation would be seen between students' performances in all practical sessions.

Based on the opinions and experiences of both students and tutors the pre and post laboratory tasks have been slightly modified to suit changes in individual laboratory sessions, but the same format is now being employed in the 1st year undergraduate chemistry practical laboratories for the academic year 2008/2009.

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APPENDIX

A

LEAVING CERTIFICATE CHEMISTRY ANALYSIS

This appendix contains the results of analysis performed on Leaving Certificate Chemistry Higher Level papers from 2000 to 2008. Analysis has been performed using Bloom's Taxonomy. For this application of Bloom's Taxonomy the following key has been used: K = Knowledge, C = Comprehension, Ap = Application, An = Analysis, E = Evaluation and S = Synthesis. Also the key seen in Table 1.7 has been used on years 2002 – 2008 to identify the sub topics on each examination paper.

Leaving Certificate Chemistry Paper Higher Level - 2000

Question Number	Question type	Marks	Question Number	Question type	Marks
Q1			iii	Ap	9
A	C	6.36	iv	An	9
B	K	6.36	v	C	15
C	An	6.36	vi	Ap	12
D	C	6.36	Q7		
E	K	6.36	ia	K	9
F	K	6.36	ib	K	12
G	C	6.36	ii	C	6
H	An	6.36	iii	Ap	9
I	C	6.36	iv	Ap	9
J	Ap	6.36	v	An	12
k	C	6.36	vi	An	9
l	K	6.36	Q8		
m	C	6.36	i	K	6
n	K	6.36	ii	C	12
o	An	6.36	iii	C	18
Q2			iv	An	18
i	C	9	v	C	12
ii	C	15	Q9		
iii	K	12	ai	K	9
iv	C	12	aii	C	9
v	An	18	bi	C	6
Q3			bii	An	12
i	C	12	c	K	9
ii	C	12	ci	An	6
iii	K	9	cii	An	6
iv	C	15	ciii	An	9
v	An	18	Q10		
Q4			a	K	6
	K	6	ai	Ap	6
i	Ap	6	aii	C	9
ii	C	15	aiii	An	12
iii	An	21	bi	C	15
iv	An	12	bii	C	12
v	An	6	biii	C	6
Q5			c	K	12
ia	K	9	ci	An	15
ib	K	9	cii	An	6
ii	C	15	di	K	9
iii	C	24	dii	C	3
iv	C	9	diii	Ap	12
Q6			div	C	9
i	K	12			
ii	C	9			

Leaving Certificate Chemistry Paper Higher Level – 2001

Question Number	Question type	Marks	Question Number	Question type	Marks
Q1			iv	C	9
a	K	6.36	v	C	12
b	C	6.36	vi	Ap	12
c	An	6.36	Q7		
d	Ap	6.36	a	K	6
e	Ap	6.36	i	C	6
f	K	6.36	ii	Ap	12
g	C	6.36	iii	An	12
h	An	6.36	bi	C	6
i	An	6.36	ii	Ap	6
j	An	6.36	iii	AP	9
k	K	6.36	iv	An	9
I	C	6.36	Q8		
m	K	6.36	a	C	18
n	C	6.36	bi	K	6
o	An	6.36	bii	C	3
Q2			ci	Ap	6
i	C	12	cii	Ap	6
ii	K	6	ciii	An	6
iii	C	9	civ	An	9
iv	K	12	cv	An	12
v	An	9	Q9		
vi	An	12	a	K	12
vii	C	6	i	Ap	21
Q3			ii	An	9
i	Ap	12	iii	An	18
ii	C	6	iv	An	6
iii	C	6	Q10		
iv	C	12	ai	K	6
v	C	9	aii	C	12
vi	C	9	aiii	Ap	6
vii	C	12	aiv	An	9
Q4			bi	An	12
i	C	6	bii	C	9
ii	C	12	biii	Ap	12
iii	Ap	12	ci	Ap	18
iv	C	15	cii	Ap	3
v	Ap	15	ciii	Ap	12
vi	An	6	d	K	6
Q5			i	C	18
a	K	6	ii	An	9
b	K	6			
c	K	6			
i	C	6			
ii	An	12			
iii	C	15			
iv	An	15			
Q6					
i	K	15			
ii	C	6			
iii	Ap	12			

Leaving Certificate Chemistry Paper Higher Level – 2002

Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				Q7			
ai	7.3(m)	C	4	a	7.5SAA3	Ap	8
aii	7.3(m)	C	4	b	7.5(c) & (d)	C	18
b	4.1(c)A	C	12	c	1.2SAA2	C	15
ci	4.1(c)A	K	5	d	7.5(e)	C	9
cii	4.1(c)A	C	5	Q8			
ciii	4.1(c)A	K	5	ai	7.2(b)	K	5
d	4.3(b)A2	An	15	aii	7.2(b)	Ap	6
Q2				bi	5.1(a)	C	3
a	7.2(e)	An	5	bii	5.1(a)	C	3
bi	7.3(k)A	K	5	biii	5.1(a)	K	3
bii	7.3(k)A	C	5	ci	5.5SAA3	Ap	3
biii	7.3(k)A	C	5	cii	5.5SAA3	Ap	3
c	7.3(k)A	C	9	d	5.4(f)	K	6
d	7.3(k)A	An	9	e	5.4(h)A	An	18
ei	7.3(k)A	C	6	Q9			
eii	7.3(k)A	Ap	6	a	2.3(c)	An	5
Q3				i	9.3(a)	C	9
a	6.2(a)A2	C	5	ii	9.3(a)	C	9
b	6.2(a)A2	C	12	iii	9.3(a)	K	9
ci	6.2(a)A2	Ap	9	bi	9.4(b)	An	12
cii	6.2(a)A2	Ap	9	bii	9.4(b)	Ap	6
d	6.2(a)A2	Ap	9	Q10			
e	6.2(a)A2	An	6	a	1.5(a)	K	4
Q4				ai	1.5(a)	Ap	12
a	1.2(d)	K	6.25	aii	1.5(a)	Ap	9
b	1.4(i)	C	6.25	bi	1.4(c)&(d)	K	4
c	1.4(g)	K	6.25	bii	1.4(c)&(d)	C	12
d	9.1(b)A	An	6.25	biii	1.4(c)&(d)	C	6
e	1.5(a)	Ap	6.25	biv	1.4(c)&(d)	An	3
f	2.2(d)A	C	6.25	c	8.2(a)	K	7
g	8.1(a)	Ap	6.25	i	8.2(b)	Ap	6
h	9.4SAA4	K	6.25	ii	8.2(b)	An	12
i	3.2(b)	K	6.25	Q11			
j	5.2(a)	C	6.25	ai	4.3(b)A7	K	4
kA	1B.5SAA3	Ap	6.25	aii	4.3(b)A7	An	6
kB	7.3SAA3	An	6.25	aiii	4.3(b)A7	An	9
Q5				aiv	4.3(b)A7	An	6
a	1.4(k)	K	8	bi	1.3(a)	K	7
b	1.4(k)	C	15	bii	1.3(a)	C	9
c	1.4(k)	C	6	biii	1.2SAA1	C	9
d	1.4(k)	Ap	9	cAi	1A.2(a)	An	6
e	1.4(l)	An	12	ii	1A.2(a)	K	4
Q6				iii	1A.2(a)	C	15
a	5.2(b)	Ap	8	Bi	2B.4(c)	K	4
b	7.2(a)	C	15	ii	2B.4(c)	C	15
c	5.2(a)	Ap	9	iii	2B.4(c)	An	6
d	7.3(n)	C	12				
e	7.2SAA1	K	6				

Leaving Certificate Chemistry Paper Higher Level – 2003

Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				Q7			
a	4.3(b)A5	C	5	a	6.1(a)	K	5
b	4.3(b)A5	C	18	i	6.1(a)	An	18
c	4.3(b)A5	An	6	b	6.2(a)	K	6
d	4.3(b)A5	K	3	i	6.2(a)	C	6
e	4.3(b)A5	An	18	ii	6.2(a)	C	6
Q2				iii	6.2(a)	C	5
a	5.6(a)A1	C	8	iv	6.2(a)	K	4
b	5.6(a)A1	C	3	Q8			
c	5.6(a)A1	Ap	6	a	4.2(a)	K	8
di	5.6(a)A1	C	5	i	4.2(b)	C	6
dii	5.6(a)A1	Ap	4	b	9.1(a)	K	6
ei	5.6(a)A1	C	9	i	9.1(a)A	An	12
eii	5.6(a)A1	Ap	9	ci	9.4(a)A	C	12
f	5.6(a)A1	Ap	6	cii	9.4(a)A	K	6
Q3				Q9			
a	3.2(a)A2	K	5	ai	7.2(c)	Ap	8
bi	3.2(a)A2	Ap	11	ii	7.2(c)	Ap	12
bii	3.2(a)A2	An	10	iii	7.3(n)	C	6
c	3.2(a)A2	Ap	6	bi	7.2SAA3	K	6
d	3.2(a)A2	An	12	ii	7.2SAA3	C	12
e	3.2(a)A2	An	6	iii	7.2SAA3	K	6
Q4				Q10			
a	1.2(c)	C	6.25	a	5.4(f)	K	7
b	3.5(c)	An	6.25	i	5.4(h)A	An	12
c	3.2(a)A2	K	6.25	ii	5.4(h)A	An	6
d	1.2SAA2	C	6.25	b	7.2SAA6	Ap	18
e	9.4(b)	K	6.25	i	7.2SAA6	K	7
f	1.3(a)	C	6.25	ci	2.2(d)A	K	10
g	4.1(a)	An	6.25	ii	2.2(d)A	C	15
h	7.2(l)	C	6.25	Q11			
i	1.1SAA2	K	6.25	a	8.2(a)	K	7
j	5.5SAA5	Ap	6.25	i	8.1(b)	Ap	6
kA	1B.2(c)	An	6.25	ii	8.1(b)A	An	12
kB	2A.3(a)	K	6.25	bi	1.4(k)	Ap	7
Q5				ii	1.4(l)	C	12
i	1.4(a)	K	4	iii	1.4(l)	An	6
ii	1.4(g)	Ap	4	cA	1B.5(a)	K	7
iii	1.4(i)	An	3	i	1B.5SAA4	K	6
iv	1.4(h)	K	3	ii	1B.5SAA6	C	12
bi	2.4(a)	Ap	6	cBi	2A.1(a)	K	4
bii	2.5(c)	K	9	ii	2A.1(a)	C	15
biii	2.5(a)	C	12	iii	2A.1(a)	K	6
c		C	9				
Q6							
a	7.2(a)	Ap	8				
b	7.3(a)	C	9				
c	7.3(b)	K	3				
d	7.3(g)	K	6				
ei	7.3(d)	C	18				
eii	7.3(d)	K	6				

Leaving Certificate Chemistry Paper Higher Level – 2004

Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				Q6			
ai	9.4(a)A3	K	4	a	5.4(g)	K	6
ii	9.4(a)A3	K	4	ai	5.5SAA4	K	5
b	9.4(a)A3	C	15	b	5.4(h)A	An	12
c	9.4(a)A3	Ap	6	ci	5.5SAA2	K	5
d	9.4(a)A3	An	15	ii	5.5SAA2	K	4
e	9.4(a)A3	Ap	6	d	5.5(a)	Ap	12
Q2				e	5.5SAA2	C	6
ai	7.3(l)A	C	5	Q7			
ii	7.3(l)A	K	6	a	7.2(e)	An	8
b	7.3(l)A	K	12	bi	7.3(k)	Ap	9
c	7.3(l)A	Ap	6	bii	7.3(k)	K	6
di	7.3(l)A	K	6	ci	7.3(o)A	C	5
ii	7.3(l)A	C	6	ii	7.3(o)A	C	5
ei	7.3(l)A	C	4	iii	7.3(o)A	C	5
ii	7.3(l)A	Ap	5	iv	7.3(o)A	C	6
Q3				d	7.3(o)	K	6
ai	7.2(d)A	Ap	5	Q8			
ii	7.2(d)A	C	6	ai	6.1(a)	K	5
iii	7.2(d)A	C	6	ii	6.2(b)	Ap	6
iv	7.2(d)A	An	3	bi	6.2(e)	K	6
v	7.2(d)A	An	3	ii	6.2(e)	An	6
vi	7.2(d)A	An	3	ci	6.2SAA3	K	5
bi	7.2(d)A	Ap	15	ii	6.2SAA3	K	4
ii	7.2(d)A	C	6	di	6.2(e)A	C	9
iii	7.2(d)A	C	3	ii	6.2(e)A	C	9
Q4				Q9			
a	1.2(e)	K	6.25	a	8.1(a)	K	8
b	2.5(a)	An	6.25	b	8.2(a)	An	12
c	2.3(c)	An	6.25	ci	8.2(a)	Ap	3
d	3.2(b)	K	6.25	ii	8.2(a)	Ap	3
e	4.2(b)	Ap	6.25	d	8.1(a)	Ap	6
f	9.4SAA1	C	6.25	e	8.1(b)A	An	18
g	2.6(a)	Ap	6.25	Q10			
h	4.1(a)	An	6.25	ai	4.3(b)A	An	10
i	1.5(d)A	C	6.25	ii	4.1(a)	An	9
j	2.2(d)A	C	6.25	iii	4.1(a)	An	6
kA	1B.1(a)	K	6.25	b	1.4(c)	C	13
kB	2B.3(a)	K	6.25	i	1.4(c)	K	6
Q5				ii	1.4SAA1	K	3
ai	1.4(i)	Ap	5	iii	1.4SAA1	C	3
ii	2.2(a)A	Ap	5	c	3.2(d)	K	5
iii	2.5(c)	C	4	i	3.2(f)	K	5
iv	2.5(c)	C	6	ii	3.2(f)A	K	3
bi	1.4(k)	K	9	iii	3.2(f)A	An	12
ii	1.4(l)	An	6	Q11			
iii	1.4(l)	An	15	a	1.3(a)	K	6
				i	1.3(a)	K	6
				ii	1.3(a)	Ap	6
				iii	1.3(a)	C	7

Question	Sub topic	Question Type	Mark
B	9.1(a)	K	7
I	9.1(a)	K	6
Ii	9.1(a)A	An	12
cA	2A.1SAA1	Ap	7
I	2A.1(a)	C	6
Ii	2A.3(a)	C	12
CBi	1B.3SAA3	K	7
Ii	1B.3SAA3	C	3
Iii	1B.3SAA3	Ap	3
Iv	1B.3SAA3	C	3

Leaving Certificate Chemistry Paper Higher Level – 2005

Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				Q7			
A	9.4(d)A	K	5	a	7.3(g)	K	5
B	9.4(d)A	K	6	b	7.3(a)	C	12
Ci	9.4(d)A	C	5	c	7.3(l)	Ap	18
Ii	9.4(d)A	C	4	d	7.3(i)	K	15
D	9.4(d)A	C	9	Q8			
E	9.4(d)A	K	9	a	4.2(b)	K	8
F	9.4(d)A	An	6	b	4.2(b)	C	6
G	9.4(d)A	An	6	c	9.1(a)A	An	12
Q2				d	9.4(d)	K	6
A	7.3(n)A	C	5	ei	9.3(b)	C	9
B	7.3(n)A	C	12	ii	9.3(b)	K	9
Ci	7.3(n)A	C	9	Q9			
D	7.3(n)A	C	12	a	8.2(a)	K	5
E	7.3(n)A	An	12	bi	8.2(a)A	Ap	12
Q3				ii	8.2(a)A	Ap	9
A	6.1(a)A	Ap	5	ci	8.1(b)A	Ap	6
B	6.2(a)	Ap	12	ii	8.1(b)A	An	18
Ci	6.1(a)A	C	6	Q10			
D	6.1(a)A	Ap	12	ai	4.3(b)A5	An	8
E	6.1(a)A	An	9	ii	4.3(b)A5	An	5
F	6.1(a)A	An	6	iii	4.3(b)A5	An	6
Q4				iv	4.3(b)A5	An	6
A	2.4(a)	K	6.25	bi	1.4(k)	C	7
B	2.5(b)	C	6.25	ii	1.4(k)	Ap	6
Ci	1.4(c)	K	6.25	iii	1.4(k)	An	6
D	1.1SAA2	K	6.25	iv	1.4(k)	Ap	6
E	1.4(e)	An	6.25	ci	7.5(a)	K	10
F	2.2(d)A	C	6.25	ii	7.5(a)	C	15
G	7.2(b)	Ap	6.25	Q11			
H	3.4(a)	An	6.25	ai	1.5(a)	K	4
Ii	7.2(b)	Ap	6.25	ii	1.5(d)A	C	9
J	3.5(a)	Ap	6.25	iii	1.5(d)A	K	6
kA	1B.5SAA6	C	6.25	iv	1.5(d)	Ap	6
kB	2B.3(a)	K	6.25	bi	3.3(a)	K	7
Q5				ii	3.2(d)	K	6
Ai	1.2(d)	K	5	iii	4.1(a)	An	12
Ii	1.3SAA1	K	3	cAi	2A.2SAA2	K	7
Iii	1.3SSA3	K	9	ii	2A.2SAA2	K	3
Bi	1.4(j)	K	6	iii	2A.2SAA2	Ap	9
Ii	1.4(j)	C	15	iv	2A.2SAA2	C	6
Ci	2.3(b)	K	6	cBi	1B.2(c)	Ap	7
Ii	2.3(b)	An	6	ii	1B.2(c)	K	5
Q6				iii	1B.2(c)	K	4
Ai	5.5SAA4	K	8	iv	1B.2(c)	Ap	9
Aii	5.5SAA4	K	6				
Aiii	5.5SAA5	K	3				
Aiv	5.5SAA5	C	3				
B	5.2(a)	Ap	18				
C	5.4(h)A	An	12				

Leaving Certificate Chemistry Paper Higher Level – 2006

Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				bi	5.5SAA5	C	6
A	4.3(b)A1	C	5	ii	5.5SAA5	C	6
B	4.3(b)A1	C	12	c	5.4(h)A	An	12
Ci	4.3(b)A1	C	6	Q7			
Ii	4.3(b)A1	C	6	a	6.2(d)	K	5
D	4.3(b)A1	An	9	bi	6.2(b)	K	6
E	4.3(b)A1	An	12	ii	6.2(b)	An	6
Q2				c	6.2(a)A2	C	12
Ai	7.3(k)A	C	4	d	6.2(c)	C	6
Ii	7.3(k)A	K	4	ei	6.2SAA3	K	6
B	7.3(k)A	Ap	9	ii	6.2SAA3	K	9
Ci	7.3(k)A	K	4	Q8			
Ii	7.3(k)A	K	4	ai	9.2(a)	K	5
Iii	7.3(k)A	Ap	4	ii	9.2SAA1	Ap	6
D	7.3(k)A	Ap	9	iii	9.3(a)	K	9
E	7.3(k)A	K	6	iv	9.3(a)	C	6
F	7.3(k)A	C	6	bi	9.1(c)	Ap	9
Q3				ii	4.2(a)	Ap	9
A	9.4(a)A	C	8	iii	7.2SAA6	An	6
B	9.4(a)A	C	6	Q9			
Ci	9.4(a)A	C	12	a	5.2(a)	K	5
Di	9.4(a)A	K	4	bi	7.3(l)A	K	6
Ii	9.4(a)A	C	5	ii	7.3(l)A	C	3
E	9.4(a)A	An	15	iii	7.3(l)A	An	6
Q4				iv	7.3(l)A	C	3
A	1.4(i)	Ap	6.25	ci	7.3(d)	C	9
B	1.2SAA1	K	6.25	ii	7.3(d)	K	6
C	1.3(b)	An	6.25	d	7.2(b)	C	12
D	3.4(b)	An	6.25	Q10			
E	4.2(b)	Ap	6.25	ai	1.2(d)	K	4
F	1.1SAA2	K	6.25	ii	1.2(e)	K	6
G	7.2(d)	C	6.25	iii	1.2SAA2	C	9
h	9.1(a)A	An	6.25	iv	1.2(e)A	An	6
i	2.2(d)	C	6.25	bi	2.6(a)	K	4
j	7.2(e)	K	6.25	ii	2.6(a)A	C	6
kA	1B.2SAA1	K	6.25	iii	2.6(a)A	K	6
kB	2B.3(a)	K	6.25	iv	7.3(o)A	An	9
Q5				ci	7.2(e)	C	7
ai	1.4(c)A	Ap	8	ii	7.2(e)	An	6
ii	1.4(c)	C	6	iii	7.2(e)	C	12
iii	1.4SAA1	K	3	Q11			
iv	1.4(g)	K	6	ai	3.2(f)	K	4
v	1.4(f)	C	6	ii	3.2(h)	Ap	3
bi	2.4(a)	K	6	iii	3.2(f)A	An	9
ii	2.4(a)	C	6	iv	3.3(a)A	An	3
iii	2.4(a)	C	9	v	3.4(b)	An	6
Q6ai				b	8.2(a)	K	7
ai	5.5SAA5	K	8	i	8.2(a)	Ap	6
ii	5.5SAA5	Ap	3	ii	8.2(a)A	Ap	6
iii	5.5SAA5	Ap	5	iii	8.2(a)A	An	6
iv	5.5SAA5	K	4	cAi	1A.2(a)	K	12
v	5.5SAA5	C	6	ii	1A.2(a)	K	3

Question	Sub topic	Question Type	Mark
iii	1A.2(a)	K	5
iv	1A.2(a)	C	5
cBi	2B.4(a)	K	12
ii	2B.4(a)	Ap	9
iii	2B.4(a)	C	4

Leaving Certificate Chemistry Paper Higher Level – 2007

Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				ci	5.5SAA4	K	3
a	4.3(b)A6	K	8	cii	5.5SAA4	K	3
b	4.3(b)A6	C	15	Q7			
c	4.3(b)A6	C	3	ai	4.2(b)	K	8
d	4.3(b)A6	K	12	aii	4.2(b)	Ap	6
e	4.3(b)A6	An	12	aiii	4.2(b)	An	6
Q2				bi	9.1(a)A	An	8
a	7.3(o)A1	K	8	bii	9.1(a)A	An	7
b	7.3(o)A1	C	9	c	9.3(c)	C	9
c	7.3(o)A1	Ap	6	d	9.3SAA1	C	6
d	7.3(o)A1	An	12	Q8			
e	7.3(o)A1	C	6	a	7.2(c)	K	8
f	7.3(o)A1	Ap	9	b	7.3(l)	K	6
Q3				c	7.3(o)	K	6
a	5.4(c)A	K	8	d	7.2(c)	Ap	18
b	5.4(c)A	K	3	e	7.3(d)	K	9
c	5.4(c)A	C	6	f	7.3SAA5	K	3
d	5.4(c)A	K	9	Q9			
e	5.4(c)A	Ap	3	ai	6.1(a)	K	4
f	5.4(c)A	An	18	ii	6.1(a)	C	4
g	5.5(g)A	K	3	bi	6.1(a)A2	Ap	12
Q4				ii	6.1(b)A	An	9
a	1.4(j)	K	6.25	c	6.2(a)	An	6
b	5.5SAA5	C	6.25	di	6.2(a)A	An	6
c	2.3(b)	An	6.25	dii	6.2SAA1	K	9
d	6.2(c)	K	6.25	Q10			
e	3.3(a)A	An	6.25	ai	8.1(b)	Ap	7
f	2.2(d)A	K	6.25	aii	8.1(b)A	An	12
g	7.2SAA3	Ap	6.25	aiii	8.2(a)	K	6
h	4.1(a)A	An	6.25	bi	3.2(d)	K	7
i	7.2(h)	C	6.25	bii	3.2(d)	An	9
j	7.5(g)	C	6.25	biii	9.2(e)A	An	6
kA	1B.5SAA9	K	6.25	biv	9.2(e)A	K	3
kB	2B.1SAA1	K	6.25	ci	1.5(b)	C	4
Q5				cii	2.6(a)	Ap	12
ai	1.4(a)	K	5	ciii	1.5(c)	Ap	6
aii	1.4(i)	Ap	6	civ	1.5(c)	C	3
aiii	1.4(g)	C	6	Q11			
bi	2.4(a)	An	5	ai	1.2SAA1	C	7
bii	2.1(a)	Ap	5	aii	1.2SAA1	C	12
biii	2.3(b)A	Ap	5	aiii	1.3(c)	Ap	6
biv	2.5(b)	An	6	bi	7.3(i)	C	7
ci	2.4(d)	An	6	bii	7.3(i)	K	6
cii	2.4(d)	An	6	biii	7.3(g)	An	6
Q6				biv	7.3(g)	K	3
ai	5.5(a)	K	5	bv	7.3(g)	K	3
aii	5.5(a)	K	9	cAi	1B.3SAA3	K	4
aiii	5.5(a)	An	9	ii	1B.3SAA3	C	6
aiv	5.4(b)	Ap	6	iii	1B.3SAA3	K	6
bi	5.5(b)	K	3	iv	1B.3SAA3	K	9
bii	5.5(b)	Ap	9	cBi	2A.1(a)	K	7
biii	5.5(b)	Ap	3	ii	2A.1(a)	C	6

Question	Sub topic	Question Type	Mark
iii	2A.1(a)	C	6
iv	2A.1(a)	C	6

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Question	Sub topic	Question Type	Mark	Question	Sub topic	Question Type	Mark
Q1				av	5.5SAA5	C	9
a	4.3(b)A2	C	5	bi	5.4(c)	Ap	8
b	4.3(b)A2	C	15	bii	5.4(g) A	An	10
ci	4.3(b)A2	K	4	Q7			
cii	4.3(b)A2	C	4	ai	8.1(a)	K	5
ciii	4.3(b)A2	K	4	aii	8.1(a)	Ap	6
d	4.3(a)A	An	15	bi	8.1(b)A	Ap	6
e	7.2SAA2	K	3	bii	8.1(b)A	An	12
Q2				ci	8.2(a)	K	6
a	7.5(a)A	C	15	cii	8.2(a)	Ap	9
b	7.5(a)	Ap	6	ciii	8.2(a)	An	6
c	7.4(a)A	K	3	Q8			
d	7.4(a)A	K	6	ai	9.1(a)	K	5
e	7.4(a)A	K	6	aii	9.1(a)A	K	4
fi	7.4(a)A	C	5	aiii	9.1(a)A	An	8
fii	7.4(a)A	C	4	aiv	9.1(a)A	An	6
g	7.4(a)A	An	5	av	9.1(a)A	An	6
Q3				bi	9.3(a)	Ap	9
a	6.1(a)A	Ap	5	bii	9.3(a)	K	6
b	6.1(a)A	Ap	6	biii	9.3(a)	C	6
c	6.1(a)A	Ap	12	Q9			
di	6.1(a)A2	Ap	9	a	7.3(l)A	Ap	8
dii	6.1(a)A2	An	6	bi	7.2(b)	Ap	6
e	6.1(b)A	An	12	bii	7.2(b)	An	6
Q4				c	7.2(a)	K	6
a	1.4(i)	Ap	6.25	di	7.3(d)	Ap	6
b	1.1SAA2	C	6.25	dii	7.3(c)	C	6
c	1.3(a)	C	6.25	diii	7.3(d)	C	6
d	1.4(c)	K	6.25	ei	7.3(e)	K	3
e	9.2(b)	Ap	6.25	eii	7.3(e)	Ap	3
f	6.2SAA3	K	6.25	Q10			
g	2.5(b)	Ap	6.25	ai	9.4(a)A2	C	9
h	6.2(d)	Ap	6.25	aii	9.4(a)A2	Ap	9
i	9.3(b)	K	6.25	aiii	2.2(d)A	C	7
j	3.5(a)A2	Ap	6.25	bi	1.5(a)	K	4
kA	1B.2(c)	K	6.25	bii	1.5(a)	C	3
kB	2B.5(b)	K	6.25	biii	1.5(b)	Ap	6
Q5				biv	1.5(a)	K	12
a	2.4(a)	K	5	ci	1.4(a)	K	4
b	2.4(a)	C	9	cii	1.4(c)	An	6
c	2.4(b)A	Ap	9	ciii	1.4(c)	K	3
d	2.2(a)A	Ap	6	civ	1.4(d)	Ap	12
e	2.5(c)	K	6	Q11			
fi	2.5(c)A	C	3	ai	7.3(q)	K	4
fii	2.5(c)	An	3	aii	7.3(m)	Ap	3
gi	2.3(c)A	Ap	4	aiii	7.2(l)	Ap	3
gii	2.3(c)A	An	5	aiv	7.3(n)A	K	3
Q6				av	7.2SAA1	Ap	5
ai	5.5SAA3	K	5	avi	7.2SAA1	K	4
aii	5.2(a)	Ap	6	avii	7.2SAA1	K	3
aiii	5.5(a)	C	6	bi	3.3(a)A	An	6
aiv	5.5SAA5	C	6	bii	3.3(a)A	An	6

Question	Sub topic	Question Type	Mark
biii	3.5(b)A	An	6
biv	3.5(b)A	An	7
cAi	1B.3SAA3	K	7
ii	1B.3(d)	K	6
iii	1B.3(d)	Ap	9
iv	1B.4SAA1	C	3
cBi	2B.4(c)	C	7
ii	2B.4(c)	Ap	12
iii	2B.4SAA5	K	3
iv	2B.4SAA6	Ap	3

APPENDIX
B

QUESTIONS EMPLOYED IN

MODULE CS201

Math Assessment

$\sqrt[3]{x}$ is the same as

A) X^3

B) ½ X

C) $X^{1/3}$

D) ¾ X

B.1

During the first opening day of a new cosmetic store, 75 women enter the store during the 8 hour period. The rate of women entering the building is:

A) 9.37 women/hour

B) 0.167 women/min

C) 0.0036 women/sec

D) All of the above

B.2

The derivative of $3x^4$ is

A) $x^{12}/3$

B) 12x

C) $12x^3$

D) $81x^3$

B.3

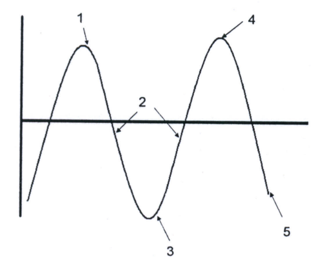
From the graph what regions show the maximum rate of change?

A) 1,3,4

B) 2,5

C) 1,2,3

D) 2



B.4

Express m in terms of u,t and s:
→ $tm = u^2 + sm$

A. $m = t + m + u^2$

B. $m = u^2 + s - t$

C. $m = u^2 - s / t$

D. $m = u^2/t - s$

B.5

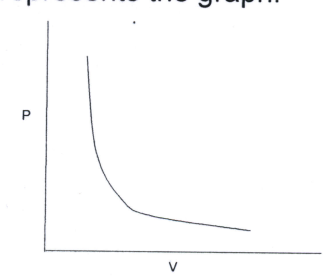
Which of the following statements correctly represents the graph.

A) P α V

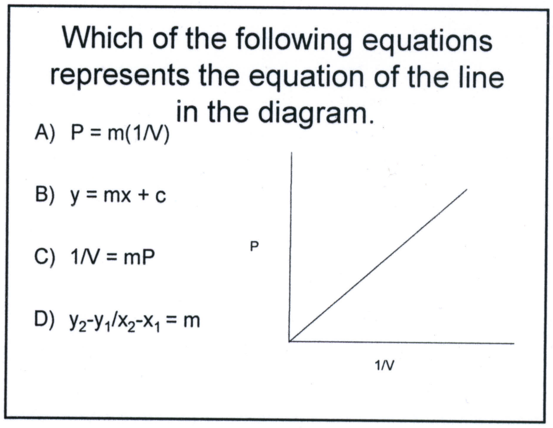
B) 1/P α V

C) 1/P α 1/V

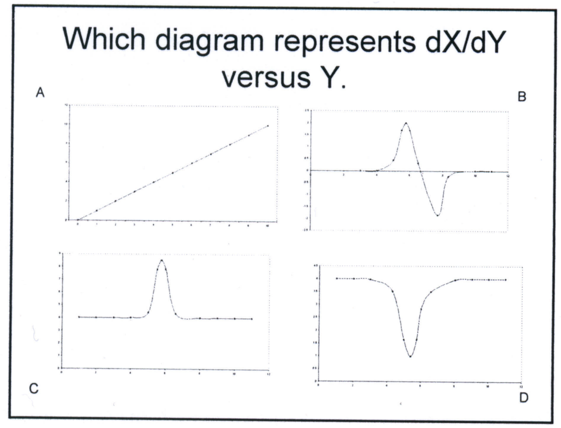
D) P α 1/V



B.6

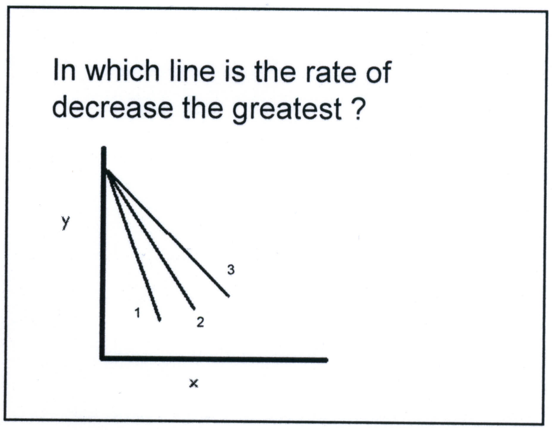


B.7



B.8

In lecture assessment



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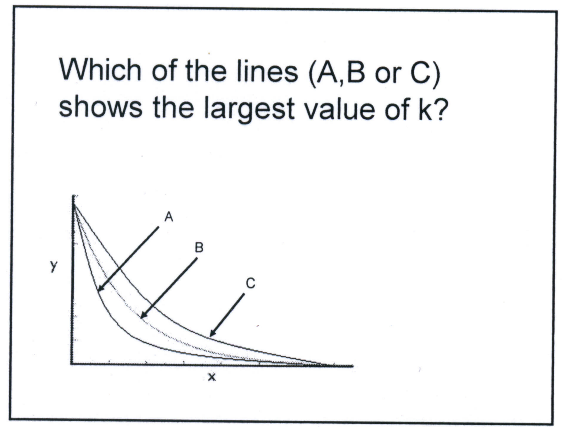
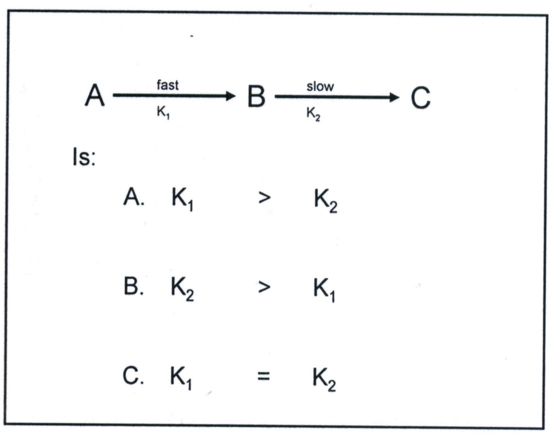


B.10



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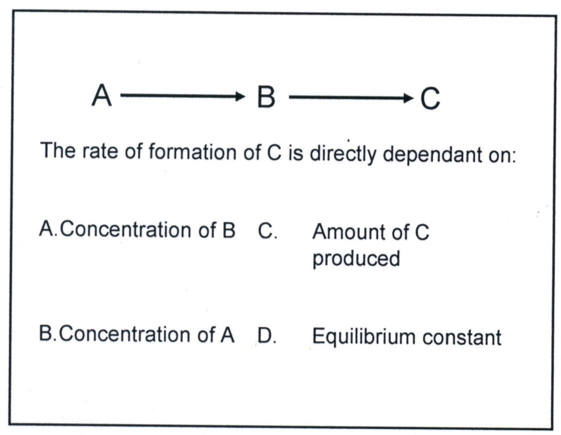


B.12

Chemical Kinetics Assessment 1

Question 1

- Write the rate equation for the general reaction 2A → P.

(a) rate = $[A]^x$
(b) rate = $k[A]^x$
(c) rate = k
(d) k

B.13

Question 2

The bigger the value of k, the ………..is the rate of reaction.

(a) faster
(b) slower
(c) rate doesn't change

B.14

Question 3

The rate data for the reaction is given below. Which is the correct rate equation?

$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O$

Exp	[NO] / atm	$[H_2]$ /atm	Rate /(atm sec-1)
1	0.375	0.500	6.43×10^{-4}
2	0.375	0.250	3.15×10^{-4}
3	0.188	0.500	1.56×10^{-4}

(a) Rate = $k\,P_{NO}$
(c) Rate = $k\,P_{NO}^2$
(b) Rate = $k\,P_{NO}P_{H2}^2$
(d) Rate = $k\,P_{NO}^2P_{H2}$

B.15

Question 4

The half life of the radioactive decay of plutonium by a first order process depends on the amount of plutonium that you have.

True or False

B.16

Question 5

- In the reaction A+B→ P, the rate of the reaction is given by (multiple ans):

(a) $-\frac{d[P]}{dt}$ (b) $+\frac{d[P]}{dt}$ (c) $+\frac{d[B]}{dt}$

(d) $+\frac{d[A]}{dt}$ (e) $-\frac{d[B]}{dt}$ (f) $-\frac{d[A]}{dt}$

B.17

Question 6

The reaction between NO and I_2 is second order in NO and first order in I_2. What change occurs in the rate of reaction if the concentration of each reactant is tripled?

(a) 27 fold increase
(b) 3 fold increase
(c) 18 fold increase
(d) 6 fold increase

B.18

Question 7

- In the general reaction of 2A → P, rate of reaction is expressed as rate = x d[A]/dt where x = ?

(a) +1/2 (c) -2
(b) -1/2 (d) +2

B.19

Question 8

For reaction $2NO_2(g) \rightarrow N_2O_4(g)$, would you increase or decrease the pressure of NO_2 to increase the rate of formation of N_2O_4?

(a) it wouldn't make any difference on the rate
(b) decrease
(c) increase

B.20

Question 9

- If a reaction A + B → P is exothermic, would you increase or decrease the temperature to increase the rate of the reaction?

(a) Increase
(b) Decrease
(c) Temperature will have no effect

B.21

Question 10

- In the previous question, why did you give the answer you gave?

(a) Because the reaction is exothermic, heating up the mixture will give off more heat
(b) Because the reaction is exothermic, need to cool down reaction to increase the rate
(c) Because increasing the temperature increases the rate of reaction

B.22

Chemical Kinetics Assessment 2

Question 1

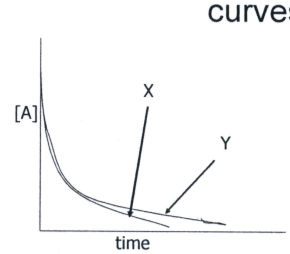
In the reaction A→ B, when the initial concentration of A was changed from 1.20M to 0.6M, the half life increased from 2.0mins to 4.0mins at 25°C.

What is the order of the reaction:

(a) 1 (c) 0
(b) 2 (d) not enough information

B.23

Question 2
Choose the order of the two curves



(a)X=1, Y=2
(b)X=2, Y=1
(c)X=1, Y=0
(d)Y=1, X=0

B.24

Question 3

As an environmentalist, you have the choice of 2 insecticides to use – one (A) decays by first order process, the other (B) by a second order process. You want the insecticide concentration to decrease as rapidly as possible.

Which one do you choose?

(a) insecticide A
(b) insecticide B
(c) Either as both can be used

B.25

Question 4

On the graph shown on OHP, conc vs time for first order process, how is k (rate constant) changing in the direction of the arrow.

(a)Decreasing
(b)Always zero
(c)Not changing
(d)Increasing

B.26

Chemical Kinetics Assessment 3

Question 5

$C_6H_5N_2Cl + H_2O \rightarrow C_6H_5OH + HCl + N_2$

This reaction was followed by measuring the increase in pressure, due to the evolution of nitrogen, by means of a xylene manometer. The results are given below:

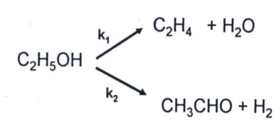
t/mins	0	12	28	40	60	oo
p/cm	0	5.89	11.52	14.47	17.74	22.62

You suspect that it follows first order kinetics – what will you plot vs t to check this?

(a) $\ln\left(\frac{p_o}{p_t}\right)$ (b) $\ln\left(\frac{p_\infty}{p_\infty - p_t}\right)$ (c) $\ln\left(\frac{p_0}{p_t - p_0}\right)$

B.27

QUESTION 1



If $k_2 > k_1$, which product will be formed first?

A. C_2H_4

B. CH_3CHO

B.28

QUESTION 2

$Cl_2 \xrightarrow{k_1} Cl^o + Cl^o$

$Cl^o + CH_4 \xrightarrow{k_2} HCl + {}^oCH_3$

${}^oCH_3 + Cl_2 \xrightarrow{k_3} CH_3Cl + Cl^o$ **(RDS)**

${}^oCH_3 + {}^oCH_3 \xrightarrow{k_4} C_2H_6$

Which of the following is the correct rate equation:

A. Rate rxn = $(k_1 + k_2 + k_3)[Cl_2]$
B. Rate rxn = $k_1[Cl_2]$
C. Rate rxn = $k_3[{}^oCH_3][Cl_2]$
D. Rate rxn = k_3 [CH3Cl] [Cl°]

B.29

$OCl^- + H_2O \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} HOCl + OH^-$

$I^- + HOCl \xrightarrow{k_2} HOI + Cl^-$

$HOI + OH^- \xrightarrow{k_3} H_2O + OI^-$

The rate of formation of OH- can be written as:

A. $\frac{d[OH^-]}{dt} = k_{-1}[HOCl][OH^-] + k_2\,[HOI][OH^-]$

B. $\frac{d[OH^-]}{dt} = k_1[OCl^-][H_2O] - k_3[HOI][OH^-]$

C. $\frac{d[OH^-]}{dt} = k_1[OCl^-][H_2O] + k_{-1}[HOCl][OH^-] + k_3[HOI][OH^-]$

D. $\frac{d[OH^-]}{dt} = k_1[OCl^-][H_2O] - k_{-1}[HOCl][OH^-] - k_3[HOI][OH^-]$

B.30

QUESTION 4

In the following enzyme reaction, what effect does a large value of Km have on the rate of maltose formation

Amylase + Starch $\underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}}$ Amylase Starch Complex $\xrightarrow{k_2}$ Amylase + Maltose

$$Rate = \frac{[E_0][S]}{K_M + [S]}$$

A. Increase rate
B. Lower Rate
C. No Effect

B.31

QUESTION 5

What is the effect of a large equilibrium constant on the rate of formation of maltose: (relative to a small equilibrium constant)

Amylase + Starch $\underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}}$ Amylase Starch Complex $\xrightarrow{k_2}$ Amylase + Maltose

A) Higher Rate
C) No Change
B) Lower Rate

B.32

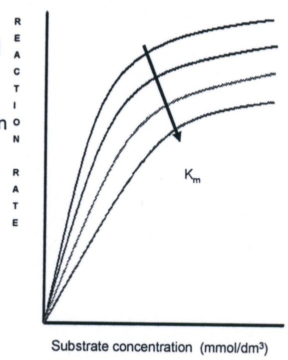
Chemical Kinetics Assessment 4

QUESTION 6

Figure shows the effect of changing [S] on reaction rate at different K_m values.

How is K_m changing in the direction of the arrow?

A. Increasing
B. Decreasing
C. Remains constant



B.33

Question 1

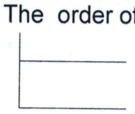
The fading of bromothymol blue in alkaline solution is a second order process. The time required for the concentration of the bromothymol blue to decrease to half of its original concentration is 5 mins, when the initial concentration is 0.01M. If the initial concentration is reduced to 0.001M, how long will it take for the same decrease in concentration.

(a) 2.5 (b) 5
(c) 50 (d) 500

B.34

Question 2

For a reaction A → P, a graph of [A] vs t gave a straight line over all concentration values studied. The order of the reaction is :

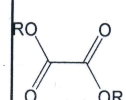


(a) zero (b) first
(c) second (d) impossible to determine from this graph

B.35

QUESTION 3

Lightstick reaction



+ H_2O_2 + Dye = 2 ROH + 2 CO_2 + Dye + hν

To follow the kinetics of this reaction, which reactant / product will you monitor over time:

a. [ROOCCOOR] d. [ROH]
b. [H_2O_2] e. [CO_2]
c. [Dye] f. hν

B.36

Question 4

Consider two reactions, one with an activation energy of $52 kJmol^{-1}$ (reaction A) and the other has activation energy of $25 kJmol^{-1}$ (reaction B).

How will an increase in temperature affect both reactions:

(a) Increase the rate of both

(b) Decrease the rate of both

B.37

Question 5

$O_3 \rightarrow O_2 + O.$ k_1

$O. + O_2 \rightarrow O_3$ k_{-1}

$O. + O_3 \rightarrow O_2 + O_2$ k_2

Ozone reaction mechanism is given above. Which of the following are true.

(a) $\frac{d[O_2]}{dt} = k_2[O_3][O\cdot] + k_1[O_3] - k_{-1}[O_2][O\cdot]$

(b) $\frac{d[O_2]}{dt} = 2k_2[O_3][O\cdot] + k_1[O_3] - k_{-1}[O_2][O\cdot]$

(c) $\frac{d[O_2]}{dt} = 0$

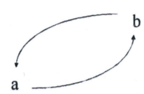
(d) $\frac{d[O\cdot]}{dt} = 0$

B.38

Thermodynamic Assessment 1

Question 1

The change in enthalpy for a circular path a → b → a, is:

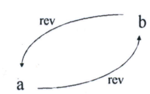


(a) 0, (b) <0, (c) >0, (d) none of these

B.39

Question 2

For a circular path a → b → a, where both steps are reversible, the change in entropy, ΔS, is

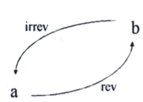


(a) 0, (b) <0, (c) >0, (d) none of these

B.40

Question 3

For a circular path a → b → a, where one step is irreversible, the change in entropy, ΔS, is

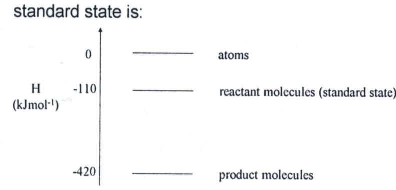


(a) 0, (b) <0, (c) >0, (d) none of these

B.41

Question 4

In the following scheme, the change in enthalpy, ΔH, for the formation of products from reactant molecules in their standard state is:



(a) $+530 kJmol^{-1}$, (b) $-530 kJmol^{-1}$, (c) $+310 kJmol^{-1}$, (d) $-310 kJmol^{-1}$

B.42

Question 5

Given the following

	ΔH_f(kJmol^{-1})
C_2H_5OH	-217.4
CO_2	-393.1
H_2O	-238.9
O_2	0

The enthalpy change, ΔH, for the following reaction;

$$2CO_2 + 3H_2O \rightarrow C_2H_5OH + 3O_2$$

is:

(a) -1004 kJmol^{-1}, (b) +1286 kJmol^{-1}, (c) +1004 kJmol^{-1}, (d) +543 kJmol^{-1}

B.43

Question 1

Calculate the heat transferred, q, to or from 1 mole of a gas which is heated from -10°C +72°C, under conditions of constant external pressure. Given that C_pM = 11 JK^{-1}mol^{-1}

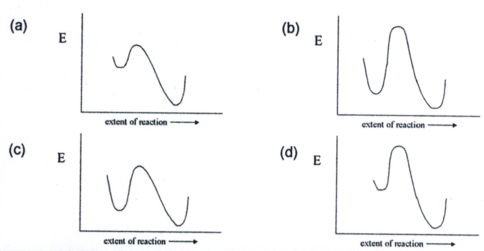
A. +902J B. -341J

C. +682J D. -902J

B.44

Question 2

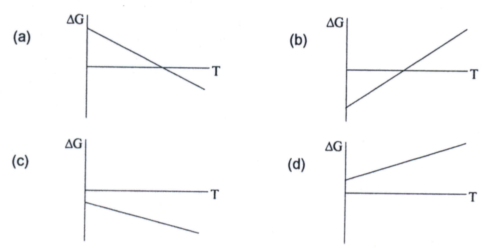
Which of the following graphs describes a reaction with a relatively strong thermodynamic driving force but with a relatively high barrier (poor kinetics):



B.45

Question 3

Given that $\Delta G = \Delta H - T\Delta S$, which of the following graphs corresponds to a reaction that can be enthalpically driven only:



B.46

Question 4

The change in enthalpy associated with denaturation of egg white protein, ΔH^0 = 35 kJmol^{-1}.

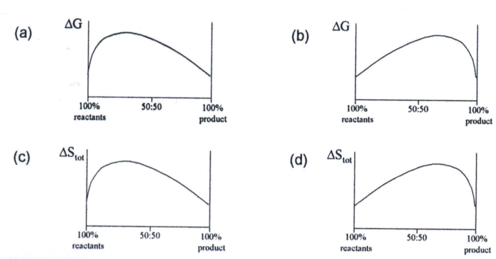
Given that eggs only cook above 83°C, the entropy change, ΔS^0, for denaturation is:

(a) -49 JK^{-1}mol^{-},
(b) +98 JK^{-1}mol^{-1},
(c) -98 kJK^{-1}mol^{-1},
(d) none of these

B.47

Question 5

Which of the following graphs describes an equilibrium reaction with the balance of the equilibrium to the reactants:



B.48

Thermodynamic Assessment 3

Question 1

Given that $\Delta S_{sys} = nR\ln(V_f / V_i)$

Which of the following relationships is also valid?

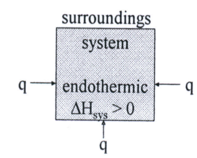
(a) $\Delta S_{sys} = nR\ln(P_f / P_i)$ (b) $\Delta S_{sys} = -nR\ln(P_f / P_i)$

(c) $\Delta S_{sys} = nR\ln(P_{ex})$ (d) $\Delta S_{sys} = -nR\ln(P_{ex})$

B.49

Question 2

Given that $\Delta S = q/T$, for an endothermic reaction the entropy change of the surroundings, ΔS_{surr} is:

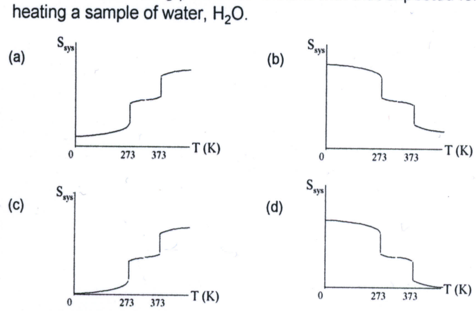


(a) 0 , (b) < 0 , (c) > 0 , (d) can't tell

B.50

Question 3

Which of the following plots is consistent with that expected for heating a sample of water, H_2O.

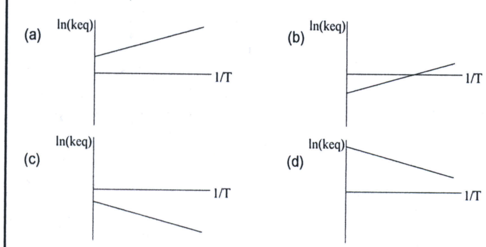


B.51

Question 4

Which of the Van't Hoff plots below corresponds to the denaturation of egg white protein, given that

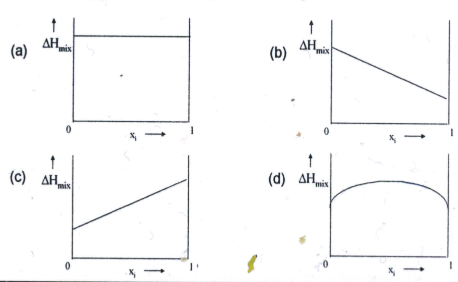
$\Delta H^0 = 35\ \text{kJmol}^{-1}$, and $\Delta S^0 = 98\ \text{JK}^{-1}\text{mol}^{-1}$



B.52

Question 5

Which of the following graphs represents the enthalpy of mixing, ΔH_{mix}, of two ideal gases, i and j.



B.53

APPENDIX
C

PRE AND POST LABORATORY TASKS FOR SEMESTER 1 AND 2

Pre lab 1.3
(C.1)

1. What is the molecular mass of K_2O_3?
   a. 138g
   b. 106g
   c. 99g
   d. 67g

2. How many atoms are in 2.00moles of Ni?
   a. 58.9 atoms
   b. 118 atoms
   c. 6.02×10^{23}
   d. 1.2×10^{24}

3. What is the mass in grams of 3×10^{23} molecules of CO_2?
   a. 22g
   b. 44g
   c. 66g
   d. 88g

4. How much $Ca(OH)_2$ of you need to have 3.2 moles?
   a. 92.96g
   b. 118.56g
   c. 185.92g
   d. 237.12g

5. How many moles are contained in 0.750g of Na_2CO_3?
   a. 0.007 moles
   b. 0.009 moles
   c. 0.07 moles
   d. 0.1 moles

6. If you want 4.2×10^{25} molecules of H_2O, how many grams would you need to weigh out?
   a. 1257.21 g
   b. 4.55×10^{50} g
   c. 628.6 g
   d. 2514.4 g

7. In the lab you calculated the weight of a mole of NaCl, H_2O and SiO_2.

a. Which was the heaviest of the three? NaCl / H_2O / SiO_2

b. Which had the greatest molecular mass NaCl / H_2O / SiO_2

c. How many particles were in each weight? 6.02×10^{23} / 58.44 / 1.2×10^{24}

8. Which solution contains the most sugar, is the most concentrated?

a. 1 spoonful of sugar in 100ml
b. 1 spoonful of sugar in 250ml
c. 1 spoonful of sugar in 100L
d. 1 spoonful of sugar in $25cm^3$

9. 1 mole of NaCl is placed in 1000mls. 500mls of the solution is poured away, how many moles of NaCl are left in the flask?

a. 1 mole
b. 2 moles
c. 0.5 moles

10. Which solution is the most concentrated?

a. 1 mole of solute dissolved in 1L of solution.
b. 2 moles of solute dissolved in 3L of solution.
c. 6 mole of solute dissolved in 4L of solution.
d. 4 mole of solute dissolved in 8L of solution.

Post Lab Assignment 1.3
(C.2)

The RDA of salt (NaCl) is 0.1moles and exceeding this, we are told is detrimental to your health. During the course of one day you ingest the following:

- 200mL of 0.06M salt solution (soft drink)
- 2.8 g of salt in a ham sandwich
- 0.5g of salt in a bag of crisps
- 400mL of a 0.098M salt solution (soup)

How many moles of salt are you ingesting during the course of the day and which food should you cut from your diet to really reduce your salt intake?

How many molecules of NaCl have you ingested?

Pre Lab 1.4
(C.3)

1. Which of the following statements is correct about the fluoride ion (F^-)?

   a. neutrons = 9 protons = 10 electrons = 10
   b. neutrons = 10 protons = 9 electrons = 9
   c. neutrons = 10 protons = 9 electrons = 10
   d. neutrons = 9 protons = 10 electrons = 9

2. Which of the following ions will calcium most likely to form?

   a. Ca
   b. Ca^-
   c. Ca^+
   d. Ca^{2+}
   e. Ca^{2-}

3. Which of the following statements is correct about the calcium ion?

   a. neutrons = 20 protons = 20 electrons = 20
   b. neutrons = 18 protons = 22 electrons = 20
   c. neutrons = 20 protons = 20 electrons = 18
   d. neutrons = 20 protons = 20 electrons = 19

4. Which of the following is the correct symbol of the chloride ion?

   a. Cl^-
   b. Cl
   c. Cl^+
   d. Cl_2

5. Which of the following is the correct symbol of the nitrate ion?

   a. NO_3^-
   b. NO_3^{2-}
   c. NO_2^-
   d. N^{3-}

6. Which of the following is the correct symbol of the sulphate ion?

   a. SO_4^{2-}
   b. SO_4^{2+}
   c. SO_3^-
   d. S^{2-}

7. Match the ions with the appropriate symbols.

Ion	Symbol
	OH^-
	SO_3^{2-}
	CO_3^{2-}
	$Cr_2O_7^{2-}$
	PO_4^{3-}
	CH_3COO^-

8. 1 mole of $CrCl_2$ is placed in 1000mL. 250mL is poured off. What is the molarity of the solution in remaining in the container?

a. 0.75 M
b. 0.25 M
c. 1 M
d. 1.5 M

9. You are given 3.7g of $Ca(OH)_2$ and asked to make it up to 100mL. What is the molarity of the (OH^-) ion solution?
a. 0.5 M
b. 1 M
c. 0.05 M
d. 0.1 M

10. Which of the following will have the highest molarity?
a. 10g of glucose in 100mL
b. 10g of glucose in 250mL
c. 10g of glucose in 1L
d. 10g of glucose in $25cm^3$

11. In relation to the solution that you have chosen in question 10, is this solution the most concentrated.
a. True
b. False

Post Lab Assignment 1.4
(C.4)

You have been given a salt X for analysis in the lab. You performed a series of tests on the salt and observed the following:

1.	Addition of the salt to water	→	salt was insoluble
2.	Addition of HCl	→	gas evolved
3.	Addition of $MgSO_4$	→	white precipitate

(i) Suggest a possible salt for X.
(ii) Suggest what gas and what white ppt have been formed.
(iii) Write the chemical formula of the gas and white ppt formed.
(iv) Suggest a possible test to identify the gas produced.

In relation to task 4 of Lab 1.4, you have been given four unlabelled bottles containing

- lead acetate $(Pb(CH_3COO)_2$
- potassium bromide (KBr)
- sodium hydroxide $(NaOH)$
- copper sulphate. $(CuSO_4)$

Your task is to correctly plan out your procedure to identify each of the contents of the unlabelled bottles. You must provide chemical equations to suggest why precipitates have/have not been produced.

Pre Lab 1.7
(C.5)

1. Estimate the pH of the following substances:

Substance	pH
Baking soda	9 – 10
Black Coffee	3 – 4
Wine	4 – 5
Milk of Magnesia	8 – 9
Fizzy cola	
Soap	
Aspirin	

2. Which of the following can be used as a primary standard?
   a. NaOH
   b. Na_2CO_3
   c. H_2SO_4
   d. $KBrO_3$

3. In relation to question 2, you chose these compounds as
   a. they readily dissolve in water
   b. they are anhydrous compounds
   c. they can be found in a stable, pure and soluble form

4. The following titration results where noted for an acid/base titrations. Given the titre results below calculate the average titre value.

Titre 1 (mL)	Titre 2 (mL)	Titre 3 (mL)	Titre 4 (mL)
5.80	5.65	5.65	5.60

The average titre value for experiment 1 is:
   a. 5.65 mL
   b. 5.675 mL
   c. 5.63 mL

5. Water is described as amphoteric because:

   a. it has neither an acidic nor basic pH
   b. it has neither acidic nor basic properties
   c. when it dissociates it can give either H^+ and OH^- ions

6. Identify each of the following as a strong base (SB), weak base (WB), strong acid (SA) or weak base(WB).

Compound	SB/SA/WB/WA
Acetic Acid	
Hydrochloric Acid	
Ammonium Hydroxide	
Sodium Hydroxide	
Citric Acid	
Sulphuric Acid	
Strontium Hydroxide	
Ammonia Gas	

7. 9g of calcium hydroxide are dissolved in solution and made up to 1L. How many moles are contained in 20mL of this solution?

   a. 0.1216 moles
   b. 0.0024 moles
   c. 0.0049 moles
   d. 0.0012 moles

8. When sulphuric acid and sodium hydroxide react the balanced equation is $H_2SO_4 + xNaOH \rightarrow Na_ySO_4 + zH_2O$ where x, y and z are:

   a. 2, 3, 4.
   b. 2, 2, 2.
   c. 1, 2, 3.
   d. 3, 3, 2.

9. When 0.2moles of sulphuric acid reacts completely with sodium hydroxide, how many moles of sodium hydroxide are required?

   a. 0.2 moles
   b. 1 mole
   c. 0.4 moles
   d. 0.1 mole

10. When preparing a primary standard the volumetric flask is inverted a number of times to:

   a. remove all air bubbles
   b. ensure all of the primary standard has been dissolved
   c. ensure a homogenous/uniform concentration of the solution
   d. ensure that the solution has touched all sides of the flask

11. If you have 0.02moles of NaOH in 22.5mL, what is the molarity of the solution?

    a. 0.02 M
    b. 0.2 M
    c. 0.09 M
    d. 0.89 M

12. From the molarity chosen above what is the concentration of this solution in g/L?

    a. 35.5 g/L
    b. 0.8 g/L
    c. 8 g/L
    d. 3.6 g/L

Post lab 1.7
(C.6)

1. In your opinion, why is a conical flask used in titrimetric analysis rather than a beaker?

2. In part 2 of the standardisation of HCl, step 6 allowed you to rinse the inside wall of the conical flask with distilled water during the titration. Won't this change the concentration of acid in the conical flask and hence change the amount of base required to neutralise it? Is this correct?

3. Why do you take burette readings from the bottom of the meniscus?

4. In this titration, you used the indicator methyl orange. If you phenolphthalein, would you have gotten the same answer? Explain.

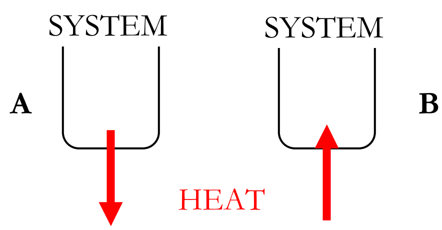
Pre lab 1.8
(C.7)

1. The units of heat capacity are:
   a. joules per gram
   b. joules per Kelvin per gram
   c. joules
   d. joules. Kelvin
   e. joules per Kelvin

2. All of the following reactions are endothermic except:

   a. sublimation
   b. vaporisation
   c. combustion
   d. melting

3.



Which of the following statements are correct?

a. (A) depicts an exothermic reaction while (B) depicts an endothermic reaction.
b. (A) depicts an endothermic reaction while (B) depicts an exothermic reaction
c. (A) and (B) depict what occurs during a neutralisation reaction.

4. Which statement describes the characteristics of an endothermic reaction:

   a. The sign of ΔH is positive and the products have less potential energy than the reactants.
   b. The sign of ΔH is positive and the products have more potential energy than the reactants.
   c. The sign of ΔH is negative and the products have less potential energy than the reactants.
   d. The sign of ΔH is negative and the products have more potential energy than the reactants.

5. The following set of procedures was used by a student to determine the heat of solution of NaOH.

A. Read the original temperature of the water
B. Read the final temperature of the solution
C. Pour the water into a beaker
D. Stir the mixture
E. Add the sodium hydroxide

What is the correct order of procedures for making this determination?

a. A, C, E, B, D
b. E, D, C, A, B
c. C, A, E, D, B
d. C, E, D, A, B

6. For each of the following statements decide whether the procedures will:
(a) increase or decrease the errors involved in determining the value of ΔH for heat of neutralisation between HCl and NaOH?
(b) raise/ lower/slightly lower the value of ΔH

Statement	**Increase/ Decrease**	**Raise/Lower/ Slightly lower**
When determining the initial temperatures of the two solutions the thermometer wasn't washed after taking the temperature of the acid before using it to take the temperature of the base.		
The Styrofoam cup was wet before the acid was poured in		
The addition of the NaOH solution to the HCl was very slow, over a period of three minutes		
The reaction mixture was not stirred before taking the temperature reading.		
The reaction mixture was stirred rapidly before taking the temperature reading.		

Post lab Assignment 1.8
(C.8)

1. When 200cm^3 of NaOH solution was added to 200cm^3 of a 0.4M solution of H_2SO_4 in a plastic container the temperature of solution rose from 11^oC to 16.5^oC. The heat capacity of the solution formed was 4.2 kJ kg^{-1}.

   (a) Why was a plastic container used?
   (b) What steps would you take to ensure an accurate measurement of the temperature rise?
   (c) Calculate the heat of neutralisation?

2. You want to keep a cup of tea "hot" for as long as possible. Rank the following containers in order of your choice and explain the order?

   (a) Styrofoam cup
   (b) Ceramic mug
   (c) Styrofoam cup with lid
   (d) Thermos flask

Pre-lab Quiz 2.3
(C.9)

1. The value of pK_a is determined by which of the following:

   a. $= \log K_a$
   b. $= -\log[H^+]$
   c. $= -\log K_a$
   d. $= -\log[OH^-]$

2. From the following dissociation constants indicate if you believe the acid to be Weak (W) or Strong(S)

   a. (Phosphoric Acid) $K_a = 2.14 \times 10^{-13}$
   b. (Boric Acid) $K_a = 5.8 \times 10^{-10}$
   c. (Hydrogen Peroxide) $K_a = 1.8 \times 10^{-12}$
   d. (Formic Acid) $K_a = 1.8 \times 10^{-4}$
   e. (Nitrous Acid) $K_a = 7.2 \times 10^{-4}$

3. Calculate the pH of the following compounds from their H^+ concentration and indicate if they are an acid or a base.

$[H^+]$	Acid or Base
7.1×10^{-7} mol/L	
1.0×10^{-9} mol/L	
0.2×10^{-3} mol/L	
3.2×10^{-5} mol/L	
8.4×10^{-10} mol/L	

4. When acetic acid [CH_3COOH] dissociates, it yields which ions

   a. CH_3COO^+ + H^-
   b. CH_3CO^+ + OH^-
   c. CH_3COO^- + H^+
   d. CH_3^- + $COOH^+$

5. In relation to the experiment, do you expect the pH of the solutions to increase from A – J or to decrease?

   a. Increase
   b. Decrease

Post lab Assignment 2.3
(C.10)

1. Explain, in your own words, what you understand by the dissociation of an acid and a base. It is also sometimes referred to as their ionisation. Do you agree with this statement? Give examples (equations) to support your answer.

2. What is the K_a value of acetic acid? Please state your source for this value (website, book, etc). How does your experimentally obtained value for the dissociation constant compare? Where do you believe the largest source of error may have been introduced?

3. Write the equation for the dissociation of sulphuric acid. Would you expect the K_a value to be higher or lower than that of acetic acid? Explain your answer.

Pre-lab Quiz 2.12
(C.11)

1. The carbonyl group occurs in all of the following organic functional groups except:

   a. aldehydes
   b. amides
   c. carboxylic acids
   d. phenols
   e. ketones

2. Which of the following is a secondary alcohol?

   a. $C_6H_5CH_2OH$
   b. CH_3CH_2OH
   c. $CH(CH_3)_2OH$
   d. $CH_3(CH_3)_2OH$
   e. $C(CH_3)_3OH$

3. Oxidation of a secondary alcohol produces:

   a. secondary alcohols cannot be oxidised
   b. aldehydes
   c. carboxylic acids
   d. esters
   e. ketones

4. All of the following compounds react with Fehling's solution except

   a. CH_3CH_2CHO
   b. $CH_3CH_2COCH_3$
   c. HCHO
   d. $CH_3CH_2CH(CHO)CH_3$
   e. $CH_3(CH_2)_3CHO$

5. All of the following compounds produce a silver mirror with Tollen's reagent except

   a. CH_3CH_2CHO
   b. $CH_3CH_2COCH_3$
   c. HCHO
   d. $CH_3CH_2CH(CHO)CH_3$
   e. $CH_3(CH_2)_3CHO$

6. When acetone is mixed with Fehlings' solution

   a. a silver mirror is produced
   b. no reaction occurs
   c. a carboxylic acid is produced
   d. a red precipitate is produced
   e. an aldehyde is formed

7. When an aldehydes reacts with Tollen's reagent:

   a. a ketone is produced
   b. an alcohol is produced
   c. the aldehyde reduces the silver ions to silver
   d. silver ions are produced
   e. a red precipitate is formed

8. Match the organic compounds with their functional group

Compounds	Functional Group
Halide	R – OH
Alcohol	R – COOH
Ether	R – X
Aldehydes	R – NH_2 – R'
Ketones	R – O – H
Amine	R – O – R'
Carboxylic Acid	R – CO – R'

Post lab assignment 2.12
(C.12)

Q1 What organic families do the following compounds belong to:

- ethanol
- propanol
- acetone
- methyl ethanoate
- chloromethane
- amino phenol

Q2 Using your knowledge of organic compounds, explain the difference in boiling points between butanol and butanal?

Q3 In the case of a chosen alcohol (your choice- make sure to name it), what products are produced during its oxidation when:

(a) the oxidizing agent is in excess
(b) the alcohol is in excess

Pre Lab 1.9
(C.13)

1. Standard temperature and pressure (STP) refers to:

   a. 0^{o}C and 202kPa
   b. 25^{o}C and 1atm
   c. 0^{o}C and 1atm
   d. 298K and 760 Torr
   e. 273K and 1Pa

2. Under which set of conditions would a gas have the greatest volume?

   a. high temperature and high pressure
   b. high temperature and low pressure
   c. low temperature and low pressure
   d. low temperature and high pressure
   e. the molar volume is always 22.4L

3. The pressure of a gas will __________ when the volume is decreased and will _________ when the absolute temperature is decreased.

   a. increase . . . . increase
   b. increase . . . . decrease
   c. decrease . . . . increase
   d. decrease . . . . decrease

4. If both the volume and the pressure of a gas are doubled, how will the temperature change?

   a. It will increase by two times its original value.
   b. It will decrease to ¼ of its original value
   c. It will stay the same as its original value
   d. It will increase by four times its original value

5. Which of the following statements correctly describe the relationship between volume and pressure at STP?

   a. As the volume decreases so does the pressure
   b. As the volume increases so does the pressure
   c. Volume and pressure are independent of one another
   d. As the volume increases the pressure decreases

6. Convert the following into Kelvin units (whole numbers)

Temperature (^oC)	Temperature (K)
0	
10	
-25	
-17	

7. Which gas will occupy a greater volume?

(a) 2 moles of CO_2 at STP
(b) H_2O vapour in a balloon of volume 4.5L.

8. If you are determining the volume of gas when you know its temperature, which two parameters do you need to keep constant?

(a) n & P
(b) V & T
(c) V & n
(d) P & n

Post Lab Assignment 2.2
(C.14)

You wish to make an engagement ring consisting of Ag and Au. The average weight of a ring is approximately 2g. There are two scenarios:

(a) You start with equal weights of Ag and Au. Assuming that they mix homogenously calculate the ratio of Ag atoms to Au atoms?

(b) You start with an equal number of particles of Ag and Au. Assuming that they mix homogenously, calculate the weight ratio of Ag and Au?

(c) What appearance (colour) will you expect each ring to have?

APPENDIX

D

CONFERENCE ABSTRACTS

AND POSTERS

Investigation of students' procedural and conceptual knowledge of the mole concept.

ECRICE, Istanbul July 2008

Richard Hoban, Edelle B McCrudden, Odilla E Finlayson, CASTeL, Dublin City University, Ireland

One of the fundamental concepts covered during the first year undergraduate chemistry course is the mole concept. It is envisaged that through a series of tutorials, lectures and laboratories that students will develop a procedural and conceptual understanding of this concept.

This paper deals with the procedural and conceptual aspects of the mole concept with two cohorts of first year undergraduate chemistry students attending Dublin City University, 06/07 and 07/08.

The mole concept involves the application of mathematics which is a great source of difficulty to many students[1]. One of the methods employed to assess students' procedural knowledge of the mole requires the completion of a titration calculation. Particularly with the procedural calculations involved in titration calculations the solver begins with the information in the problem statement and works forward performing operations until the goal is reached[2].

Concomitantly in order to ascertain the conceptual wherewithal with regard to students' understanding of the mole concept, elements from the work of Howe & Krishnan [3] in this domain have been employed. Questions 1-3 with minor altercations are taken from their diagnostic instrument. The underlying tenets upon which the development of the instrument are based, are those concerned with the work of Treagust [4]. In designing such 'diagnostic tests', Treagust employs four fundamental stages to such an activity.

The first of these, is defining the content to be assessed, in our case the mole concept. The second is defining the learning objectives, which are in essence 'sub concepts' of the mole concept. The third stage, involves the collation of current research on students' misconceptions with regard to the mole concept and compiling this information into a list, which informs the development of items in the diagnostic instrument relevant to each question/learning objective. Lastly, this instrument entails the formulation of test items that ultimately reasonate with the learning objectives under analysis in stage two ; the identified misconceptions in stage three are then used as 'distractors' or as deemed otherwise in the test items.

During the course of their first year students have completed 20 mandatory laboratory sessions, which included two laboratory exams. Students were required, during both laboratory sessions and exams, to complete calculations based on titrations they had performed. In order to assess students' procedural knowledge of the mole, they were required to complete calculations on a basic acid/base titration and a water hardness titration. Students were awarded marks based on (a) the average titre value, (b) moles involved in the reaction and (c) conversion of mole to (i) moles/L or (ii) g/L depending on the titration involved.

In the second semester, both cohorts were asked to complete a questionnaire which assessed students' conceptual understanding of the mole by examining three learning objectives pertinent to the mole concept. They are:

- The mole is a counting unit and one mole of any substance contains the same number of units as one mole of any other substance.
- The mole is defined as the amount of substance containing Avogadro's number of units or particles of that substance.
- The atomic ratios in the formula of a molecule is also the molar ratio of atoms in that molecule.

Students' results of semester one laboratory exam revealed that neither cohort performed well on this calculation, showing particular difficulty with conversion of units and the calculation of mole ratio. In semester two, students from both cohorts showed a general improvement in the second lab exam, with the second cohort (07/08) performing slightly better on the overall completion of the calculation.

Preliminary results of the conceptual questionnaire suggest that the 07/08 cohort of students is showing an improvement in learning objective one on a percentage basis. For learning objectives 2 & 3, there was a drop percentage wise in the correct answering of this question for the 07/08 cohort in comparison to the 06/07 cohort.

1. Newell A and Simon HA (1972)'Human Problem solving' (Englewood Cliffs, NJ Prentice-Hall)
2. Owen E and Sweller J (1985) 'What so students learn while solving mathematics problems?' Journal of Educational Psychology, 77, 272-284

Changes in the Leaving Certificate Higher Level Chemistry Syllabus, have they been reflected in the assessment?

ECRICE, Istanbul July 2008

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Assessment at both second and third level has come under immense scrutiny over the last decade with particular emphasis placed on the role it can play in student learning. Good assessment strategy should be preformed in such a way that is justifiable and allows all students to achieve their maximum potential [1]. Assessment should also reflect the stated objectives and leaning outcomes of a curriculum [2].

The revised Irish second level national syllabus (Leaving Certificate) in Chemistry was implemented in 2000 and first examined in 2002. The syllabus aims to:

- Stimulate and sustain student interest in and enjoyment of chemistry
- Encourage an appreciation of the scientific, social and economic, environmental and technological aspects of chemistry among others. [3]

This syllabus will be assessed in relation to its objectives which include:

- an ability to interpret experimental data and assess the accuracy of experimental results.
- an ability to organise chemical ideas and statements and write clearly about chemical concepts and theories. [3]

This new revised syllabus has received criticism due to the implementation of mandatory experiments without the proper equipping of all Irish Secondary and Vocational Schools, and also the failure of the terminal exam to provide adequate assessment for the shift in emphasis to the applied aspects of chemistry. [4,5]

The new syllabus is structured into thirteen examinable topics, nine core and four optional topics. The examination consists of two sections; section A containing three questions dealing with mandatory experiments completed by students during the course of their two years of study and section B containing seven questions which contain questions dealing with theory, applied aspects and applications of chemistry.

In this study, analysis has been completed on the last seven annual exams, with focus placed on the frequency of appearance of these particular topics in order to ascertain if there is a high level of predictability within the chemistry paper. Topics which haven't appeared on the last seven years, in either section A or B, also have been identified.

While there are issues in relation to the use of Blooms Taxonomy [6] in determining question type, in this study it is being used purely as a tool in order to compare the examination questions over a number of years.

Questions have been identified as knowledge, comprehension, application, analysis, synthesis or evaluation, and this has revealed that the predominant question type is of lower order with only a small percentage of higher order questions appearing in each examination.

Both the question type and frequency of appearance of keys areas and concepts of chemistry will be presented in this talk in an effort to identify or map out the trends in the examination.

Also as the Leaving Certificate Chemistry paper in 2008 has recently been completed in Ireland (05/06/08), an analysis of this paper will also be included in this study.

[1] Bennet Stuart, Open University Press, Milton Keynes (2002)
[2] Doran, R. , United Book Press, Virgina (1998)
[3] Leaving Certificate Chemistry Syllabus, NCCA The Stationary Office Government Publications Dublin (1999)
http://www.education.ie/servlet/blobservlet/lc_chemistry_sy.pdf?language=EN
[4] Matthews, P., Chemistry in Action 46, 24-35 (1995)
[5] Childs, P.E., Chemistry in Action 46, 42-44 (1995b)
[6] Bloom B, Taxonomy of Educational Objectives, David McHay Co Inc, New York (1956)

Analysis of Leaving Certificate Chemistry Examination

SMEC,DCU, Dublin October 2008

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Assessment at both second and third level has come under immense scrutiny over the last decade with particular emphasis placed on the role it can play in student learning. Good assessment strategy should be preformed in such a way that is justifiable and allows all students to achieve their maximum potential [1]. Assessment should also reflect the stated objectives and leaning outcomes of a curriculum [2].

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This syllabus will be assessed in relation to its objectives which include:

- an ability to interpret experimental data and assess the accuracy of experimental results.
- an ability to organise chemical ideas and statements and write clearly about chemical concepts and theories. [3]

This new revised syllabus has received criticism due to the implementation of mandatory experiments without the proper equipping of all Irish Secondary and Vocational Schools, and also the failure of the terminal exam to provide adequate assessment for the shift in emphasis to the applied aspects of chemistry. [4,5] This study aims to assess the level of questioning used in the Leaving Certificate examination and how well the final examination assesses students competence of the stated outcomes.

While there are issues in relation to the use of Blooms Taxonomy [6] in determining question type, in this study it is being used purely as a tool in order to compare the examination questions from 2000 to 2008, for the higher level examination papers. Questions have been identified as knowledge, comprehension, application, analysis, synthesis or evaluation using a devised rubric, and this has revealed that the predominant question type is of lower order with only a small percentage of higher order questions appearing in each examination.