THE DEVELOPMENT, IMPLEMENTATION AND EVALUATION OF ALTERNATIVE APPROACHES TO TEACHING AND LEARNING IN THE CHEMISTRY LABORATORY

By

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A thesis submitted to Dublin City University for the degree of

DOCTOR OF PHILOSOPHY

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September 2005

Volume 1 of 2

To my parents

AUTHOR DECLARATION

I hereby certify that this material, which I now submit for assessment on the programmes of study leading to the award of Doctor of Philosophy is entirely my own work 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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ABSTRACT

The focus of the thesis is on the evaluation of the effect of the implementation of a three-hour per week problem-based learning (PBL) module for 1st year undergraduate students. The research questions are outlined below:

- What approaches to learning are undergraduate students adopting at the initial stage of tertiary education?
- Are student approaches to learning related to age/gender/ time in university/achievement in examinations?
- Can a PBL module in chemistry be developed that can provide an effective teaching and learning environment, which develops students' understanding in chemistry and engages the students with the context and processes of chemistry?
- Will the introduction of such a PBL module in chemistry have an effect on students' approaches to learning?

The main evaluation tool for determining student approaches to learning was the learning style inventory – Approaches and Study Skills Inventory for Students. Other evaluation tools employed were student surveys, interviews and assessment data.

Key findings were that students on entry to tertiary level report a preference for deep and strategic approaches to learning over a surface approach. However, with time in university, the profile shifts with students indicating increasing use of a surface approach. Mature students tended to prefer a deep approach in comparison to their younger counterparts and female students were more strategic than males in their approach.

An introductory year-long chemistry PBL laboratory module was developed, implemented and evaluated. Interestingly, students who took part in the PBL module showed a lower preference for a surface approach having successfully completed the PBL module compared to those who followed the traditional approach despite showing similar trends at the start of the study. The effect on a deep approach to learning, after taking the PBL module, one sixth of the 1st year course, was not evident however. Conversely, the PBL students did significantly better in a non-formal exam designed to assess students learning in the first year chemistry laboratory. The students also successfully engaged with the chemistry content, context and processes and reported the benefit of the pre-lab, group work and practical aspects of the PBL approach.

ACKNOWLEDGEMENTS

I wish to thank my surpervisor, Dr. Odilla Finlayson, for her guidance, support and encouragement throughout the course of my postgraduate studies. I would also like to thank my fellow postgraduates and the staff of the School of Chemical Sciences, especially the technical staff, whose help was very much appreciated.

I am indebted to the Science Education students from the last four years who took part in the PBL module and the laboratory staff for their support and help. I am also indebted to the students and teachers who took part in the microscale trials.

I would also like to acknowledge and thank the financial support of the School of Chemical Sciences.

I would also like to thank present and past members of X149, especially Mairead and James, who have made the last few years very enjoyable. I would also like to say a special thank you to Eadaoin and Susan whose friendship and support means so much to me.

Finally, I would like to acknowledge the invaluable support, advice and help of my family and friends especially my parents, my brothers Declan and Ronan, my sister-in-law Eadaoin, Ciaran and the girls. Thank you all so much.

Publications

Chemistry in Action! Issue No.69 Spring 2003

Small-scale chemistry in the school laboratory

Oral Presentations

***28th August - 1st September 2005** ESERA

Universitat Pompeu Fabra, Barcelona

Investigation into Gender Differences in Approach to Learning of Undergraduate Science Science Students

28th August - 1st September 2005 ESERA

Universitat Pompeu Fabra, Barcelona

Student experiences of a laboratory-based problem-based learning module for 1st year undergraduate chemistry students

***4-8th July 2005** European Variety in Chemistry Education

Jagiellonian University, Krakow

Approaches to learning of undergraduate chemistry students – the Irish experience and comparison with Australia

4-8th July 2005 European Variety in Chemistry Education

Jagiellonian University, Krakow

First year undergraduate laboratories in Chemistry – experience of a problem-based laboratory approach

***28th March 2004** Sharing Science, A Joint North South Science Education Conference, Dundalk Institute of Technology

Microscale Chemistry for Leaving Certificate – A safe and effective practical experience for teachers and students

***27th March 2004** Sharing Science, A Joint North South Science Education Conference, Dundalk Institute of Technology

Microscale – promoting learning through hands-on investigative activities

***21st January 2004** Science Education Research Seminar
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Problem Based Learning in the First Year Chemistry Lab – 'A Work in Progress'

***4th September 2003** Teacher Training Course,
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Microscale in Investigative Science

***2nd September 2003** Variety in Chemistry Teaching,
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Dublin City University

Problem Based Learning and Approaches to Learning

***12th October 2002** Chem-Ed Ireland,
University of Limerick

Small Scale Chemistry in the School Laboratory

(*Main presenter)

Poster Presentations

28th August - 1st September 2005 ESERA
Universitat Pompeu Fabra, Barcelona

Microscale chemistry - Evidence of its effective use in teaching practical chemistry to senior second level students

23rd – 24th September 2004 SMEC International Conference
Dublin City University

Evidence of the Effective Use of Microscale Chemistry for Leaving Certificate Chemistry

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Workshops

27th July 2002 and 12th July 2003 Science Teachers Summer School
Dublin City University

Alcohol Module

May 2002 and 6th – 8th May 2003 School Liaison Activity
Dublin City University

Leaving Certificate Chemistry Experiments on a Microscale

INTRODUCTION

The disengagement of students with science is well documented internationally, and this manifests itself particularly at senior second level and tertiary level where students are opting out of science especially the physical sciences – chemistry and physics. This is certainly the case in an Irish context, where the numbers taking chemistry and physics at second level have followed a downward trend over the last fifteen years. Various national measures have been taken to address this including the reintroduction of primary science and the development of new science syllabi at second level in Ireland. Furthermore, research on science education has resulted in the development of a variety of teaching and learning approaches to engage students with science.

Research in this area has indicated the benefits of a shift in the teaching of science from a teacher-oriented approach, which is associated with information transfer and routine memorising, to a student centred approach, with the focus on the active involvement of the student with the content, context and processes of science. This is related to a deep approach to learning by the student. These student centred approaches have foundations in constructivism, where students construct their own meaning from what they are learning by relating them to previous knowledge and experiences. An overview of approaches to teaching and learning, particularly in science, is given in Chapter 1.

This study has two main objectives, firstly to investigate students' approaches to studying and learning in science both at the beginning of their undergraduate careers and during their 1st and 2nd years of their degree. Secondly to develop, implement and evaluate the effect of a problem-based learning (PBL) module on students' experience in the chemistry laboratory, their approaches to learning and academic achievement.

The 'Approaches and Study Skills Inventory for Students' (ASSIST) was used to determine the predominant approach to learning of the students. The approaches to learning of science students in Dublin City University over time are presented. Furthermore, these results are also compared to those of a group of science students in the University of Wollongong, Australia. Age and gender differences are also investigated. See Chapter 2. The University of Wollongong was chosen because an opportunity presented itself to spend time at the University of Wollongong and as the Australian second level education system is similar to that in Ireland, a comparison was useful.

PBL has its roots in constructivism and it is very much a student centred approach. Students have the opportunity to engage with the content in a relevant and interesting context. A year-long PBL module was designed for a 1st year fundamental laboratory chemistry course. The PBL module was developed to allow for the typical learning outcomes to be met as well as life-long skill development, such as problem solving, team-work and communication skills and other learning outcomes. The module focused on the development of three key areas – concepts, understanding and skills in chemistry. The 'problems' provide the focus of the learning. It incorporates the use of pre-labs, group work, discussion, inquiry and practical work. Also, the assessment methods involve written reports as well as oral and poster presentations. Another key aspect is that the demonstrator takes on the role of 'facilitator'. Details of the development and implementation of the PBL module is given in Chapter 3.

The evaluation of the PBL module is described in Chapter 4. Student interviews and questionnaires were used to evaluate students' experiences of the PBL module. The ASSIST inventory was used to monitor to changes in the students approach to learning having followed the PBL approach. Finally, formal and alternative assessments were used to determine the academic achievement on these students in comparison to students who followed the traditional approach.

The final part of the thesis discusses the development of microscale experiments for Leaving Certificate chemistry and their trial with second level students. This work was undertaken to help overcome some of the problems of doing practical work in second level schools. All of the experiments and an evaluation of the trial are reported in Chapter 5. Additionally, due to the benefits of microscale techniques such as ease of use, increased safety and reduced cost, generally allowing for more hands-on work PBL and microscale could be combined to provide a very effective teaching and learning environment in the laboratory. This is however beyond the scope of this research.

CHAPTER 1

APPROACHES TO TEACHING AND LEARNING:

TRADITIONAL AND ALTERNATIVE APPROACHES

1.1: THE STATE OF SCIENCE EDUCATION

1.1.1: THE GLOBAL ISSUE OF SCIENCE EDUCATION

There is a global issue in science education, which Fensham[1] has described as students' disengagement with science, especially the physical sciences: chemistry and physics. National and international reports have highlighted this issue[1,2,3,4]. There are also three significant ongoing international studies investigating science education at primary and/or secondary level, one of which determines students' attitudes towards science, the ROSE project[5], where as the other two determine students' achievement in science: TIMSS[6] and PISA[7]. These three projects are described briefly below.

ROSE, the Relevance of Science Education, is an international comparative research project designed to shed light on factors of importance to the learning of science and technology as perceived by the learners as they reach the end of their compulsory schooling (15 years)[5]. In comparison TIMSS and PISA are based on students academic achievement. TIMSS, the Trends in International Mathematics and Science Study, collects educational achievement data at the fourth and eighth grades (or equivalent) at primary and second level to provide information about trends in performance in mathematics and science over time, together with extensive background information to address concerns about the quantity, quality, and content of instruction[6]. PISA, a three-yearly survey (2000, 2003, 2006) also of 15-year-olds assesses how well students near the end of compulsory education have acquired some of the knowledge and skills that are essential for full participation in society, the 2000 survey focused primarily on reading, 2003 on mathematics and 2006 will see the main results for science[7].

These three studies show the global concern for science education for all students, both those students going on to further study in the sciences and hence into the workforce but also, to equip future citizens and leaders with necessary life skills in the sciences! As Lederman[3] puts it:

'Science education has two reasons for being emphasised:

1. To populate the 21st century work force
2. To produce citizens who are 'savvy enough' to help guide their families, community and nation in 21st century decisions and in a 21st century culture'

Internationally, initial results from the ROSE 2003 study[8] show that science, in most countries, is less popular than most other subjects, except in developing countries such as Uganda and Ghana, where science is popular among 15 year olds. Also, when asked to respond to the following statement 'I would like to become a scientist', it was revealed that very few children wanted to become scientists, once again except in developing countries. Also, some gender issues were revealed, with girls liking science even less than boys, and wanting to become scientists even less than boys. Fensham[1] reports on three separate studies of student experiences of school science, which suggest a negative perception of school science. The three studies involved England, Australia and Sweden with the predominant results suggesting that students perceive school science as:

- Knowledge transmission of correct answers
- Irrelevant and containing boring content
- Difficult in comparison to other subjects.

The second and third point highlight potential reasons for students disengaging with science. With regards to the first point - Knowledge transmission of correct answers – this is a problem which is not necessarily confined to the sciences and not confined to school either. 'Today's new ideas are tomorrow's out-dated information'[9] so why then do students spend so much time rote-learning and memorising facts and figures? Ramsden[9] comments above on the fact that students often reduce their learning to rote-memorising of lecture notes, summaries, definitions etc without engaging with the content, which is futile in an environment where information is changing at a very fast rate. Entwistle[10] reports that learning should not be simply a passive process of absorbing pre-digested knowledge. In higher education, learning should involve many activities; memorising where necessary, but also relating new ideas to old, linking theoretical ideas or academic knowledge to personal experience wherever possible, adopting a critical stance to other people's ideas, and evaluating evidence with caution. Marton and Saljo[11] describe the 'evil path in education', where clear and concise notes and textbooks enable answers to be learnt by heart and reproduced in the examination, which can lead to worthless teaching, churning out the same knowledge time and time again, with little imagination. Rote-learning is however seen to go hand-in-hand with science departments as shall be seen in the next chapter whereas in arts departments, for example, other approaches are more common e.g. deep learning.

New strategies to engage students in the sciences include development of new syllabi and curricula. For example, 21st Century Science[12] is a new science curriculum for 14-

16 year old students in the UK leading to the GCSE (General Certificate in Secondary Education), which will be available to students from September 2006. Another project CASE[13] – Cognitive Acceleration through Science Education – is a combination of a curriculum and teaching method. The curriculum is designed to challenge children's present concepts of science and present them with problems that they are unable to solve using their current strategies. The teaching method involves specific management of classes so that every child participates in constructing ideas while working on the task in small groups, and then listens while these ideas are shared in whole-class discussion. The main aim of the initial project was to investigate the possibility of raising general levels of thinking among average students aged about 10-14 years. Junior Certificate science in Ireland has also received a revamp in recent years (2000), with a move towards investigative science. The Junior Certificate is the exam taken at age 15 by all students. These new curricula all have generally similar objectives, which are to raise the engagement of students in science and improve their learning experience.

As well as new curricula, the increased interest in science education research, with foundations in education theory, and psychology has given further scope for effective classroom practice, which has sound basis in the wider teaching and learning field. However, Fensham[14], Tsarpalis[15] and Bailey & Garrett[16] have made clear that research in chemistry education is only useful if it is effective at actually improving the science classroom/lecture/laboratory etc. i.e. bridging the gap between research and practice.

It is clear that effective teaching and learning is required at all levels in science education including primary, secondary and tertiary sectors to ensure a scientifically literate generation for the future. There is a definite need to address the problem of rote memorising at the expense of understanding, as well as to engage students' interest in the sciences, especially chemistry. Finally, the transition from secondary to tertiary education can be problematic for many students. It is essential to provide a supporting learning environment for these students, as well as a challenging environment for those students who excelled at school.

This thesis promotes the use of two alternative approaches to laboratory teaching in chemistry to encourage effective, deep learning from practical activities. A problem-based learning (PBL) module is developed for a first year undergraduate general chemistry laboratory course to enhance the laboratory experience by giving students real opportunities to engage with the chemistry and develop life-long skills. Secondly, microscale techniques are put forward as an alternative to the traditional scale for Leaving Certificate Chemistry as a means to provide more opportunity for students to get hands-on experience in an environment where resources and time are limited and health and safety is a major concern.

1.1.2: CURRENT STATE OF CHEMISTRY IN IRELAND AND COMPARISON WITH THE UK

Fensham[1] describes a situation where many countries are concerned with the decline in enrolments in science at university and the low interest in science during schooling including Ireland, the UK and Australia. A brief introduction to the current state of chemistry in Ireland is given here, with detailed studies of both Ireland and UK at second and third level given in the following sections. Childs[2] describes how in Ireland 'industry and government have become aware that the fall away from science will affect the long-term health and continued growth of a science-based economy' and reports that both the chemical industry and the IT sector have been experiencing a skills shortage. The final examination taken by school leavers at the age of 17-18 in Ireland is the Leaving Certificate and a new Leaving Certificate Chemistry syllabus was introduced in 2000, and was first examined in 2002. It was hoped that the number of students taking chemistry would increase. Previously, high failure rates and a perception of chemistry being a 'hard' subject resulted in students opting for 'easier', less time consuming subjects[2]. Entry to university and most third level colleges in Ireland is based on the performance of students in their final examinations, and is a highly competitive process, thus students' choices can be based on potential academic success rather than interest, resulting in students taking perceived easier subjects. Even when students are required to have a science subject to gain entry to third level, students mostly opt for biology[2]. A concern regarding the low take up of science subjects, especially the physical sciences resulted in the setting-up of the Task Force on the Physical Sciences in late 2000 by the Irish government, which has since made its report and recommendations[17](April 2002). This action was taken to address concerns about the declining levels of participation in the physical sciences at second level and in higher education and in recognition of the fact that the development of the skills base in the area of the physical sciences is central to sustaining Ireland's economic growth. However, much of the recommendations of the Task Force Report remain to be implemented (Irish Times 17/08/05).

1.1.2.1: Second Level developments

United Kingdom

In terms of secondary education, as far back as 1987, Britain recognised the need to change the secondary school science curriculum. A report in 'Chemistry in Britain' [18] describes how the traditional O and A level courses had been attacked as outdated and uninspiring – 'Students today need to see the relevance of science to everyday life and a new approach to secondary school teaching is essential to rekindle interest in science and technology'. The science curriculum was described in terms of three elements; the content, the processes of science, and the context of science. What was needed was a shift in emphasis towards the processes and skills of science and the curriculum set in a more student-friendly context.

By 1990, they expected to have students that were:

- Better in experimental and problem solving skills
- Able to communicate more effectively what they have studied
- More socially aware of the implications of science
- Studying science in a wider context, perhaps recalling less detail of the subject matter, but able to put it in a better framework.

However, in contrast to this, Marton and Saljo[11] reported in 1997 that at A-level the students still learn too much detail and they've no time for thinking.

The current A-level chemistry encourages students to[19]:

- Develop essential knowledge and understanding of the concepts of chemistry and the skills needed for the use of these in new and changing situations
- Develop an understanding of the link between theory and experiment
- Be aware of how advances in information technology and instrumentation are used in chemistry
- Appreciate the contributions of chemistry to society and the responsible use of scientific knowledge and evidence
- Sustain and develop their enjoyment of, and interest in, chemistry
- Bring together knowledge of ways in which different areas of chemistry relate to each other.

In addition to the traditional A level, there is also an alternative option for students to do other syllabi which are recognised by the British Government - the Nuffield Advanced

Chemistry[20] and more recently the Salters' A level Chemistry[21]. In the Nuffield A-level Chemistry[20] course students are encouraged to speculate about likely patterns of behaviour from their previous experience and from general chemical principles. They then investigate these experimentally, and the outcomes of practical work are discussed and used to consolidate theoretical understanding. The Nuffield Advanced Chemistry has been around for more than 30 years, with four editions of the course materials published in 1970, 1984, 1994 and 2000. In contrast the Salters Advanced Chemistry is a fairly new curriculum, with the first edition of the materials released in 1994 and the second edition in 2000 with plans to produce a third edition. The Salters Advanced Chemistry provides an innovative approach to teaching and learning advanced school chemistry in which chemical principles are developed in the context of modern applications of chemistry and the work that chemists do[21]. The course aims to[22]:

- Emphasise the ways chemistry is applied and the work that chemists do
- Broaden the appeal of chemistry by showing how it relates to people's lives
- Emphasise frontier areas of chemistry
- Include a broad range of teaching and learning activities
- Provide a rigorous and stimulating treatment of chemistry that both lays appropriate foundations for future studies, and satisfies those who will study no further chemistry.

Ireland

In contrast, the Irish Leaving Certificate offers only one chemistry course, which can be taken at two levels, ordinary or higher. According to the Department of Education and Science in Ireland, science education in the senior cycle should reflect the changing needs of students and the growing significance of science for strategic development in Ireland.[23] In line with the recommendations of the NCCA (1996)[24], a revised Leaving Certificate Chemistry syllabus was introduced, and first examined in June 2002 as well as new physics and biology courses which were first examined in 2002 and 2004 respectively.

The revised Leaving Certificate science syllabi are 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%)

The number in brackets refers to the % of the syllabus dedicated to each component. There is a 30% social and applied aspect, which is one of the changes to the revised syllabi combining the two areas 'Science for Action' and 'Science, which deals with issues of concerns to citizens'. Submissions to the Task Force on the Physical Sciences identified deficiencies in the former Irish science curriculum, asserting that the curriculum[17]

- Emphasised science education as a preparation for further study, rather than as a broad preparation for citizenship
- Was dominated by historical thinking and out of line with modern ideas, both scientific and pedagogic
- Promoted rote learning and recall of scientific facts, with insufficient emphasis on building higher-order skills
- Was too theoretical, missing opportunities to develop practical and investigative skills
- Was lacking in relevance to students' own lives and fails to examine the role and contribution of science in society.

The revision of the chemistry syllabus also took account of the need to increase the vocational emphasis within chemistry, the continuing fall in uptake of the subject over a number of years, the imbalance of male and female students and the length of the previous syllabus[25].

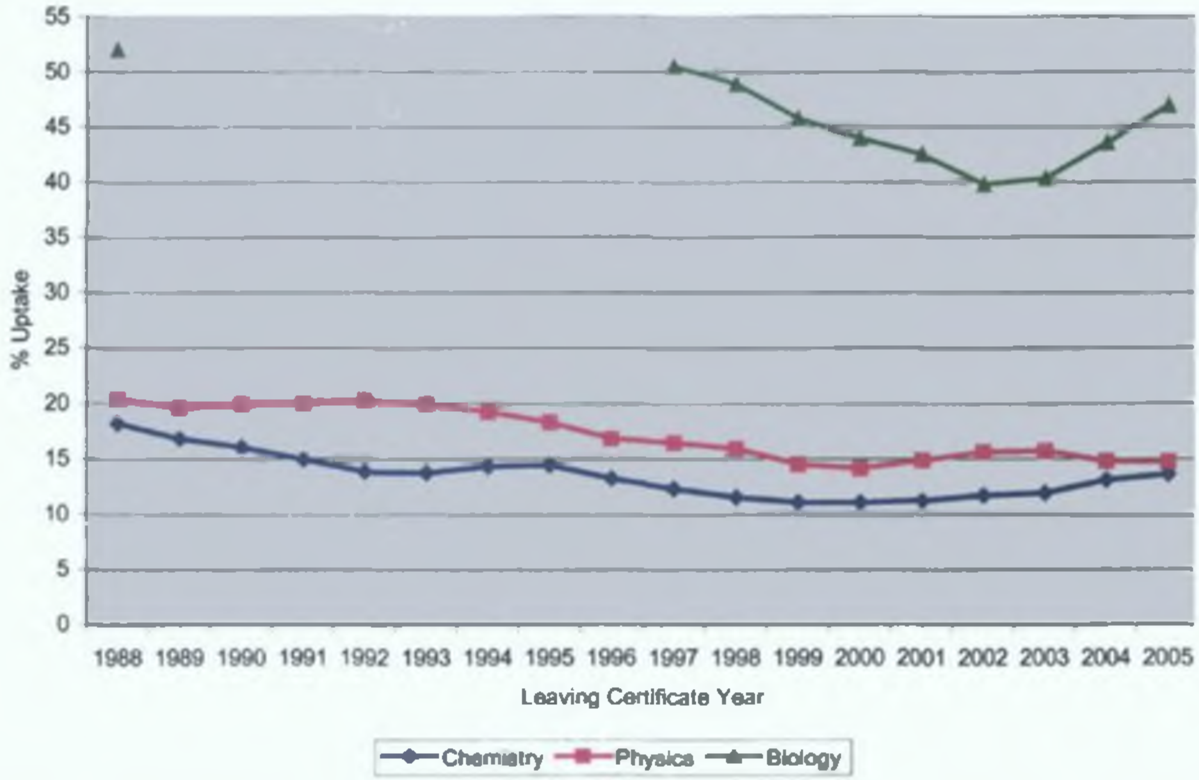
A new investigative Junior Certificate Science curriculum and the reintroduction of Primary Science to schools is further raising the profile of science for all in Ireland. Other developments include the Discover Science and Engineering Programme, which was developed as a response to a key recommendation of the Task Force on the Physical Sciences to pursue a co-ordinated approach to increase interest in science and encourage young people to consider science as a viable career option[26] and Discover Primary Science, which aims to introduce students to science in a fun and interactive way and support teachers in delivering the new Social, Environmental and Scientific Education curriculum[27].

1.1.2.2: Decline in numbers taking chemistry at senior secondary

Ireland

It is well documented that there has been a decline in the uptake of science subjects, particularly the physical sciences in an Irish context[17,28,29]. Figure 1.1 shows the uptake of chemistry, physics, and biology from 1988-2005, as a percentage of the total number of students in the Leaving Certificate programme. The trend for chemistry has been increasing for the last four years – will this trend continue? (Data for biology is incomplete)

Figure 1.1: The % uptake of chemistry, physics, and biology[17 30 31]

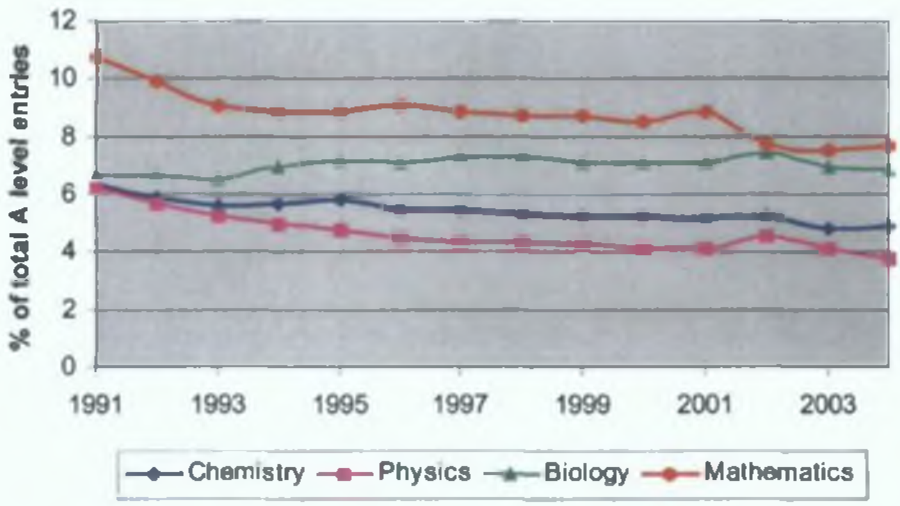


Different reasons for the low take-up of chemistry are reported. Young people perceive chemistry as being very difficult, very mathematical, heavily-content-loaded, very dull, and, possibly the most significant, demanding passive rather than active involvement with the learning process[32]. Schools successful in science reported compulsory science in Junior Cycle as the most important factor for their schools success in science, as well as commitment and quality of the teachers[33]. Significantly, the importance of practical work is also recognised.

United Kingdom

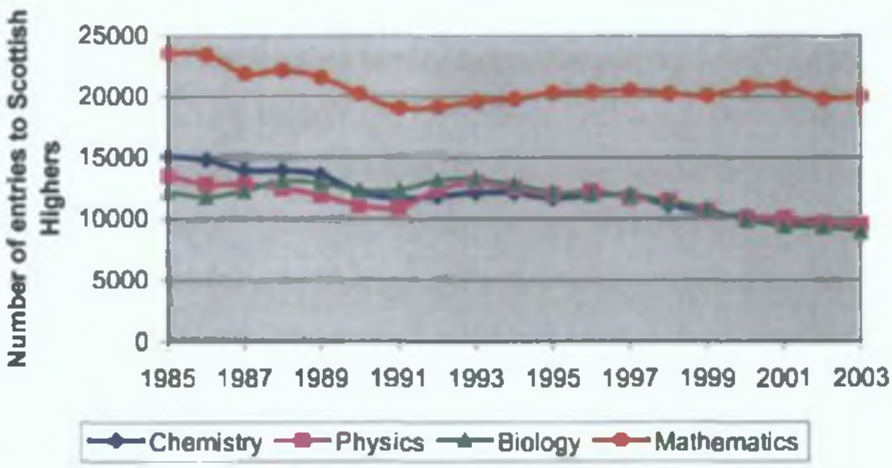
A report published by the Committee on Science and Technology[4] primarily described the state of science education for 14-19 year olds in the UK and was published in 2002. This showed similar trends with numbers taking the physical science subjects falling at upper secondary level. This is supported by a recent report by Reed[34], who described a similar worrying trend, that though the number of "A" level chemistry students had remained constant for many years, the last few years had seen a downturn in chemistry numbers. The choice in "A" level courses had shifted and chemistry, mathematics and physics were in decline with only biology and non-laboratory based courses showing an increase. Between 1992 and 2001 the overall number of A level entries increased by 26%[4], however, Figure 1.2 shows the proportion of these entries that came from science and maths. Only biology has maintained its position with chemistry, physics and maths becoming steadily less popular choices with students.

Figure 1.2: Graph showing entries to science and maths A levels as a percentage of all A levels entries over time[35]



In Scotland, students typically take 4 or 5 subjects at Higher level at age 17. Figure 1.3 shows the number of entries to the Scottish Highers, the equivalent to the A-level in England, in the sciences and maths. These subjects are attracting progressively fewer entries, as in England. However, unlike Ireland and England where biology is consistently a more popular choice, the three sciences are equally underrepresented in Scotland.[4]

Figure 1.3: Graph showing the total number of entries to science and maths Scottish Highers[36]



Australia

Chapter 2 will investigate and compare the approach to learning and studying of science students in both Dublin City University, and the University of Wollongong, Australia, therefore it is important to set the scene in terms of the scientific backgrounds of these two cohorts of students. It has already been shown that the majority of students who take science courses in Ireland at senior secondary take biology, and approximately 14% take chemistry. Does Australia have a similar profile? Table 1.1 shows the percentages of Year 12 students, the equivalent to the Leaving Certificate year in Ireland, enrolled in science subjects in 1980 and 1998. It is also worth mentioning that science is compulsory to age 15 in Australia, unlike in Ireland.

Table 1.1: Percentages of the Year 12 Cohort Enrolled in Various Science Subjects in 1980 and 1998[37]

SUBJECT	% 1980	% 1998	% DIFFERENCE 1998-1980
Biology	52	27	-25
Chemistry	33	20	-13
Physics	29	18	-11
Geology	4	1	-3
Alternative PESs	9	13	+4
SASs	1	5	+4

PES – Public Examination Subjects, SAS – School Assessed Subjects

It is quite clear that there has been a definite drop in students' choice for the three traditional sciences Biology, Chemistry and Physics. However, this is not reflected by an increase in students' choices for alternative science subjects offered such as General Science, Marine Science, Physical Science, Science for Life and Sports Science (offered as PES) or Astronomy, Horticulture and Marine Studies (offered as SAS). Secondly, another indicator which reflects this decline in school science is that in the years 1980 to 1988, the number of science subject enrolments exceeded the number of students, that is, on average, each student's enrolled in more than one science subject. However, from 1990, the number of science enrolments was less than the number of students, that is, on average, each student enrols in less than one science subject[37]. More recent figures from New South Wales, where the University of Wollongong is, suggest that the picture is quite similar with a ratio of 0.93 and 0.91 for number of science enrolments to the number of students, in 2003[38] and 2002[39] respectively, showing that students on average are enrolling in less than one science subject (inclusive of Biology, Chemistry, Physics, Senior Science, Earth and Environmental and Science for Life Skills). Table 1.2 shows the % of students taking each of the science courses in Year 12 in New South Wales.

Table 1.2: % of students taking science courses in Year 12 against the total number of students enrolled in Year 12 in New South Wales from 2001-2003[38,39,40]

SUBJECT	% OF STUDENTS		
	2001	2002	2003
Biology	32.0	29.1	29.5
Chemistry	24.0	21.9	23.3
Physics	24.2	23.5	24.8
Senior Science	13.8	12.2	11.7
Earth and Environmental Science	3.3	3.0	2.8
Life Skills	0.8	0.7	0.9

1.1.2.3: Issues at Third Level

In terms of tertiary chemistry education in the UK, Reed[20] reports that

> 'Currently, around 90% of 'A' level chemistry students do not progress to take chemistry courses at university. The majority take computer science, medicine and media courses. Since 1995, there had been a 20% decrease in the number of chemistry undergraduates and a corresponding drop in the quality of graduates.

This was mainly because not enough of the top "A" level students were being attracted to take degrees in the chemical sciences. However, those who do take chemistry at "A" level, tend to do very well.'

It was suggested that poor take up of chemistry may be related to some extent to the academic background of teachers. Around 40% of chemistry teachers do not have a degree in chemistry and 25% don't even have an "A" level in chemistry[34].

Similar sentiments are expressed by Price[41] in an Australian context. Price reports that though overall the number of university students in Australia has risen by 40%, the percentage of students taking chemistry has dropped from 2.1% in 1990 to 1.4% in 2003. He suggests several reasons for this decline in chemistry including pre-tertiary education, uninspiring courses, its image as a hard subject, and lack of career opportunities. There has also been a rapid decline in the size of chemistry departments, with the number of staff (academic and technical) per department dropping from an average of 44 in 1990 to 22 in 2000. This problem is also revealing itself in Britain through closures of Chemistry Departments in a number of universities, which is a more noticeable result of the decline in chemistry. There have been high profile closures of chemistry departments at Kings College London, Queen Mary London, Swansea and Exeter University since 2001[42].

Attrition (or non-completion) rates provide a measure of the proportion of students who 'drop out' of an award course at an institution each year. It gives insight into whether particular groups or categories of students are more inclined to drop out of higher education than others, and whether attrition is greater at particular institutions, in particular fields of education or in particular course types than in others. Unfortunately for the chemistry community, high attrition rates are a problem. Even when the small numbers of students have finally enrolled in chemistry/science courses at third level, the problems facing chemical educators and their students are not over. It is reported that on average one third of all entrants leave university without graduating across the OECD member countries[43] and even more worrying in an Irish context, science courses at university level have been shown to have higher rates of non-completion in comparison to other subjects such as law, medicine, dentistry and veterinary medicine. Non-completion was reported to be associated with low grades at Leaving Certificate, unclear career aspirations, lack of information and guidance on course and career options, financial and work-related problems, unsuitable course choices, difficulties with some or all subjects and motivation[44,45]. Table 1.3 below gives a breakdown of the profile of students starting in the academic year 1992-93 in science and business undergraduate courses from all seven universities in the Republic of Ireland.

Table 1.3: Profile of students commencing either a science or business course in 1992/93[43]

	NUMBER STUDENTS	% GRADUATING ON TIME	% GRADUATING LATE	% NON-COMPLETION
Science	2068	63.4	14.3	22.2
Business	2095	78.9	9.4	11.6

* Science = Science/Agric. Science/Food Science & Technology

Business = Business Economic & Social Studies/Commerce

In a similar study, progression data was obtained on first-time entrants to Institutes of Technology. Of the students who began their courses in 1995, just over half (52.1%) graduated on time; a small percentage (5.3%) graduated late or were still in attendance in 1998-99; and just over two-fifths (42.6%) did not complete the courses they had enrolled in when they entered college[44]. The highest rate of non-completion was in Engineering and Computing: half of students on these courses failed to complete. The next highest rate was in Science, in which nearly two-fifths of students failed to finish.

It has been shown that science, engineering and technology exhibit among the highest non-completion rates across all subject areas in both the universities and the institutes of technology[17]. The problem is even furthered at Dublin City University where 33.5% of students did not complete their course in science in DCU, compared to the national average of 22.2%[43] with only NUI Maynooth having a higher non-completion rate. This is based on the study carried on the students commencing courses in 1992-93.

Finally, the majority of students who do drop out do so at the end of first year. Costello[46] reports that 85% of the total number of students in Dublin Institute of Technology that failed to complete withdrew within or during their first year.[46] Therefore, many interventions are targeted at this stage of tertiary education. These include pre-science induction courses in chemistry and physics, science mentoring schemes, streaming of first year classes in chemistry, physics and mathematics to accommodate students who have not studied such subjects to a level appropriate to the course, diagnosis and intervention in the area of mathematics, targeted tutorial sessions and the development of tailored electronic multi-media tutorial programmes for self-learning and revision[17].

In conclusion, despite variations in non-completion for different subject areas across institutions, the Science, Engineering and Technology (SET) areas exhibit the highest non-completion rates in every university and every institute of technology. This represents a serious attrition of undergraduate students principally through withdrawal from, and exam failure in, the first year of SET studies. This trend of non-completion by first year students is also reflected in Australia, where despite the 2002 attrition rate for all domestic students and all international students being at its lowest since 1994, attrition rates in the first year after commencement of a course are around double that of those in the second year[47]. Unfortunately, information on specific disciplines was not available.

Another development at third level is the recognition that transferable skills are a "must have" for every graduate, regardless of their discipline. While content knowledge is important, more and more, such qualities as good communication skills, problem-solving ability, IT skills, leadership and organisational skills are seen as highly desirable by employers[48]. Ultimately, third level should provide students with the opportunity to develop their 'critical thinking' skills, which has been recently described as

> 'The art of thinking about thinking in an intellectually disciplined manner. Critical thinkers analyse thinking, they assess thinking, and they improve thinking (as a result).[49]

The importance of a society at home with chemistry, and that can deal with chemistry in everyday life is clear. How then can the level of understanding and enjoyment of chemistry be increased, for both people who want to pursue a profession in chemistry and for those who want to learn it for life? With the recent re-introduction of Primary Science (September 2003) to the Irish School Curriculum, the move towards investigative science at Junior Certificate and the revised Leaving Certificate Chemistry syllabus already discussed, there is an attempt to raise the awareness and enjoyment of science/chemistry in Ireland for all school students, in a context that they can relate to. Already there is a slight turn around in terms of uptake of chemistry, with the percentage of students opting to take chemistry on the increase in the last three years.

This should have a knock-on effect at third level, with students perceptions and confidence in science being raised, resulting in students choosing chemistry courses and surviving their third level experience. However, as well as changes in curriculum, alternative approaches' to teaching and learning also provide a platform for increased understanding and enjoyment of science and chemistry, with students being given the opportunities to fully develop transferable skills.

As already mentioned, this thesis describes a hands-on problem-based approach to first year undergraduate chemistry and the use of microscale techniques for Leaving Certificate Chemistry. These two alternative approaches to practical work encompass ideas from education theory such as constructivism, and, with particular reference to the problem-based learning, use a variety of teaching and learning approaches to give students an opportunity to maximise their learning and enjoyment of science. The following sections review the traditional and recent innovative or alternate approaches to science and chemistry teaching before finally discussing both microscale and problem-based learning as effective alternatives to the traditional mode of teaching.

1.2: TRADITIONAL APPROACHES TO TEACHING CHEMISTRY

Whether at second level or tertiary level, the approach to teaching chemistry typically combines elements of chalk and talk lectures, prescribed practical tasks, and written summative assessment among other activities such as group work or projects. Though instead of the old style 'chalk and talk', in this IT driven society the use of OHPs or Powerpoint presentations is probably more common! Either way, if the mode of exchange is predominantly a transmission of information from teacher to student, there is little opportunity for students to engage with the content and the adventure of chemistry is then reduced to passive lectures (or prescribed 'cookbook' laboratories) that stifle student questions, exploration and interest[50,51]. Research on learning processes and difficulties in chemistry has shown that many teaching models lack effectiveness in the transmission of concepts[52]. Roberts[53] reports that teachers seem to choose a resource on the basis of ease of use rather than suitable learning styles or meeting the students' needs/interests. As far back as 1985, Rogers commented on the situation that the vast majority of educational institutes, at all levels, were locked into a traditional and conventional approach, which makes significant, deep learning improbable, if not impossible[54]. Fortunately, since then there have been many developments in teaching and learning in science, and advances in IT have provided another platform for novel approaches to teaching and learning. However before some of these alternative and novel approaches are discussed, it is worth examining the traditional approach to teaching chemistry courses i.e. lectures, laboratory work, and written exam.

The Lecture

Zielinski & Shibata[55] commented that some teachers continue to think that lecture is the most efficient mode of instruction, although this opinion may be based more on what they themselves experienced during their academic career rather than on any valid assessment protocol. Consider some of the common characteristics of the archetypal general chemistry lecture. The class is usually large. The professor lectures and the students take notes, a practice that provides for little instructor-student interaction. The lecture notes and sample problems often duplicate textbook material. Martinez *et al.*[52] state that 'lecturing is not teaching, nor is listening learning'. However, the lecture is well documented as a successful strategy for communicating ideas, or transmitting information to others[56]. Bligh[57] also reports that the lecture is as effective as other teaching methods, for example computer-assisted learning, inquiry, reading or independent study, for transmitting information. Johnstone[58] however reports that this common assumption – that lecturing is an efficient way of transmitting information accurately – is wrong. He describes how after a chemistry lecture, 11 chemistry students assembled for a related tutorial. During the tutorial they referred to their notes, but the discussion revealed serious errors, omissions and misapprehensions arising from their records. A detailed study followed spread over three years, with sample sizes of 15, 28 and 32 respectively. The sample sizes were small to allow for the frequent and detailed analysis of lecture notes, but were representative of the large classes (500 in each year). The same lectures were sampled each year from the middle of different areas of a first year chemistry course including organic, and inorganic. The results showed that on average, students recorded 90% of blackboard information in terms of both words and information units but fell far short on completeness, assuming that the blackboard information was sufficient. The parts of lectures that went almost entirely unrecorded were demonstrations, examples of applications, detailed sequences of logical arguments and the meaning of technical terms and symbols. Another, more simple study[59] compared examination questions that had been answered pretty badly to the students lecture notes on the topic and found that the examination answers were fairly accurate reproductions of their notes. This shows that students were capable of reproducing the material in the examination, however had misinterpreted the lecture material in the first place! Despite these findings, and others, lecturing is still the predominant teaching method in college classrooms[56].

A legitimate response to these findings is that students must also bear some of the responsibility for their learning. With lecturing, good note taking skills are required if students are to benefit from it, and the students need to be adequately prepared with the prior knowledge expected by the instructor. Also, lecture notes in combination with the textbook, provide the basis for continued study, refinement and development of understanding. The disciplined student who reviews the material shortly after the lecture and before the next class will usually develop a deeper understanding than the student who leaves any substantive review until shortly before the exam[60].

The lecture method can be seen as[61]

- Boring and uninteresting
- Lacking teacher/student and student/student interaction
- Poorly organised and presented

- Having irrelevant, non-current content, which is inaccessible outside the lecture
- Focusing mainly on the lowest level of cognition
- Ignoring individual differences.

Bligh[57] discusses how most lectures are not as effective as discussion for promoting thought, also that lectures are relatively ineffective at teaching behavioural skills and at inspiring interest in a subject. Yuzhi[62] reports that the traditional lecture is intrinsically not conductive to learning unless augmented by activities which involve students directly, and which give them opportunity to acquire the necessary knowledge by other means besides passive listening. Lectures combined with questioning, discussion or group work can help to engage students in lectures. Byers[63], for example, reports the use of questions to promote active learning in lectures and Sirhan *et al.*[64] report the use of pre-lectures to ensure that the essential background knowledge is established and is accessible so that new learning in the lecture can be built in.

Finally, Hodgson[56] reports that a significant difference was found between teachers who were interesting and enthusiastic and those who were boring and lifeless, with the students commenting that teachers should demonstrate their commitment and their interest in communication of their subject. The lecture can and should be a strategy that engages students more, and allows for more interactions with the content. The lecture is at its best when it actively engages the whole person. Questions must be encouraged and outside readings that provide a clear and thorough explanation of the material are important.

The Laboratory

Ask any teaching chemist about the importance of a laboratory component in the course he/she teaches, and you'll most likely get a response suggesting that laboratory work is critical to the understanding of chemistry. However, it is reported that there is little direct evidence that supports this point of view i.e. that students who do practical work perform better than those who don't do any practical work[65]. The traditional approach to teaching chemistry in the laboratory may explain why. It typically involves having students perform teacher-structured laboratory exercises or experiments. Each step of a procedure is carefully described and students are expected to follow the procedures exactly. Usually, little is left to the students' thought or ingenuity. This type of structured laboratory is often called a verification laboratory experiment.[66] Montes [67] reports advantages and disadvantages of verification experiments, for both student and teacher. See Tables 1.4 & 1.5.

Table 1.4: Advantages of Verification Experiments as listed by teachers [67]

Feature	Primarily Affected	
	Student	**Teacher**
Easy to time		*
Easy to prepare		*
Easy for large classes		*
Easy to grade		*
Students learn techniques	*	
Students learn to follow directions	*	
Students learn use of equipment	*	
Relevant to lecture	*	
Easy to supervise	*	
Structured		*
Quieter		*
Less controversial		*
Everybody does the same thing		*
High likelihood of success		*
Instructor knows outcome		*
Easy to help students with problems		*
Known expectations of students		*

Table 1.5: Disadvantages of Verification Experiments as listed by teachers [67]

Feature	Primarily Affected	
	Student	**Teacher**
Boring	*	
No flexibility	*	
Not individualised	*	
Students are mentally passive	*	
Students only do what is needed	*	
No excitement of discovery	*	
All perspectives are the same	*	
Easy to manufacture the data	*	
Easy to copy	*	
Doesn't require creativity	*	
Doesn't teach problem solving skills	*	
No exploration	*	
No learning from unexpected results	*	

It can be easily seen that the majority of the advantages (Table 1.4) associated with verification experiments primarily benefit teachers, rather than the student, whereas the items listed in Table 1.5, all primarily disadvantage students. Cooley[68] expresses similar sentiments. He reports that when students are provided with a description of the data that they are supposed to obtain, they do not take the matter of collecting their own data at all seriously. When they are given an explanation of what the data means, they accept such interpretations without question and complete the laboratory with minimal effort or ability to interpret data. Published laboratory manuals that give the results to be expected and their meaning do not force the students to think about their experiments.[68] As expressed by Monteyne & Cracolice[69] 'cookbook labs use highly structured materials to verify a concept presented previously in lecture or in a pre-lab reading', with students mindlessly following written instructions, with their primary concern being to finish the lab. Furthermore, the 'follow-the-recipe' style of traditional teaching laboratories is a far cry from the largely independent research most students will engage in after graduation[70]. This will be discussed in more detail in Chapter 3.

However, as students progress through their undergraduate degree, they often get opportunities to engage more with practical work such as on work placements or in project work. This gives students an opportunity to experience the whole experimental process. However, like with the lecture, drastic changes or overhauls of the whole process is not needed, instead just change what is done with them! Group work, short projects, and investigations are just some of the approaches that can greatly enhance the laboratory experience. The aims and learning outcomes of a general laboratory practical is further discussed in Chapter 3 as well as a further reflection on the typical first year chemistry laboratory course.

Assessment

Assessment is important for students and teachers, if not the most important aspect of teaching and learning for students[71,72]. It tells them both whether or not they have been successful – the student in learning and understanding the material, and the teacher in teaching and trying to develop understanding[72]. Assessment is the engine that drives student learning, and it should be valid, reliable and transparent[73]. Validity means that it must assess what is meant to be measured i.e. if students conceptual understanding of a topic is to be assessed then multiple choice questions are probably not the way to do it, reliability in the sense of fairness and consistency, and transparency meaning there should be no hidden agendas, such as nasty surprises on the exam paper![73] Assessment should be in line with the intended learning outcomes. Also, the link between these outcomes and the assessment criteria should be plain to see[74].

Bennett[71] describes the closed-book, fixed-time examinations, and he reports that this type of assessment features in almost all institutions, and makes a significant contribution to chemistry based programmes. However, he recognises the advantages and disadvantages of these formal examinations compared to non-examination based examinations. See Table 1.6.

Table 1.6: Comparison of aspects of formal examinations with non-formal examination –based assessment

FORMAL EXAMINATIONS	NON-EXAMINATION BASED ASSESSMENT
Allow for verification of student work	Can be less certain that it is the student's own work
Performed in limited time	Time is student-limited
Relatively easy to administer	Can be more difficult to administer
Disadvantages some students	Perhaps a more even playing field
Relatively easy to grade consistently	Difficult to grade consistently
All skills and knowledge may be tested at the same time	Skills and knowledge tested over a longer time but wider range of skills tested
Unable to test some important skills well	Skills tested more effectively
Tests at a particular point in time	Time for reflection
Good discriminator of certain criteria	Reasonable discrimination
Tests memory	Not so memory dependent

Race[74] also discusses the advantages and disadvantages of the traditional unseen, time-constrained written exam:

Advantages

- Relatively economical on time, resources, and staff
- Equality of opportunity
- No plagiarism
- Teaching staff familiar with exams of this type
- Exams cause students to get down to learning.

Disadvantages

- Students get little or no feedback
- Badly set exams encourage surface learning.

- Technique is too important
- Exams only represent a snapshot of student performance, rather than a reliable indicator of it

It is clear that both types have their advantages and disadvantages. Therefore, the traditional time-limited examination needs not to be replaced necessarily by novel approaches but used more effectively by asking students more conceptual and problematic questions! The type of questions typically found in first year undergraduate chemistry examination papers will be discussed in Section 1.3.3, as well as alternative types of assessment such as peer- and self-assessment.

Conclusions

Having discussed the typical format of teaching chemistry, we can see clearly that the accepted format of lecture, laboratory, and written exam, may not be as beneficial to the student as is generally perceived. There are advantages to each method but also many disadvantages, and as we have seen these can often be due to the teachers, who seem to choose a resource on the basis of ease of use rather than suitable learning styles or meeting the students' needs/interests[53]. This is, of course, detrimental to the student. When we put together in one scheme such elements as a prescribed curriculum, similar assignments for all students, lecturing, as almost the only mode of instruction, standard tests and teacher chosen grades as the measure of learning, we can almost guarantee that deep learning will be at an absolute minimum[54]. Rogers[54] describes the change that is needed 'is a shift in emphasis from teaching to learning', with a vision of the facilitation of learning as the aim of education.

What follows next is a discussion of alternative approaches to teaching chemistry, encompassing areas from inquiry in the chemistry laboratory to peer-led co-operative learning. These all have in common the idea that students must be engaged with their learning for any meaningful learning to take place. Also, constructivist theory, which will be discussed in the next section, underlies many of these new approaches. Problem-based learning has its roots in constructivism and, in this research, uses elements of group work, discussion, and inquiry-based laboratory work among others to facilitate student learning. Therefore, these approaches will be the focus of Section 1.3.

1.3: ALTERNATIVE APPROACHES TO TEACHING AND LEARNING

Students require a wide variety of skills as they prepare for careers beyond the halls of academia. Some of these include being quick thinking, problem solving, computer literacy, and articulate in both verbal and written expression. Furthermore, they need experiences that will promote self-confidence so that they can rely on their own rational thought process for future job-related non-textbook type problems or situations[75]. The RSC Undergraduate Skills Record is a framework for skills recording and development to be used throughout an undergraduate programme. The Undergraduate Skills Record (USR) has been introduced to support students in the chemical sciences to help develop a range of skills during their degree. A.D. Ashmore, Registrar of the RSC, is quoted as saying that 'Employment in the sciences has become increasingly multidisciplinary and the need to communicate well and work effectively with others is essential. These vital skills as well as the ability to plan, organise and solve problems are crucial aspects for all successful careers'[76].

This need for students to develop key skills as well as developing a deep understanding about their subject has led to many alternative approaches to teaching and learning in chemistry. More and more it is recognised that one teaching style does not suit all students and that programmes should contain a variety of methods to cater for the diversity of students who are in second and third level education, including mature students, non-standard applicants and those with learning difficulties[77] among others.

1.3.1: SHIFT IN EDUCATIONAL FOCUS

Cohen *et al.*[78] refer to three teaching styles: closed, framed and negotiated. Closed is the formal didactic style as described in Section 1.2, framed is where there is overall structure but some room for student contribution, and finally negotiated is where teachers and students have negotiated content and activities. From closed to negotiated there is a clear movement from a teacher centred model to a student centred approach. Two extreme approaches to teaching are also recognised by Prosser *et al.*[79], which are similar to Cohen's 'framed' and 'negotiated'. One is a teacher-focused information-transfer approach to teaching, which supports a surface approach to learning, in contrast to a student-focused conceptual-change approach, which supports a deep approach to learning.

Students' approach to learning has been researched at length and has led to three categories of learners: deep, surface and strategic[80,81,82]. This research is extensively discussed in Chapter 2, but for now, a basic description of each learner will suffice. Deep learners are motivated by an inherent interest in the subject and want to understand the subject; the surface learner on the other hand is motivated by the fear of failure and sticks closely to the syllabus, and relies on rote memorising; finally the strategic learner is motivated by success, and wanting to achieve the best grades, closely monitors their learning and has developed good study techniques. Students approach to learning is influenced by many factors, including their prior experience, the teaching and learning environment, and most importantly the perceived assessment demands.

To put these different approaches to learning and distinct approaches to teaching in context with each other, there are two extremes to teaching reported, one which transmits information, with limited teacher-student interactions and the other which supports student understanding, with frequent teacher-student and student-student interactions. The latter style is associated with a deep approach to learning, whereas the former is matched with a surface approach. The recent innovative and alternate approaches to teaching and learning, as shall be described in the coming sections, have the unifying theme of trying to support student understanding, and development of life skills. There is a definite drive to move away from the routine memorising, passive reception of knowledge form of student learning to active student involvement and engagement in the learning process.

Johnstone[83] put forward the 10 Educational Commandments, which he described as the principles for teaching and learning. See Figure 1.4. The first three have a distinct link, which is that previous experience has a definite impact on what students can learn. If students are to learn successfully, new information and concepts need to be linked with prior experience. This has similarities to the constructivist approach, which is an approach to teaching and learning, which allows learners to build their own learning and meaning. Constructivism was born from the work of educational theorists John Dewey, Jean Piaget and Lev Vygotsky, whose main beliefs were that[84]:

- Education should be child centred
- Education must be both active and interactive
- Education must involve the social world of the child and the community.

Figure 1.4: Ten Educational Commandments[83]

1.	What you learn is controlled by what you already know and understand.
2.	How you learn is controlled by how you have learned successfully in the past.
3.	If learning is to be meaningful it has to link on to existing skills and knowledge, enriching and extending both.
4.	The amount of material to be processed in unit time is limited.
5.	Feedback and reassurance are necessary for good learning.
6.	Assessment should be humane.
7.	Students should have opportunity to consolidate their learning by being shown linkages and associations.
8.	There should be room for problem solving of all kinds to consolidate linkages.
9.	There should be room to create, defend, try out and hypothesise.
10.	Students should have the opportunity to teach.

Dewey's general philosophical position is usually known as 'instrumentalism', where the main idea is that what counts as knowledge and truth is what works i.e. what produces satisfactory results for men in their interaction with their environment[85]. In a teaching context, this means that students must be set tasks which develop their intelligence, their capacity to live adequately and this must be done in a way which makes them a co-operative social being.

Piaget focused his research on how children arrive at what they know, rather than what they know and when they know it[84]. Piaget's theory is basically that learners have basic 'schemas' (ideas, concepts), which can be used directly (assimilation) or which can be adapted and built on to give new schema (accommodation). Assimilation can also be described as acquiring information, where as accommodation can be seen as readjusting or reorganising information. At all times a balance exists between assimilation and accommodation, sometimes one or other being more prominent. It is through this process of assimilation and accommodation that the individual constructs new concepts, skills and meanings[84,86,87]. Piaget called the balance between assimilation and accommodation 'equilibrium'[87]. In Piaget's theory, motivation for learning is seen to come from within the person, rather than from an outside stimulus.

Constructivism is also based on Vygotsky's theory, but he promotes that it best happens through social interactions[84]. In essence, an individual can achieve a certain amount of understanding, but with others through social interaction can achieve more. This gap between what people can achieve on their own and what they can potentially achieve with the help of others is called the 'Zone of Proximal Development'[84, 88]. The 'Zone of Proximal Development'(ZPD) is also indicated by the discrepancy between a child's actual mental age and the levels he reaches in solving problems with assistance[89]. 'What a child can do with assistance today, she will be able to do by herself tomorrow'[88]. If the ZPD is not used to match student learning, instruction is oriented towards students' weaknesses rather than their strengths. The theory encourages teachers to plan curriculum that extends children's knowledge, and to scaffold their learning by putting them in situations where their competence is stretched.

The main difference between these two theorists is that Vygotsky's constructivist approach promotes the importance of social and cultural factors on learning, whereas Piaget is more concerned with the biological factors of the person, and how these affect learning[90]. However, both have had a major influence of the constructivist theory of learning. Constructivism has led to a few different learning theories, which have been developed since the 1930s. Table 1.7 shows where problem-based learning fits in with constructivism, along with other popular theories. Rosalind Driver[91], whose contribution to research and scholarship in science education spanned almost 30 years, advocates a contructivist pedagogy, which begins at the level of the individual learner, with student preconceptions. Students are encouraged to develop their models, step by step, alongside their experiences as described below:
'Experience by itself is not enough. It is the sense that students make of it that matters'.[92]

B. F. Skinner, a contemporary of Piaget, Vygotksy and Dewey, viewed education in a very different light. He is from the 'Behaviourist' school of thought. Earlier behaviourists include Ivan Pavlov and John B. Watson. They believed that all learning whether in lower animals or humans can be defined in purely mechanistic terms, with learning resulting in changes in behaviour. For example, Skinner's theory was based on the behaviours of pigeons and rats to various stimuli[93], resulting in the animals being trained toward certain behaviours. It is chiefly concerned with external stimulus and response connections, and in the case of Skinner, the power of reinforcement as a motivational factor. Therefore, learning can be controlled to produce a desired effect, i.e. good students do as they are told and conform to accepted norms. According to behaviourist theory, information exists as known facts, and knowledge is merely a collection of information. Behaviourist theory became popular in the 1900's.

Table 1.7: Constructivist-based learning theories[94]

Theory	Popular	Exponents
Humanist	1950s	Carl Rogers Abraham Maslow
Learners should be assisted to learn what they choose to learn		
Reflective Learning	1970s	David Kolb Jack Mezirow David Schon
Learning is not sequential it is cyclical and more knowledge can be created by constantly re-thinking about a learning experience		
Problem-based Learning	1980s	Stepien and Gallagher Barrows and Tamblyn
Knowledge is complex, contextual construct and learning occurs through a complex reiteration of finding, testing and applying information and knowledge to solve a problem		
Resource-based Learning	1990s	
Knowledge is a complex, contextual construct and learning occurs through developing strategies for seeking information resources with which to extend knowledge.		

Other learning theories include cognitivism, which was made popular by David Ausubel among others in the 1950s, which views learning as something that happens as a result of thinking and that learning is a process in which the student is actively engaged. Information is processed to create symbolic meaning. Learning is mainly based on the meaning that students associate with symbols. Symbols and meaning have to be organised in a retrievable manner for learning to have occurred. As with behaviourists, knowledge and information is still perceived as something that exists as fact external to the learner, however, behaviour change is not necessarily demonstrated as a result of learning. This is in sharp contrast to the constructivist theory, where knowledge is seen as something much deeper than facts and information. Another difference between the behaviourist and cognitivist theory and constructivism is that the former are more teacher oriented whereas the latter is more student centred.

Constructivism and Metacognition

Gijselaers[95] identifies three key factors that influence learning:

- Learning is a constructive and not a receptive process
- Knowing about knowing affects learning
- Social and contextual factors influence learning.

These three factors are encompassed under the umbrella of 'constructivism' where students create their own conceptual structures and assimilate and accommodate new experiences and learning into them[78] and 'metacognition' where the raising of students' awareness of 'learning how to learn' figures significantly in successful memorising, retention, recall and use of concepts[78].

To recap, constructivism is achieved by adapting and building on prior knowledge, skills and concepts, thus allowing the learner to seek meaning for themselves and not the meaning as constructed by their teacher. Social constructivism occurs through social interaction with peers, educators, family, society and culture as advocated by Vygotsky. One of the apparent reasons for the current popularity of constructivism, according to Entwistle and Smith[96], is that learning is in terms of the development of individual understanding rather than as the reproduction of a body of information or the acquisition of a repertoire of appropriate behaviours, such as in behaviourism.

'Criticisms of constructivism have concentrated on its almost exclusive focus on the construction of meaning, while omitting issues such as individual cognitive and motivational differences'[96]. Mooney[84] highlights a similar problem, where she comments that 'teachers think Piaget focused too much on thought processes and not enough on children's feelings and social relationships with teachers and peers'. It is also argued that the role of the teacher is largely ignored and that if students construct their own knowledge, how are they supposed to know they have learnt successfully. Also, Piaget's work has been criticised as scientific research, since he based his findings almost exclusively on his own children![84]

Metacognition is the process by which students monitor their own learning process and allocate their mental resources accordingly[97,98]. Reasons for the growing interest in metacognition over the past three decades relate not only to the anticipated improvement in learning outcomes, through interventions that aim at developing students' metacognition, but also to the broader rise in interest in cognitive theories of learning[99]. The construct of metacognition also has the potential to bridge the concerns of educators primarily concerned with critical thinking, and researchers preferring more concrete defined constructs, whose work is the development of skilled thinking.[100]

Metacognition refers to higher order thinking which involves active control over the cognitive processes engaged in learning. Activities such as planning how to approach a given learning task, monitoring comprehension, and evaluating progress toward the completion of a task are metacognitive in nature[101]. Case *et al.*[102] comment that 'enhanced metacognition is a learning outcome in itself, as well as having a critical impact on the achievement of content-based learning outcomes'. However, it is also recognised, as with promoting a deep approach to learning, metacognitive development is not easy to foster[102,103]. Students need to reflect on their motives and strategies, asking themselves:
What do I want out of this? And how do I propose going about getting there? Kuhn *et al.*[100] propose a similar form of 'self-questioning', and not questioning by lecturers or teachers in a formal didactic setting.

> 'One way of supporting metacognitive development is to encourage students to reflect on and evaluate their activities. Doing so should heighten interest in the purpose of these activities. Why are we doing this? What was gained from having done it? Questions such as these are less likely to arise when activity is imposed by authority figures without negotiation, and especially when the activities serve as occasions for evaluating students' standing relative to one another—a function that so often steals attention away from any other objective.'[100]

However, Hacker and Dunlosky[103] report two major concerns with this form of metacognitive questioning. Firstly, metacognitive probing may be effective only when students have acquired a sufficient amount of knowledge in the content area in which the problem solving is to occur. If students are only just beginning to acquire knowledge in a domain, they may not possess the necessary concepts or procedures for explaining their problem solving. Secondly, teachers must consider the difficulty of the tasks that students are to perform. Problem solving, verbally encoding the problem, and verbalizing ongoing mental activity can place overwhelming demands on a student. And when excessive demands are placed on memory, students' thinking may falter, which slows their progress toward the goal. Johnstone[83,104] reports that within working memory there is a constant trade-off between what has to be stored in the memory and the processing activities required to interpret it. If there is too much information to hold, there is not enough space for processing, conversely if a lot of processing is required, there is not enough space to store. A good indication that the task is too difficult, for example during problem-solving, is when a student becomes quiet for excessively long periods or requires numerous reminders to continue talking in group discussions.

Study skills programmes, it is reported, have limited success at enhancing metacognition and it is suggested that far greater success is achieved where it is integrated with the content matter that students are primarily involved in e.g. concept mapping, peer discussions, and an emphasis on qualitative reasoning for example in physics.[102] Another source of metacognitive development is the 'interiorization' that both Vygotksy and Piaget talked about, which occurs when forms that are originally social become hidden within the individual. If students participate in discussion for example where they are frequently asked, "How do you know?" or "What makes you say that?" they become more likely to pose such questions to themselves. Eventually, it is sugested, they will 'interiorize' the structure of argument as a framework for much of their own individual thinking.[100]

In the case of science education, research in metacognition is practically at its infancy[99]. Research available to date seems fragmented and lacking coherence, since it is scattered in the three areas of physics, chemistry and biology, and across an age range that usually extends to university students or science teachers, often overlooking primary school ages[99]. The familiar CASE project (Cognitive Acceleration through Science Education), however, was developed to investigate the possibility of raising general levels of thinking amongst average students aged 10-14 years[13] with metacognition being one of the main pillars of the intervention programme employed[99]. It was found that those students who had experienced the CASE methodology achieved significantly higher grades than students who had not experienced the CASE methodology, not only in science but also in mathematics and English language[13]. Also educational research shows that promoting metacognition in the science classroom prompts students to refine their ideas about scientific concepts and improves their problem-solving success[105].

'Close to the problem of sufficiently defining metacognition lies the difficulty of identifying and assessing students' metacognitive abilities or performance. This is a practical obstacle caused by the fact that metacognition is an inner awareness or process rather than an overt behaviour and because individuals themselves are often not aware of these processes'[99].

Meyer's Reflections of Learning Inventory (RoLI)[106] is one evaluation technique used to assess students' metacognition[97,107.] The inventory consists of 75 items, which form 15 subscales, and these are shown in Table 1.8.

One study[97] used the RoLI to help raise students' metalearning awareness, and aimed ultimately, to improve student retention. A second study[107] examined the use of the RoLI to help first year undergraduate students study. The research concluded that RoLI can be used for assisting in the diagnosis of study problems and that the inventory raised students awareness of their approach to study. Another study[102] used student interviews and journal entries to evaluate metacognitive development and a deep approach to learning in undergraduate students, with the study concluding that factors such as a heavy workload out of class, and time pressure in assessment as inhibiting metacognitive development, whereas time available in class for discussing and doing problems, unlimited time tests and journal tasks as all supporting a conceptual approach.

A previous study carried out by Webster[108] indicated that the ability of each individual to develop a personal learning resource and to reflect on the role of their metacognitive characteristics could be a useful instrument in the development of the autonomous life long learner. The evaluation techniques included 'Cognitive Styles Analysis', 'Approaches and Study Skills Inventory for Students', 'Myers-Briggs Type Inventory' and reflective journals.

The 'Cognitive Styles Analysis' was developed by Riding[109], and measures personal preferences for representing and processing information. The cognitive styles are described within two fundamental style dimensions, the Wholist-Analytic and the Verbal-Imagery. The dimensions may be summarised as follows:

1. The Wholist-Analytic dimension of whether an individual tends to organise information in wholes or parts.

2. The Verbal-Imagery dimension of whether an *individual is* inclined to represent information during thinking verbally or in mental pictures.

Table 1.8: Summary of RoLI subscales with examples[107]

SUBSCALE	EXAMPLE
Learning is fact-based	Learning means collecting all the facts that need to be remembered
Thinking independently	I know I have learned something when I can form counter arguments of my own
Memorising as rehearsal	I learn things that don't make sense to me by reading them over and over until I can remember them
Seeing things differently	I believe that learning involves seeing things from a new perspective
Memorising before understanding	I need to commit something to memory before I can make meaning out of it
Relating ideas	In learning new concepts or ideas I relate them as far as possible to what I already know
Knowledge discrete and factual	Knowledge really just consists of pieces of information
Memorising after understanding	I need to know the meaning of something before I can commit it to memory
Detail-related pathology	I have difficulty in fitting together facts and details to form an overall view of something
Rereading a text	When re-reading a text I add to the meaning of what I already know about it
Learning experienced as duty	When I am learning I feel as if I am fulfilling an obligation
Memorising with understanding	Knowing the meaning of something in effect organises it in my memory at the same time
Fragmentation	Much of what I have learned seems to consist of unrelated bits and pieces of information
Repetition aids understanding	Repetition helps me to remember things by creating a deeper impression
Learning by examples	My learning has developed as a result of emulating other people's examples

The 'Approaches and Study Skills Inventory for Students' (ASSIST) is used extensively in the research presented in this thesis, and is discussed at length in the next Chapter. However, a brief introduction will be given here. It is an inventory which describes students' predominant approach to learning and studying as either deep, strategic or surface and was developed by Noel Entwistle[110]. Each main scale is described by a number of subscales as shown below:

DEEP: seeking meaning; relating ideas; use of evidence; interest in ideas

STRATEGIC: organised study; time management; alertness to assessment demands; achieving; monitoring effectiveness

SURFACE: lack of purpose; unrelated memorising; syllabus boundness; fear of failure

Finally, the Myers-Briggs Type Inventory' is for classifying personality type and can be used to measure cognitive style. Myers[111] suggested 16 basic personality types which were created by the combinations of the elements of the four main scales:

- Extraversion (E) and Introversion (I)
- Sensing (S) and Intuition (N)
- Thinking (T) and Feeling (F)
- Judging (J) and Perceiving (P)

'The student comments and qualitative data suggest that knowledge of and reflection on the characteristics of individual cognitive profiles could also affect the design and content of individual learning environments, albeit in different ways. Several respondents questioned why they did not have access to this type of metacognitive information earlier in their school or university careers. They also suggested that they would have found the knowledge particularly useful for the transition to university life and the greater demands of independent learning'[108].

Features of a successful curriculum

Despite the approach to teaching and learning, there are certain aspects of any curriculum which are required for it to be successful[78]. These are coherence, continuity (progression), differentiation, breadth, balance and relevance among others. For example, in the Proposals for the Future Development of Senior Cycle Education in Ireland[112] it is recognised that the general aims of senior cycle education are to:

- Ensure coherent and meaningful continuity from the junior cycle of post-primary education and to allow progression to further education, the world of work and higher education
- Provide a curriculum characterised by breadth and balance, while allowing for some degree of specialisation
- Ensure improved access to, and equality in senior cycle education for all, within a context of lifelong learning
- Contribute to the emergence of Ireland as a knowledge society
- Educate for participative citizenship at local, national, European and global levels
- Contribute to the development of each individual's moral, social, cultural and economic life and enhance their quality of life
- Ensure that the highest standards of achievement are obtained by every person, appropriate to their ability.

Also Scotland's 'A Curriculum for Excellence'[113], which is a proposed curriculum for 3-18 years olds, puts forward the following as the Principles for Curriculum Design

- Challenges and Enjoyment
- Breadth
- Progression
- Depth
- Personalisation and Choice
- Coherence
- Relevance.

Coherence covers the fact that students can assimilate new concepts and ideas through the process of adapting old concepts and ideas. Continuity or progression looks more at the actual curriculum; where by there must be a definite continuance from day-to-day, week-to-week, year-to-year in the syllabus being taught. Both of these can clearly be promoted through a constructivist approach. In the former case, it would be the students who cause the subject matter and knowledge to cohere in the sense of being able to assimilate it and accommodate it to existing conceptual structures in his or her mind[78]. Therefore, though coherence can be planned, it might not occur unless it is communicated and facilitated in the student's conceptual framework – their Zone of

Proximal development[88]. Similarly, it is the student who ultimately establishes the continuity between existing knowledge, concepts, skills, ways of working, and teaching and learning styles[78]. Differentiation is matching work to individual abilities. Differentiating learning will need to take account of personality characteristics, social interactions, emotional development, potential for and willingness to study, their preferred modes and ways of working and learning, interests, self-concept, motivation and degree of self-government. This is a social constructivist view of differentiation[78].

Breadth, balance, and relevance are other factors, which should be addressed in all curricula as shown above. Breadth encompasses students' entitlement to a wide range of curriculum areas, and a wide range of contents within each curriculum area but also to breadth of teaching styles, and learning processes[78]. Balance addresses the need for 'appropriate attention being given to the areas of experience and the elements of learning – knowledge, concepts, skills and attitudes'[78]. Finally relevance means that students are entitled to a curriculum that serves both their present and future needs, advocating experiential, practical learning and problem solving and the need to relate experiences in education to the wider society[78].

Throughout the following chapter approaches which promote constructivism and metacognition, and/or which adhere closely to the factors which support a successful curriculum will be discussed.

1.3.2: TEACHING AND LEARNING APPROACHES

Group work, discovery learning, discussion, project work, enquiry, problem-solving, and hands-on approaches are just some of the different styles of teaching and learning which are used in alternative learning environments. These styles have one underlying core principle and that is that they are all student-oriented approaches to teaching, giving students control over how and in some cases, what they learn. The styles which are most relevant to this research, i.e. group work, discussion, inquiry-based learning, problem-solving, and experimental/hands-on work are discussed below, since these are all elements of the problem-based learning method described in Chapter 3 and 4.

<u>1.3.2.1: Group learning</u>

Learning can be a collaborative endeavour, and therefore science learning can also be collaborative. All science, especially research and development, depends on the ultimate sharing and debating of ideas. When carefully guided by teachers to ensure full participation by all, interactions among individuals and groups in the classroom can be very effective in deepening the understanding of scientific concepts[114]. Let's take a look at whole class instruction. This means that students are taught as a single, large group. In whole class instruction, there is often an emphasis on uniformity, rather than on diversity, of instruction. The emphasis is on teacher explanations and encouragement, rather than peer explanations and encouragement, to promote student learning. Also, the level of student participation can be low for a few and minimal for many[61].

Grouping is a way of organising students for teaching and learning. When using groups for instruction, context, content and the learner must all be looked at[61]. The context involves the physical, and socio-economical environment. The physical environment must lend itself to group work, for example with the groups in a place where each member can be easily supervised by the teacher. In terms of the socio-emotional environment, the teacher must maintain a cohesive environment by prohibiting certain behaviours, and encouraging others. The content aspect must match knowledge and understanding outcomes, allowing for peer interpretation and sharing of insights or experiences. Some purposes of group work are given in Figure 1.5.

Figure 1.5: Some purposes of group work[90]

<table>
<tr><th>INTELLECTUAL</th><th>PERSONAL</th></tr>
<tr><td>Cognitive understanding
Appreciating other perceptions
Changing conceptions
Questioning assumptions
Developing oral skills
Feedback to staff</td><td>Providing opportunities for practice in self-expression
Developing self-awareness
Encouraging commitment
Weakening defensive attitudes
Improving attitudes to the subject</td></tr>
<tr><th>SOCIAL</th><th>PRACTICAL</th></tr>
<tr><td>Encouraging co-operation and an awareness of others
Developing a sense of social identity
Developing a sense of belonging and community</td><td>Develop team work
Solve practical problems
Carry out specific tasks
Create...
Write...
Collect...</td></tr>
</table>

Factors, which define a group-learning environment, include:

- High or low level teacher dominance
- Large or small number of students
- High or low academic level of class
- Active or passive student participation
- Individual or co-operative effort
- Task/learning oriented or examination oriented
- Teacher directing or helping/facilitating.

In small group instruction, there is an emphasis on the diversity, rather than the uniformity, of instruction. The teacher may provide either a single or brief explanation to the class as a whole or give different instructions to each group. The teacher may either vary the assignment from group to group or give them all the same. In small-group instruction, peer helping is often encouraged to promote student learning[115]. Mueller *et al.* [116] report that students must learn how to work together toward a mutual goal. The idea of 'Your progress is necessary to mine' is encouraged with group learning, and if students are to achieve the educational values of respecting and understanding other persons and cultures, then the very process of collaborative learning needs to be promoted[117].

In terms of the learner, there will no doubt be a wide diversity of students. Therefore, there should also be a wide variety of roles for each member to play in the group. A variety of learner roles within a group are listed below: [61]

- Direction giver
- Summariser
- Generator
- Observer
- Record Keeper
- Evaluator
- Reader
- Time Keeper
- Encourager
- Resource person.

Lou *et al.*[115] suggest advantages of using small-group instruction:

- The emphasis on peer learning means that the teacher may have more time to provide help to those students who are struggling with the basics, and also, to develop further activities to those who have already mastered the assignment
- Within-class grouping means that teachers may have greater flexibility in adjusting the learning objectives and the pace of instruction to meet individual learning needs
- Students in small groups may rehearse material orally, explain it to others, discover solutions, debate, discuss content and procedural issues
- Students who learn together in small groups may be motivated by cooperative, as opposed to competitive, incentive structures
- Students may have the opportunities to develop social and communication skills because of the need and opportunity to work with others to learn.

The term cooperative learning is also used to describe a type of small group instruction[118]. Cooperative learning has its theoretical underpinnings in social constructivism; this encourages students to work together and to use a variety of activities to improve their understanding of subject matter and achieve academic objectives[119]. This point is also discussed by McManus[118]:

> 'The goal of cooperative learning is for students to help each other succeed academically. To be successful, all members in a group much achieve mastery of the material or contribute to the completion of a group assignment. It is believed to enhance cognitive skills to the extent that students share ideas and explain their thinking as they work together.'

According to constructivist theorists, positive peer interaction in cooperative groups such as cognitive elaboration, multiple perspective, and help giving and receiving may provide the learners with more opportunities to be engaged in active knowledge construction[115]. Remembering Johnstone's 10 Educational Commandments, the latter two were:

'There should be room to create, defend, try out and hypothesise'

'Students should have the opportunity to teach.'

Co-operative group learning lends itself for these principles to be carried out effectively since students can discuss their ideas with each other, and if conflict arises, they can defend their ideas and potentially teach each other to come to a group consensus.

Several goals of cooperative learning are listed below[115]:

For the student:

- To gain leadership responsibility
- To participate equally and actively in the group.

For the teacher:

- To develop the self-esteem of the student
- To encourage positive group interactions
- To foster academic cooperation among students.

The results of studies[115,118,119] showed a positive effect of small group instruction on student achievement. Social benefits were also attributed to group instruction. Lou *et al.*[115] report on the effects of within-class grouping on student achievement. The review included research, which had occurred within the class at elementary, secondary and postsecondary school level. The minimum group size was 2, the maximum 10. The results showed that in general students learned more in classes where small-group instruction was used than in classes where it was not used. It was also reported that the positive effects were more significant when further training was provided to the teachers using small-group instruction, such as changing their roles from 'knowledge dispensers' to 'learning facilitators', using appropriate instructional materials, and employing effective group-learning strategies. Grouping on the basis of ability as well as gender, and group cohesiveness, such as friendship, are suggested as means to increase the effectiveness of within-class grouping.

With respect to the second point, grouping on the basis of ability, Cooper *et al.*[120] report contrasting results. Research showed that homogeneous grouping can result in widening the gap in academic performance between high and low achievers. It is suggested that in addition to slower pacing with lower ability groups, teachers focus more on low-level objectives and routine procedures than they to with higher ability groups. Also, mixed ability teaching forces teachers to recognise the problems of having to stretch the brightest students and having to cater for the less able students, homogeneous grouping can result in negatively labelling students, and hence consigning them to failure. Cohen *et al.*[78] also comment that 'advocacy of homogeneous ability groups failed to recognise within-group differences and the well established evidence that motivation is a key determinant of effective learning and that social processes and dynamics can exert as great an influence on effective learning as academic similarity.' It is also reported that students of all abilities improved their skills of discussion, suggesting, concluding, testing, inferring, and reflecting when working in mixed ability groups and that they improved in terms of co-operation and independence.[121] Figure 1.6 gives advantages of mixed ability grouping.

Figure 1.6: Advantages of Mixed Ability Grouping[78]

There are fewer 'sink' groups
Different teaching styles are opened up
There is potentially less negative labelling of students
Teachers have contact with a wide range of students
Troublesome students are diluted through the groups
There is a wide social mix in groups
Students' self-esteem, and motivation are promoted
Equality of opportunity and outcome are furthered
Mutual respect, support, understanding and tolerance are developed between students
Teachers develop new teaching skills
Competition is replaced by co-operation
The errors of selection are avoided

Byers[122] described an intervention to promote active learning through small group laboratory classes in a second year module. The study was based on two environmental experiments (Examination of a Natural Water Sample and Heavy Metal analysis of Solid Samples), and prior to the laboratory class, students were required to discuss factors which might influence the parameters they were to measure, agree what samples each student would obtain and investigate and write a brief synopsis of their ideas. The students then collected the samples and did their analysis individually on their sample in the following laboratory class. A post-laboratory discussion then followed, where the groups' results were pooled and discussed. Individual and group reports were required. Evaluation of the intervention involved a student questionnaire and classroom observations. The results showed strong support for the two 'alternative' experiments, with 30% and 43% of the students naming the 'Examination of a Natural Water Sample' and 'Heavy Metal analysis of Solid Samples' experiments respectively as the most interesting experiments. Students generally found the experience improved their learning, their team-work and communication skills, with some students commenting on an increase in confidence.

Gupta[123] describes the use of co-operative learning in a physical sciences course. Groups of four to five students worked together in tutorial and practical sessions. Mid-term and practical examinations were abolished and 40% of total marks were allocated to the cooperative learning activities. A peer- and self-assessment system was successfully adapted to account for individual performance in cooperative learning group assignments. The results suggested that cooperative learning was very well received by students, and they expressed willingness to join cooperative learning groups in other courses. In addition, cooperative learning offered many benefits to students in terms of graduate attributes such as teamwork, communication, lifelong learning and problem-solving.

In conclusion, through group learning, individuals can pursue their own learning needs within the context of the group, referring to others for support, feedback, and validation. Much learning occurs from interactions between group members, with an emphasis on democratic decision-making and considerations for different points of view[124]. The main aim of small-group cooperative learning should be to maximise each student's opportunity to reach the same common goal. As highlighted however, there is conflicting evidence as to the best form of grouping, with some promoting same ability or homogeneous grouping and others reporting heterogeneous, or mixed ability grouping.

1.3.2.2: Discovery-Based Learning

During the past few decades, many science teachers and educators have proposed inquiry teaching to enhance learning in science, which has roots in constructivism. Inquiry teaching techniques generally involve students gathering information, collecting and interpreting data, formulating hypotheses and drawing logical conclusions[115]. Students have significant input into most aspects of their learning – how their classroom is set-up, how time is structured, which resources are used, which topics are explored, how investigations will proceed, and how findings are reported. In this mode, teachers are not the sole purveyors of knowledge, and students' passive receptacles[125] and students build their scientific understanding and investigative skills through active inquiry – connecting their previous knowledge with new ideas and evidence[126]. The science projects promoted in the 1960s and 1970s by the Nuffield Foundation in the UK were the first real vehicles for 'discovery learning in science'. The teaching approach promoted by the Nuffield Foundation 'starts where the children are', building on the ideas children bring with them to their lessons and helping them to develop their understanding of scientific concepts[127].

Inquiry-based learning

In the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students develop an understanding of the natural world when they are actively engaged in scientific inquiry – alone and with others.[114] Investigative work has enormous benefits. Students have autonomy over their work, they must use research, solve problems and if necessary, set out in new directions and in the end, try to make sense of their results. They develop practical skills, attitudes of resourcefulness, perseverance, and enterprise[128].

Educators focus inquiry dominantly on real phenomena, in classrooms, outdoors, or in laboratory settings where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities[114]. In contrast to 'cookbook' labs, inquiry labs follow a data-to-concepts approach where students are expected to identify and explain the data collected[69].

Figure 1.7 shows different types of science inquiry. At one end of the scale, there is structured inquiry. It involves students engaging in hands-on activities from which conclusions are drawn. However, teacher generated instructions are followed precisely by the student. Guided inquiry is where students may assume responsibility for determining the procedure for the investigation, but the teacher chooses the question to be investigated. Finally, student-initiated inquiry, involves the students generating their own questions from the topics selected by the teacher, and designing their own investigations. Given choice and freedom in a thematic unit, students actively engage in content, language activities, social learning and academic interaction[61].

Figure 1.7: Types of science inquiry[129].

Students engaged in student-initiated inquiry are doing the following:[125]

- Learning in a rich environment
- Thinking of a question, and shaping it into something they can investigate
- Hypothesising
- Planning an investigation
- Collecting data
- Analysing the data
- Forming a conclusion
- Communicating their findings.

Inquiry-based projects in primary school science provide a context, which may help children to understand the processes of science by actually doing them. They encourage children to work together, to share ideas, to challenge one another and to develop a critical awareness. They may also encourage a degree of independence from the teacher and so begin the process of independent learning and judgement.[78]

For the teachers of inquiry-based instruction to be successful, a number of skills are required. They must be skilled observers of students, as well as knowledgeable about science and how it is learned. The teachers must match their actions to the particular needs of the students, deciding when and how to guide –

> 'when to demand more rigorous grappling by the students, when to provide information and particular tools, and when to connect students with other sources.'[114]

They must also constantly make decisions. For example, the teacher must decide when to change the direction or focus of a discussion, or how to use an opportunity to model scientific skills and attitudes. Jarrett [125] describes how a teacher might progress toward full inquiry. (See Figure 1.8); Initial inquiry starts with laboratory activities solely experienced through books etc. with the gradual move to student initiated inquiry, where students answer questions of their own through open-ended practical activities.

Figure 1.8: Summary of Steps towards Full Inquiry[125]

Activities focus on textbooks, library, reports and worksheets

Demonstrations are done for students

Students conduct "cookbook experiments" (student replications, not discoveries)

Students do laboratory activities that lead to student discoveries

Students answer questions generated by the teacher from open-ended laboratory activities

Students answer questions of their own from open-ended laboratory activities

Examples of inquiry in science

Many studies have been carried out on the use of inquiry-based instruction, and findings from some of the studies will be discussed here[119,70,130,131,132] Von Secker[130] reports on the effects of a student-centred inquiry based model on science excellence and equity; excellence being the achievement of all students, and equity, achievement among students with different demographic profiles. Five practices were put forward as combining toward an inquiry approach:

- Eliciting student interest and engagement
- Using appropriate laboratory techniques
- Problem solving
- Conducting further study
- Scientific writing.

Results show that the inquiry model was associated with higher science achievement of all students. The average science achievement of all students increased when the teachers placed the emphasis on the five practices mentioned above. However, the findings did not support the argument claiming that differences in the way students are taught will result in more equitable achievement among the more or less advantaged students[130], reporting that inquiry-based teaching is sensitive to social context differences, and could result in widening the gap between groups of students and simultaneously narrowing the gap within groups.

Chang *et al.*[119] report on a similar investigation – comparing student outcomes with inquiry-group versus traditional instruction for junior high school students in Taiwan. This study involved 612 ninth-grade students attending 16 earth science classes. They investigated this in terms of student learning and student attitudes towards the subject matter. To measure student achievement in earth science content, an earth science achievement test was constructed, which had three underlying assessment areas: knowledge, comprehension and application. The achievement test included 5 items at the knowledge level, 16 items at the comprehension level and 5 at the application level. Results showed significantly higher achievement overall in terms of academic achievement for the experimental group compared to the traditional students. However, on analysis of the three areas it was revealed that the significant difference was due to achievement in terms of knowledge, but not in terms of the higher order cognitive skills comprehension or application. In terms of attitude, there was an overall significantly higher score for attitude for the experimental group. Within this the study focussed on three areas: involvement, confidence and learning interest. There was a significant difference for involvement and confidence in favour of the experimental group but not learning interest. Overall, in this study, inquiry group instruction was seen to be superior in promoting student achievement and attitudes. However, the study did not increase students' comprehension or application of knowledge which would suggest that this approach is not effective at supporting a deep understanding of science.

Marx *et al.*[132] in 2004 report on an inquiry based approach to learning science in 6^{th}, 7^{th} and 8^{th} grade classes in Detroit, USA. 14 schools were involved over a three-year period, with four curriculum projects being evaluated; one for 6^{th} grade, two for 7^{th} grade and one for 8^{th} grade. The projects lasted 8-10 weeks and were designed to 'engage students in inquiry-based learning activities supported by embedded learning technologies'. The intervention was evaluated using pre- and post-tests, with a mix of low, medium and high cognitive level questions. Results showed that significant gains were made at all cognitive levels for each cohort over the three-year period, except in the first year for the low level questions in the 6^{th} grade project.

Finally, Hutchison *et al.*[70] report on an inquiry model for 1st and 2nd year undergraduates in the Department of Chemistry, University of Kentucky. This work stemmed from the growing consensus among chemical educators on the need to expose undergraduate students to the scientific research process early[133,134]. The inquiry model involved 1st or 2nd undergraduate chemistry student undertaking a research project. The students were paired with a graduate student who was familiar with the project and who oversaw the research. The student developed suitable techniques and experiments, and carried out the laboratory work under the supervision of the postgraduate student. The postgraduate was responsible for teaching the undergraduate student the skills required for the work they were doing, and giving assistance as needed. The overall benefits for the students are listed below:

- Peer recognition
- Knowledge of how a research lab functions
- New appreciation of the importance of laboratory safety, and waste disposal
- Providing the students with a clearer understanding of what they were studying in class
- Tackling real world problems
- Through inquiry
    - Learning how to set a realistic research goal
    - Planning how to get to the goal
    - Searching literature for precedent and procedures
    - Modifying them to suit particular needs.

Both thinking skills, and conceptual understanding are put forward as benefits of inquiry[69]. Wallace and Kang[135] investigated secondary science teachers' beliefs about inquiry, and while it was a very limited study with only 6 teachers being questioned, it revealed two benefits of inquiry in science similar to those mentioned earlier. One set of teachers believed that inquiry could foster independent thinking, deep thinking, and problem solving, where as the others felt that 'conceptual understanding', 'scientific thinking' and 'stimulating creativity' were benefits of inquiry. However, there was a general consensus that certain factors such as the students themselves 'being too lazy and immature', efficiency, and exam preparation, can override inquiry implementation. Marx *et al.*[132] put forward another complication with inquiry, that is that 'learning can be even more daunting, especially when there are discontinuities in scientific and cultural ways of knowing'.

It is clear from these examples that inquiry based instruction has many benefits, and can be even more beneficial with a student-initiated inquiry method. In terms of the actual running of a full student-initiated inquiry for a large number of students however, there would be obvious problems. For example, lack of faculty experience and know-how to create the materials and inexperienced teaching assistants are put forward as potential barriers to implementation of inquiry[69]. Also, in a chemistry laboratory, maintaining safety at all times and provision of apparatus and chemicals would be a big issue. For large numbers, a structured or guided inquiry method would be easier to manage and control, and this is probably why many undergraduate and school practical laboratory sessions are done this way.

Problem solving

Problem solving sounds as if it would directly enhance problem solving skills and actively engage the learner, however this is often not the case. Unfortunately, the type of problem solving often seen in classrooms is where the focus is upon giving students a lecture or an article to read and then a set of questions based upon the information given. The students expect to find the solutions to these questions in the information supplied directly by the teacher, and invariably do, and therefore the solutions are bounded by the content and students are expected to explore little extra material other than that provided[136]. However, this type of problem solving is often merely solving exercises, which give no experience of 'what we do when we don't know what to do'[140]. Childs[72] reports on the lack of 'a problem' in typical problem solving questions:

> 'The problems in exams are not problems at all - they are usually algorithmic exercises, putting numbers into formulae and working them out. Practice enough and they present 'no problem'. They are just exercises in the recall of the standard method.'

However, it is widely used as an instructional tool[137,138,139]. In most cases, the data required is given, the methodology is either familiar or unfamiliar and the goal is clear[140]. Here follows examples of where problem solving of this type is promoted for chemistry in the literature:

- For quantitative numerical problems [137]
- In balancing chemical equations [138]
- In calculating the answers to chemistry problems using 'George' - a computer-based program[139]

1.3.2.3: Questioning/Discussion

Questioning as form of teaching

Science teachers, it is suggested, should encourage their students to use questioning for many reasons[78], such as to support active, student-centred learning, facilitate inquiry-based learning, help students to construct knowledge and develop problem-solving skills, and improve long-term retention of knowledge. As well as teacher-led questioning, students should question themselves and each other in a critical manner, appreciate that different kinds of questions can be answered in different ways, appreciate that not every question has a correct answer, and develop a range of strategies to deal with different questions. In terms of the scientific method, students should be able to generate a range of scientific questions, support answers to questions using data from investigations or other sources, and question the validity of their own and other data.

Wimer *et al.*[141] report that higher order questioning is a powerful learning tool as it encourages the students to think critically. A question that requires a student to think more elaborately is considered 'higher' than a question in which the student simply replies on factual knowledge[142]. It is also suggested that students would benefit more if they created and answered their own higher order questions and if the teacher acted as a guide by facilitating the creation of these questions[142].

Marbach-Ad & Sokolove[143] investigated if undergraduate biology students can learn to ask higher-level questions. Two comparable populations were examined, both undergraduates in an introductory biology class but taught in different formats – one in a traditional lecture style and the other in a cooperative/active learning style. Results showed that more students in the active learning group were able to pose better, written questions, with their questions becoming more insightful, thoughtful, and content-related and were not easily answered by consulting a textbook or another readily available source. In contrast, the quality of student-posed questions in the traditional group was largely unchanged.

Discussion as a form of teaching

Discussion can be defined in a broad sense as a wide range of informal situations where talk between people occurs. More specifically, it refers to a particular form of a group interaction where members join together to address a question of common concern, exchanging different points of view in an attempt to reach a better understanding of the issue.[144] Discussions usually begin with the teacher giving the students a question to discuss and then the students exchange ideas, explain and elaborate on their views, question and respond to each other and jointly derive an answer. The questions should be open-ended and should require higher-level cognitive reasoning to answer. The goal should be to get students to think critically and creatively, and questions should be presented to meet these demands.[144]

Learning environments that involve teacher–student and/or student–student dialogue are known to develop critical thinking and deep conceptual understanding in students. However, the growth of mass higher education, with increased numbers of students per class, makes it difficult for the teacher to implement methods centred on dialogue and discussion.[145] Two peer-discussion methods are evaluated in the research conducted by Nicol and Boyle.[145] These two teaching methods, referred to as 'PERG' and 'Mazur', though centred on peer discussion, have two different sequences, as outlined in Figure 1.9. These methods were both used during the first semester of a year-long engineering mechanics course for first years undergraduates. They were evaluated using semi-structured interviews, and a 36-statement survey based on results from the interviews. Overall, the results showed that the teaching methods used in the course helped the students improve their understanding of concepts compared to conventional lecture classes.

Figure 1.9: The sequence of activities for peer instruction and class-wide discussion[145]

Peer instruction: Mazur sequence	Class-wide discussion: PERG sequence
1. Concept question posed	1. Concept question posed
2. *Individual Thinking:* students given time to think individually (1-2 minutes)	2. *Peer Discussion:* small groups discuss the concept question (3-5 minutes)
3. Students provide individual responses	3. Students provide individual or group responses
4. Students receive feedback – poll of responses presented as histogram display	4. Students receive feedback – poll of responses presented as histogram display
5. *Peer Discussion:* students instructed to convince their neighbours that they have the right answer	5. *Class-wide Discussion:* students explain their answers and listen to the explanations of others (facilitated by tutor)
6. Retesting of same concept	6. Lecturer summarises and explains 'correct' responses
7. Students provide individual responses (revised answer	
8. Students receive feedback – poll or responses presented as histogram display	
9. Lecturer summarises and explains 'correct' answer	

With respect to the in-class discussion, in the interviews all students reported that dialogue with other students in peer groups was central to the development of their understanding of concepts and ideas.

> 'Peer discussion provided opportunities to think about the problem in more detail, to explore alternative viewpoints and problem-solving approaches, and to ask for and hear different explanations...Some students also noted that it was easier to admit lack of understanding of a concept to peers rather than to the teacher and this opened up the opportunity for discussion.'[145]

Students also maintained that peer explanations were often more accessible than teacher explanations. This was supported by Linn[146], who comments 'Discussions can expand the repertoire of ideas held by students – sometimes hearing an idea in the words of a peer makes it accessible for the first time. Often, hearing ideas more than once strengthens their allure.'

In terms of the whole-class discussion, some students maintained that knowing that one might be called upon to explain the thinking behind a response encouraged them to formulate explanations in advance and that this increased attention levels during the class. The effectiveness of class-wide discussion, according to these students, depended on which students were selected by the teacher. However, it was also reported that different students answers sometimes led to confusion and therefore it was of most importance that the teacher clearly explained which was the right answer and why after a class discussion.

Though discussion is mostly thought of as interaction with people face-to-face, discussion boards via the internet now provide a new platform. Linn[146] suggests that class discussions may support less reflection than electronic discussions because on-line discussions give students a chance to think before they respond, while class discussions often move on and leave the more reflective students behind.

> 'Well-designed discussions and collaborations can also contribute to the deliberate aspect of knowledge integration by sustaining thinking about a topic. When asked to explain an idea, students get the opportunity to generate connections among their views, to compare their ideas with those of others, and

to re-visit ideas. For all of these reasons, innovators seek to use technology to support collaboration and discussion'[146].

A study by Bahar[144] reports on the use of oral presentations followed by class discussions in an environmental course. In an effort to investigate different motivational styles and preference for discussion, it found that of four motivational types, 'Socials' had a higher preference for discussion than 'Achievers', however, overall all types showed a high liking for discussion based activity. The four motivational types are described below.

Achievers have a distinct preference for an expository method of teaching to enable themselves to achieve well. They compete to be top and get pleasure from excelling.
Conscientious students want to be told exactly what to do and enjoy clearly stated objectives.
Curious students keep asking why. They have a distinct preference for discovery learning and problem solving activities.
Social students enjoy their opinions being heard. They conform easily and like working in groups. They like studying and discussing problems with their friends.

These studies confirm that students can gain significant understanding and enjoyment from discussions in small/large groups, as well as develop confidence and communication skills provided appropriate guidance and facilitation is given.

1.3.2.4: Practical work

'Laboratory work and other forms of practical work have gained wide, but not universal acceptance as one of the most important and essential elements in the teaching and learning of science'[147]

It is typical of science courses to combine lecture modules with laboratory classes. This is the case both at second level and third level. But what is the purpose of laboratory work? Various aims and outcomes of laboratory work have been reported[148,149] but the most common ones are outlined below[147,150]:

- Manipulative skills

- Observational skills
- The ability to interpret experimental data
- The ability to plan experiments.

Bennett[150] observes two key limitations to laboratory work. The first is that there is a lack of active participation in experimental design and the second is that the time available for developing manipulative skills is not always well used. The first has been addressed to some extent already in this section, with the discussion on student-initiated inquiry and it is obvious that this certainly promotes students engagement with experimental design. However, there are other changes which can be introduced to laboratory classes which can greatly enhance the overall experience, for example the use of dataloggers and microscale techniques. The advantages of data-loggers in science will now be discussed, which include giving students more time to engage with their results since the task of manually collecting data and drawing graphs is done for the students. A discussion on the use of microscale techniques follows as another approach to enhance student engagement with laboratory work. Microscale also addresses some of the issues with practical work in laboratories, such as safety concerns, resource problems, and time constraints among others.

Data-loggers

Datalogging is the collecting and storage of information. Traditionally, data from science practical experiments were collected by hand, and graphs and charts were produced manually. By the 1980's, software tools were developed to do these tasks electronically[151]. This gives students more time to engage with their data and the whole experimental process.

Advantages of data logging in teaching are listed below: [152] [153]

- The speed of capture and plotting of graphical data
- Wide-range of inter-sample times available
- Expanded range of opportunities for students to obtain data that relates to everyday life
- Opportunities to replicate the experiment frequently and quickly
- Reduction of the tedium of data production and manipulation by pupils
- Easy identification of shape of graph
- Real-time graphing, resulting in immediate feedback
- Pairing of real-time events with their symbolic representations

- Providing scientific experiences similar to those of scientists in actual practice
- Encouraging collaboration and group interaction
- Added opportunities for learning, investigation and analysis
- Increased accuracy and error analysis.

Data loggers have been found to have a positive effect on the development of scientific enquiry skills. It also promotes discussion among the pupils. Research carried out by Walshe[153] investigated how the use of hand-held datalogging in science affects the teaching and learning of Junior Certificate Science. A total of 44 students took part in the research over a period of four years. One third of these students used hand-held datalogging technology to facilitate a constructivist teaching and learning approach to science. The remaining two-thirds were taught in a traditional manner. The results showed that students taught using an investigative approach with datalogging retained the science learned at Junior Certificate level better, were better at analysing and interpreting graphs and had increased scientific process skills.

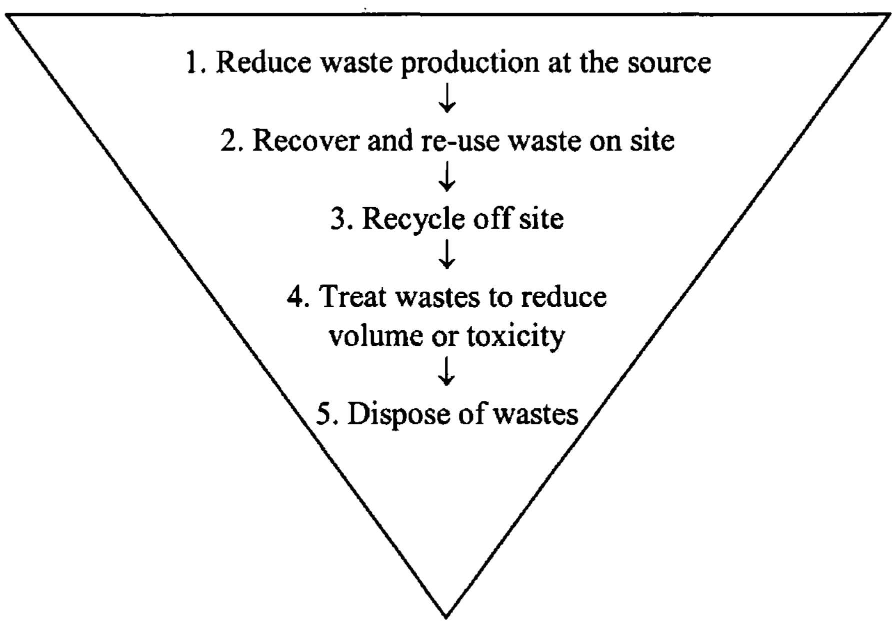
Microscale chemistry

Microscale chemistry is chemistry carried out on a reduced scale using small quantities of chemicals and often, but not always, simple equipment[154]. Small-scale and microscale are used to refer to a similar scale of chemistry; with the US tending to use small-scale, especially for reduced scale at secondary level, and microscale used to describe reduced scale organic experiments done in specialised glassware[154]. Microscale chemistry is recognised as small-scale chemistry by the International Union of Pure and Applied Chemistry[155].

Reduction of waste production at the source was the initial driving force that led to the concept of 'microscale' chemistry. Reducing the amounts of potentially hazardous solvent vapours in the lab, for example, could be done in two ways, i.e. improving the ventilation through a major building operation or reducing the amount of solvent[156]. The obvious financial preference was to reduce the amount of solvent by scaling down the experiments. Skinner[154] and the National Microscale Chemistry Centre[155] also quote the reduction of the use of hazardous reagents, and the ease of disposal of waste products as the motivations behind their interest in microscale chemistry. This conversion started in earnest about 20 years ago[157].

Figure 1.10 shows the 5 steps to the best practice in waste management, with step 1 being the most desirable[158], i.e.reducing waste at the source. This is similar to the 3 R's concept, of Recycle, Recover, Reuse, promoted by many chemical institutes[159,160]. Pollution prevention means not generating waste by reducing it at the source, and this is the most desirable action in the Waste Management Hierarchy and the initial driving force behind microscaling efforts.

Figure 1.10: The 5 steps in the Waste Management Hierarchy[158]



There are other motivations behind the global move towards microscale chemistry. Ciardullo[161] says it results from a number of rising demands which many teachers of high school chemistry face. The increasing cost of laboratory equipment and chemicals, coupled often with a strained financial budget means teachers are sometimes unable to adequately provide for the students. Also, since many schools do not have laboratory technicians, particularly in an Irish context, a great proportion of the teachers' time is taken up preparing and cleaning-up the laboratory. Finally, some of the experiments often take longer than the prescribed laboratory time, which leads to students not completing the laboratory, and with a certain feeling of frustration, which the teacher is left to deal with. Breuer[156] adds that the increasing application of safety legislation to educational establishments, coupled with the desire for more hands-on experience, and, if possible, enhancing the students' interest in chemistry has promoted microscale chemistry. In 2000, Brooks [162] stated that 'microscaling is currently in a period of both high development and sorting out', the development stage resulting from teachers inventing new ways to perform experiments, and, in a few cases, trying experiments that were inappropriate for academic laboratories when run at a larger scale.

There are many advantages to microscale chemistry apart from the benefits of reduced waste and improved environmental protection. A few authors cite increased laboratory safety when using microscale, due to a variety of reasons[154,156,160,163]. These include less clutter on the benches, better laboratory air quality, no spills or accidents, and less exposure to toxic chemicals. For example, on a normal scale organic synthesis various heating methods are used, and these can, and have resulted in small fires. On a microscale, a sand bath is the preferred method for heating organic reactions, and this is much safer. The use of the sand bath will be further discussed later. The time factor is a major benefit; references to time include less laboratory preparation time, quicker experiments, and less clean-up time.[154,156,160,164] Kelkar[164] reports that 'a tug-of-war has always been part of many chemistry academic institutions to balance the budget of running practical course and yet maintaining the high standards of training expected'. Since the economy is always the winner, the number of experiments and the chemicals used therein, has been the losers! Microscale is promoted as a money saving way to teach experimental chemistry, and also a very economical way. A factor in this is that a large portion of the microscale equipment can be plastic and therefore breakages are less likely and the apparatus cheaper to replace[154,156,160]. Breuer[156] comments that the amounts of chemicals that were previously used by one student, will now supply an entire class for a whole year and that more costly/exotic reactions and reagents can be introduced because large amounts are not needed. Kelkar *et al.*[164] state that if the microscale experiments were introduced into their university, the existing stock of all the chemicals would be adequate for at least 5 years.

Mayo[157] comments that the microscale techniques that his students will learn will allow them to gain more hands-on organic chemistry experience than many of their predecessors. This highlights the educational advantage to students. Even from the days of alchemists, it was anticipated that every chemical concept and physical property should be validated by experiments[163]. Using microscale techniques students can do more numerous and more varied experiments[156].

Microscale experiments require students to rethink their approach to experimental techniques and encourage increased accuracy and skill in carrying out procedures[154].

Singh further discusses this saying microscale chemistry changes the way a chemist thinks and works. It fosters growth of a future chemist who is prepared to keep the environment safe and healthy[160]. Working on this scale implements excellent laboratory manipulative techniques, leaving no margin for error so students practice accuracy and precision when doing their experiments[159].

Microscale not only provides an easier option for the provision of practical work in school labs, it simultaneously allows the students to actively engage with the experiment. Microscale takes away the problematic aspects of carrying out experiments, such as safety, resources, time etc, and instead allows students to focus on the chemistry. It is reported[165] that by using microscale techniques students can get more actively involved in their learning since beyond their reduction in experiment size, microscale techniques uniquely engage students in hands-on learning experiences and allow them to share the responsibility for their own learning. Microscale techniques foster creative, inquiry-based problem solving abilities. Another obvious benefit of microscale chemistry is that, instead of watching the teacher carry out experiments, students can do them themselves and so get more out of it. Overall, it is anticipated that microscale would lend itself to real inquiry based learning in the laboratory, because of reduced demand on resources, both chemicals and apparatus, as well as increased safety, students can be given more freedom to take control of the whole experimental process.

Many of the educators who promote the use of microscale however, also realise that normal scale experiments must be performed to learn the techniques.[160,163,166] It is important that students going out to work would be familiar with both scales of experimentation. Microscale is particularly useful, for example, in the area of R&D, but it would be important to be familiar with and comfortable using the larger scale apparatus too.

Experiences in Microscale Chemistry

Pagni [167], in 2003, commented that 'the undergraduate organic chemistry laboratory course has changed significantly since I took it more than four decades ago. Reactions unknown then are frequently run today. The use of standard taper glassware is the norm. Options for running reactions at full, small, and microscale are available.' Microscale has become so popular, especially in the US, that a lot of science teachers meetings now have workshops on the subject and many education publications, such as the Journal of Chemistry Education, feature regular columns on microscale science.[168] Across the US, more than 2000 colleges and universities have adopted at least some form of microscale[169].

In Lancaster, Breuer[156] introduced microscale in the 2nd year undergraduate organic course, and due to its success has now introduced it to 1st years. He reported that the students adapted to it very well and were as successful on the microscale as on the normal scale. A survey was carried out and highly favourable results were found. For example, 'Did you enjoy it?' and, on a scale of 1 to 5, the answer was an average of 3.96. 6th class students from the local schools also got a chance to try out microscale experimentation. It was reported that the students had no difficulty doing the experiments, and generally enjoyed the experience. The more time the individual students spent on the experiments, the more they liked them[156]. Mayo[157] reports that the majority of students who went through the microscale program during its development found the Microscale Organic Laboratory to be a 'surprisingly pleasant adventure'.

Beginning in 1989, the University of Michigan's Department of Chemistry began implementing microscale chemistry techniques. A costing was carried out between the normal scale and microscale for chemicals required for an Aldol Condensation experiment. The amount and cost per person for each chemical required was calculated for both traditional and microscale[170]. The financial benefit of reducing to a microscale level was obvious since the cost per student to do the experiment on a microscale is only ~4.4% of the traditional cost a decrease from \$5.21 to \$0.23 per student.

To summarise, microscale has been shown to have many advantages, especially for the school budget, the teacher and most importantly the students. In terms of cost benefits, the fact that less chemicals are used means chemicals will go a lot further, secondly, the cost of waste disposal will be reduced as waste will be minimised and finally some of the apparatus used is plastic, which means less breakages, and is generally cheap to buy. The issue of safety in the laboratory is of huge concern, and microscale is well documented as a safe method for carrying out experiments. For the teacher, less time will be needed to prepare and clean-up the lab, and in many cases, the actual practical time is reduced too. Finally, there are many educational advantages for the students. Microscale allows for more numerous and varied experiments, it encourages the students to rethink their approach and to increase their accuracy and precision. Lastly, they develop excellent laboratory manipulative techniques. In conclusion, the time spent in the microscale laboratory, is time well spent, coupled with student-initiated inquiry the learning potential would be greatly increased for the students.

1.3.3: ASSESSMENT

Assessment has already been discussed in terms of the traditional closed book, limited time written examination and though advantages were noted for, it was also clear that it had disadvantages. When it comes to designing an examination, test items should be easy to construct, to answer and to mark, which is probably why questions, which have a definite right or wrong answer, often appear on exam papers[171]. Generally speaking neither understanding nor analytical ability is required of the respondent. Examinations are also restricted in their form, content, and duration, therefore selection of certain topics within a subject is often a necessary evil for the students, who have a large volume of material to cover[172]. To them it seems unnecessary to understand more than what is demanded in exams.

Ramsden[9] expresses attitudes of students towards assessment:

> 'Where students feel the assessment situation is threatening, they are more likely to adopt a mechanical, rote-learning approach to the learning task. Students often explain a surface approach or negative attitudes in terms of their experiences of excessive workloads or inappropriate forms of assessment'.

The word 'assessment' is commonly equated with testing, grading, and providing feedback to students on their academic achievement, which is known as summative assessment[90]. Assessment data also provides information for communicating about students' progress with individual students, parents, other teachers, and administrators[114]. As well as this however, assessment can be used to enhance learning and this type of assessment is often called 'formative' assessment[90]. An example is the use of concept maps. A concept map is a diagram of nodes, each containing concept labels, which are linked together with directional lines, also labelled. The concept nodes are arranged in hierarchical levels that move from general to specific concepts. Teachers can also use formative assessment to enhance learning by reflecting on the teaching and learning process by reflecting on the experience of the students. Other types of formative assessment include[173]:

- Questioning
- Feedback through marking
- Peer and self-assessment by students
- Formative use of summative assessments.

There are many other types of assessment, here are some examples of the less traditional[74]:

- Portfolios
- Poster displays and exhibitions
- Presentations
- Reviews and annotated bibliographies
- Student projects.

Despite the variety of assessment techniques, written examinations are still widely used, especially in chemistry departments[71]. Bennett[71] reports on an investigation into the type of questions appearing on typical closed-book time-limited written examinations in chemistry. A total of 88 first year university chemistry-based examination papers were analysed (papers from 58 UK, 13 USA and 4 Australian universities). All the questions in each paper were examined and classified as Problem Type 1 to 8, according to Johnstone's[174] categorisation of problem types, with the problems becoming more 'problem-like' the further away from 1. Table 1.9 shows the categorisation of problems from all the examination papers.

Table 1.9: Categorisation of problem in examination papers[71]

TYPE	NUMBER OF QUESTIONS ANALYSED	PERCENTAGE
1	409	94.7
2	13	3.01
3	9	2.10
4	0	0.00
5	1	0.20
6	0	0.00
7	0	0.00
8	0	0.00

It is quite clear that the predominant style is type 1 representing 95% of the examination questions. This type of question can be described as requiring reproduction of information or involving a calculation, which is often replicated year after year, with only change in the numerical data in the question. This type of question is similar to the 'problem-solving' type described in an earlier section.

As well as written examinations in chemistry, assessment of laboratory modules are often based on students' notebooks or laboratory reports. Ruiz-Primo *et al.*[175] report on the use of notebooks in 5th grade science as a means for obtaining information about students' learning and their opportunities to learn. The results suggested that students' notebooks were reliably scored across examiners, also that high and positive correlations with other performance assessment scores indicated that the student performance score in their notebook assignments could be considered as an achievement indicator.

Although commitment to the subject area, and hence enthusiasm, on the teacher's part has a part to play in positive attitude and hence approach to student learning[9], student perceptions of the way marks are awarded are probably more influential on approach to learning than any other aspect of the teaching and learning experience[9,176]. It is reported that different types of assessment seem to encourage either a deep approach. Provided that the questions demand a demonstration of personal understanding, essay questions and problems are described as promoting and encouraging a deep approach[177]. In contrast, when factual tests are anticipated, even the best students will shift from a deep to a surface approach[176]. Does this suggest that the predominant type of assessment in chemistry departments is promoting a rote-learning approach?

Computer aided assessment is now popular in science. Byron & MacDonald[178] carried out a study to determine the effect of computer-aided formative assessment on students' achievement. A test bank of exam questions was written for dental students enrolled in two different biomedical science courses. Half the questions were arbitrarily assigned to an electronic test site; the other half were used as a written summative classroom exam taken later. Students who took the online formative exam in the first semester course scored 8.8% higher on the summative exam than did those who did not take the practice exam. A similar result was found when the study was repeated in the second semester.

Under these experimental circumstances, providing formative online exams appeared to promote student performance as reflected by higher scores on the summative exams.

How can assessment be modified? [73]

- Peer and self assessment so as to get students involved
- Reducing quantity of assessment
- Increasing quality of assessment
- Increasing diversity of assessment so as to avoid students being repeatedly discriminated against by the same old traditional formats
- Training students to better demonstrate their achievement of the intended learning outcomes.

Let's take a closer look at peer- and self- assessment. Students in their own right are already doing peer assessment by asking each other 'How am I doing' during a practical or tutorial class. Also, by using peer and self assessment, students are getting more involved with their own assessment, and this would give them a sense of ownership, and it is reported, this leads to a deeper learning by the students[74]. Peer assessment allows students to learn from each other – both in terms of success and weakness. For the teacher, involving students in the assessment process, rather than diminishing the responsibility of the teacher actually increases it. The teachers are required to help students develop skills in self-reflection by building a learning environment where students review each others work, offer suggestions and challenge mistakes in investigative processes, faulty reasoning or poorly supported conclusions[114].

Race[74] reports the use of self and peer-assessment in practical work. He suggests that getting students to assess their own practical skills can be one way round the impossible workloads which can be involved if staff were to do all the requisite observations, whereas the act of assessing a peer's practical skills is often very good for the peer-assessors, in terms of improving similar skills of their own, and learning from others triumphs and disasters!

Though many advocate the involvement of students in their own assessment, when using self and peer-assessment, it is important that they are used in carefully selected curriculum elements, where it is possible for students to be sufficiently knowledgeable to be able to make informed decisions[179]. The assessment process must guarantee a reasonable level of reliability, and self and peer-assessment can be an easy target for criticism, especially by external examiners who are not themselves that convinced of the benefits[179]. Other disadvantages include that students can be reluctant to participate, and they may lack knowledge of the criteria or be unfamiliar with assessment techniques[180,181]. Also, it is possible, in peer assessment for collusion between students, and therefore making the assessment process unreliable and unfair on other students[181].

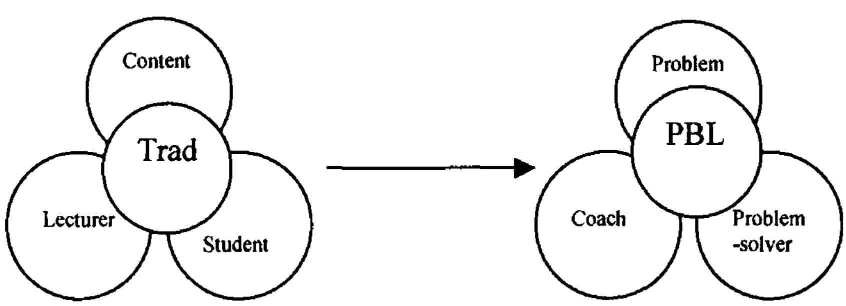
In conclusion, there is a wide diversity in students in terms of how they learn so why stick to one overused method of assessment when they are many ways that students can be assessed for their understanding of the material and not just their memorisation skills. Peer and self- assessment allows for students to have a part in their assessment, which leads to a better attitude toward learning, and hence understanding.

1.4: PROBLEM-BASED LEARNING

Overview

In Section 1.3, the initial discussion was on the shift in educational focus from a teacher centred approach to teaching and learning to a student-centred one, where students construct meaning for themselves by relating new concepts and ideas to previous knowledge. Alternative approaches to teaching and learning were then discussed which encouraged active involvement of the learner and had underpinnings in constructivist theory. Problem-based learning (PBL) is one such innovative approach, and is characterised by its student-centred approach. Figure 1.11[182] below shows the shift in focus from the traditional, didactic method of teaching, where the lecturer is the expert, transmitting knowledge to the students, with coverage of content the focus to the student-centred PBL style, where students are problem solvers, the lecturer is in a coaching or facilitating role, and the problem is the focus of the learning from which content is derived[182].

Figure 1.11: Adaptation of Tan's Model of the Educational Shift[182]



PBL is a pedagogy drawn from constructivism. As a learner-centred method that challenges the learner to take a progressively increasing responsibility for his or her own learning it is therefore consistent with the constructivist theory[183]. In relation to the use of a constructivist approach in PBL there are two areas to take into consideration – Piaget's curriculum and Vygotsky's interactions. A Piaget influenced curriculum would typically contain the following features[86]:

Student centred

Social interaction

Interaction with learning resources

Appropriate to the development of meaning

Assessed by direct observation

A Vygotsky influenced curriculum would use the Zone of Proximal Development to decide the level of difficulty[88]. If the task is too easy then the Zone of Proximal Development is not being used to its full capacity, however, if the Zone of Proximal Development is stretched too far then the learning task will be too difficult. Both of these extremes result in an ineffective learning environment, and will achieve only negative factors such as demotivation, frustration, lack of interest etc. The social interactions take place in terms of group work among peers, as well as interactions with the facilitators but also interactions in terms of discovery learning and problem-solving. Learners can achieve greater meaning for themselves through interactions with their peers, but also by interacting with new material in a discovery or problem-solving environment. Learners engage personally with the new material and therefore construct meaning for themselves[89].

The aim of PBL is to develop self-directed, reflective, lifelong learners who can integrate knowledge, think critically and work collaboratively with others[184]. By using unstructured real-life problems rather than the content as the focus students are given opportunities to really learn how to learn[182].

In 1969, McMaster University introduced PBL in Medical Education for the first time, since then it has been adopted elsewhere in different forms and to various degrees[185]. Their approach to PBL involves case based, small group (of no more than eight), self-directed learning, in which a group of students is given a problem to solve. The group has a tutorial leader or facilitator who shares information, rather than an expert imparting knowledge. This approach encompasses what are the main components of most PBL courses

- Self-directed group learning
- Problem as the focus for learning
- Teacher as facilitator

White[186] states that PBL provides an alternative to traditional lecture-based education.

> 'In principle, PBL reverses traditional education by putting the problem first and using it to motivate learning. By using real-world problems, PBL enables students to see the relevance that they often miss in other contexts. The promise of PBL was that students would learn better, understand what they learned, and remember longer by working cooperatively in groups.'

The problem is typically an ill-structured, complex one, with no clear 'right answer'. This provokes extended collaboration among groups, leading to conceptual learning. In comparison, the use of tasks with clear procedures and right answers, which is associated with limited exchange of information among students, leads to simple explanations and routine learning[187]. The other clear difference between PBL and traditional approaches is that the students do most of the talking, and the teachers do most of the listening! Each of the components of PBL shall be discussed in more detail in the coming sections.

Albanese and Mitchell[188] carried out an extensive review of literature from 1972 to 1992 on the effectiveness of PBL in medical education, describing PBL as 'an instructional method characterised by the use of 'patient' problems as a context for students to learn problem-solving skills and acquire knowledge about the basic and clinical sciences'. Overall, PBL was found to be more nurturing and enjoyable for students than the traditional approaches to medical education, PBL graduates performed as well and sometimes better, in both basic science and clinical science examinations, compared to their traditional counterparts and were more likely to enter family medicine. Therefore, it is not surprising that in a recent study of the numbers of citations of PBL in various journals[183] it was found that medical journals cited PBL 1,671 times, compared to 858 in education, 344 in psychology and 39 in business. There was no reference to science. However another article[189] described the number of undergraduate institutions worldwide with faculty members using PBL in 2001, and Table 1.10 below gives a breakdown of the disciplines using PBL over the 106 institutions cited.

Table 1.10: Number of faculty members using PBL in each discipline[189]

MEDICINE	MATHS/ SCIENCE	ARTS/ HUMANITIES	ENGINEERING/ COMPUTING	BUSINESS
50	18	19	29	11

Table 1.11 gives a further breakdown in terms of the maths/science discipline. It is clear that medicine is still at the forefront for using PBL, but other disciplines are now using it. Though maths and science departments are using it, only one makes a specific reference to its use in chemistry.

Table 1.11: Number of maths/science faculty members using PBL in each discipline[189]

SCIENCE	MATHS	BIOLOGY	CHEMISTRY	PHYSICS	SCIENCE EDUCATION
9	6	13	1	1	1

Prideaux[190] comments on the limitations of evaluating educational interventions in medicine. These limitations really apply across the range of all disciplines. Random control trials, he comments have three limitations

- Randomisation
- Control of variables
- Choice of appropriate outcome measures.

He questions if it's fair or justifiable to enrol students in courses in which they are given no choice over the learning methods they will engage in? Secondly, a range of factors including facilities, resources, teacher and student motivation, individual expectations and institutional ethos affect the process, and are difficult to control. Finally, the outcomes must be appropriate for the research, and in many cases, success is influenced by many factors, and so it is difficult to correlate success with the intervention alone.

Examples of the use of PBL in various disciplines are given below; in medical subjects including nursing[191], ophthalmology[192], dental[193], occupational therapy[194], and, of course, medicine[195] [196] itself, in business such as management education[218] [219] [183] [197], marketing[182] and human resources[198], and in science including school science[199,200] physics[201] [202] [203] [204][205], biology[206], biotechnology[182] and engineering[182] [207]. Examples of the use of PBL in chemistry are presented in Section 1.4.2.

1.4.1: COMPONENTS OF A PBL APPROACH

Problems

The starting point for learning in PBL is the problem, which can be an un-structured problem, query or puzzle that the learner is given to do[208].

> 'They (the tutors) move students towards the acquisition of knowledge and skills through a staged sequence of problems presented in context, together with associated learning materials and support from the teachers.'

Similarly, Belt *et al.*[209] suggest that problems act as the context and driving force for learning, and that the acquisition of new knowledge is done through these contexts. PBL differs to the familiar case-based or problem-solving approaches since in PBL the problems are encountered before all the relevant knowledge has been acquired[188,209].

A problem is often presented as a simulation of professional practice or a real life problem[208]. A key element of the problem is that it must be of relevance to the student, therefore providing an incentive to learn. Students know why they're learning since all the information they gather is for the purpose of resolving the 'real-life' problem. Albanese & Mitchell[188] report that it is 'crucial to PBL that the problems raise compelling issues for new learning'. Boud & Feletti[208] suggest that learning takes place most effectively when students are actively involved and learn in the context in which knowledge is to be used. The problems are also selected in order to ensure that students cover a pre-defined area of knowledge and to help students learn a set of important concepts, ideas and techniques, among others[210]. Problems do not encourage simple, lower level solutions but demand that students pursue new knowledge through the process of solving the problem leading to conceptual learning. The application of knowledge and skills is essential during the process of problem solving[211].

A good PBL problem should engage students, involve decision-making, promote thoughtful discussion, stimulate searches for substantive information, and lead to understanding of important course concepts[212]. Furthermore Allen *et al.*[213] emphasise that problems should be open-ended, based on previous knowledge, and perhaps, controversial, and above all, that problems are only good if they successfully achieve the objectives of the course. 'End-of-chapter textbook problems in general do not require the analytical, synthetic, and evaluative thinking needed for PBL, nor do they provide the contextual richness. Consequently, a major "problem" for adapting PBL was the necessity to write problems appropriate to the instructional goals.'[214]

Figures 1.12 and 1.13 give examples of PBL problem in chemistry, which are used in the University of Delaware. These are good problems because they are immediately engaging and are presented in a form easily understood by the learner. It is obvious that the problems fit within particular content areas, the former in thermochemistry, the latter in chemical bonding and build on previous knowledge. Also, there is no clear-cut answer, and certainly no prescribed approach. Therefore students would have to work together, with support from their tutor, to solve these real problems.

Figure 1.12: Saving for a Rainy Day Written by Susan E. Groh[215]

You've been invited to spend the weekend at your cousin's new cabin in the Poconos. She and her husband, having decided to "live simply", have constructed their home far from the beaten path, with an eye to being as energy efficient as possible. They've installed solar cells and collectors for generating electricity and heating their home, but are still trying to decide on the best way to trap and store energy for use at night and on cloudy days. They had planned to construct a tank containing some substance that can absorb the energy of sunlight, and then use that energy to provide heat for their home. They've found some plans for how to distribute the heat from such a storage reservoir throughout the house, but are still unsure about what materials to use for the tank and that substance. They'd originally thought of having a steel tank full of water, but are now intrigued by a magazine article that discussed the use of "phase-change materials" to store energy.

They show you some tables that appeared in the article.

Table 1. Heat Storage Materials

Material	**Specific Heat** (Btu/lb/degF or cal/g/degC)	**Density** (lb/ft^3)	**Heat Capacity** ($Btu/ft^3/degF$)
Water	1.00	62	62
Steel	0.12	490	59
Copper	0.09	555	50
Aluminum	0.22	170	37

Table 2. Properties of Phase-Change Materials

Material	**Density** (lb/ft^3)	**Heat of Fusion** (Btu/lb)	**Melting Temperature** (degF)
Glauber's salt $Na_2SO_4 \cdot 10\,H_2O$	91	108	88 - 90
Hypo $Na_2S_2O_3 \cdot 5\,H_2O$	104	90	118 - 120
Paraffin	51	75	112
Calcium chloride $CaCl_2 \cdot 6\,H_2O$	102	75	84 - 102

The problem here is that neither your cousin nor her spouse have much of a background in science, and they don't know what to make of the data in these tables, and so can't proceed with their decision making. They're hoping that you might be able to interpret this, and give them some advice about choosing a heat storage system (both the tank material and the substance to be kept in it) that will enable them to store as much heat as possible, within a reasonable physical space. They'd like to be able to store enough energy for three day's use; the article gives an estimate of about 480,000 Btu as the thermal energy needed to heat a house similar to theirs for a day.

What advice would you give?

Figure 1.13: THE BROMINATOR[216]

Stage 1

Running a reaction that liberated copious amounts of H_2S just as the President and the Board of Trustees were touring the new chemistry building was, in hindsight, not a good idea. As a result, Professor Zaney was promptly moving to a new employment situation in Manhattan. In his haste to depart he forgot to clean out a small chemical storeroom, so the chemistry department hired several undergraduates to pack up the remaining materials and prepare them for shipping to New York.

"What are we going to do about this bromine?", one of the students asked. "Doc Z wants to drive down this weekend and pick these things up, but I don't think you're allowed to carry hazardous stuff like this either through the tunnels or over the bridge. We don't have the time to go through the paperwork to get this packed properly for shipping."

"I've got an idea!" (Crazy Eddie always had an idea about everything.) "Maybe we can turn it into something that is safe. Let's see what else is here.......Whoa - check it out! Magnesium, calcium...even some strontium! This'll be a snap - all we've got to do is to turn the Br_2 into a bromide salt; Doc can carry that in his car. Then, when he gets back to his lab, he can turn it back into bromine and the metal again."

"Umm – well, sure, cool, I guess. Sounds like it'll work. Does it matter which metal we use?"

"There's about a kilogram of bromine here; it'd probably be better if Doc just has to deal with one product. Leave it to me!", said Eddie, heading off to the lab.

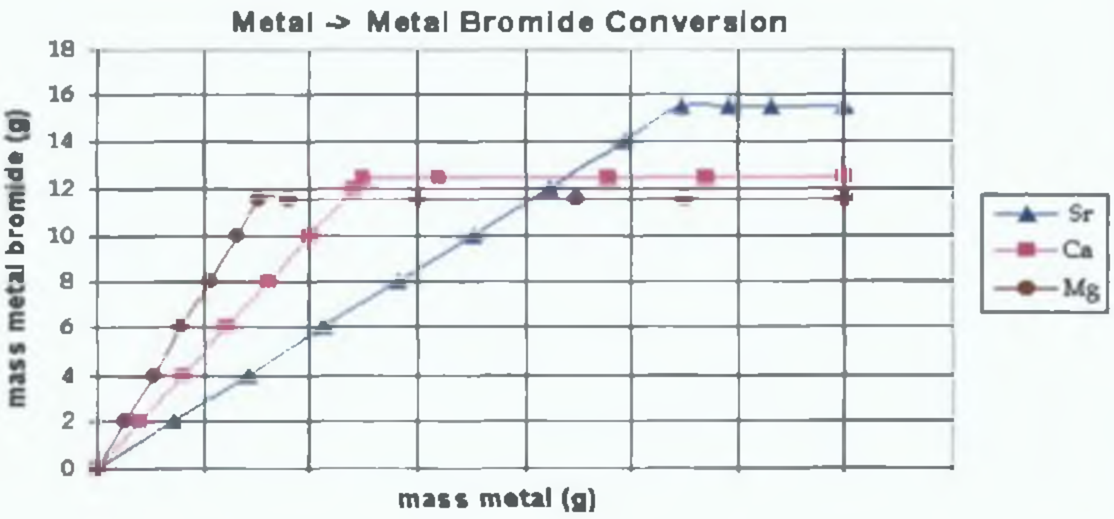
1. *What products are predicted to result from the reaction of Br_2 with each of these metals? Why? Extending your line of reasoning, predict the products you would expect from a reaction between (1) Rb and S, and (2) Sc and O_2. Write balanced equations for each of the reactions considered in this question.*
2. *What suggestions would you give Eddie? What do you think he will decide to do?*

Stage 2

Some time later Eddie reappeared with a handful of papers. "I've just done some experiments to see how much bromide we could get from each metal, but there's something weird going on."

Eddie's data are plotted below. In each trial of his experiment he (carefully!) added a known amount of Mg, Ca, or Sr to a flask containing a fixed mass of bromine. After the reaction was finished, he isolated and weighed the metal bromide produced. He plotted the mass of product against the mass of metal used in the reaction. In his haste, though, he forgot to label the scale on the x-axis.

Continued...



3. *What fixed mass of bromine must Eddie have used in each of these experiments? Show your reasoning.*
4. *Eddie expected to see the mass of each product increase with the mass of the metal used, but he doesn't understand why the plots level out at some point, and why that point is different for each metal. Can you explain this behavior to Eddie?*
5. *You have 100 g of magnesium, 300 g of calcium, and 500 g of strontium. If you only want to make one metal bromide, which of these will be the best choice for using up the kilogram of bromine? Show how you reached your conclusion.*

Stage 3

The students picked a metal and prepared its bromide salt. In a note to Professor Zaney, they explained what they had done, but forgot to tell him which metal they had used. Once Doc Z got back to his new lab with the bromide, he submitted a sample of the material for analysis and learned that it contained 86.8% bromine.

6. *Which metal had the students used?*
7. *How could Doc recover the Br_2 from this sample?*

Student-centred group work

A key condition that facilitates successful PBL is greater input and accountability on the part of the student, requiring that students take part fully in their small groups and undertake independent study[188]. Learning to learn and students taking responsibility for that learning are crucial for deep learning. Student-centred group work however needs to be properly managed and facilitated if it is to be successful for the students.

Determining the best group size in PBL is dependent on various factors, including how many tutors are available, how many students there are, and in some cases, how many rooms are available[187]. However, the recommended group size is from 4 to 6 students[217], with Wilkerson[187] reporting that groups of five are the most productive for small group discussion in PBL, allowing more opportunity for participation and requiring more preparation on the part of the student. Smaller groups also mean that student-to-student discussion is essential, as they depend on each other for clarification and elaboration.

Students can engage with group work at two distinct levels; a low level where students research his or her own topic, and then comes back to the group to present their findings in contrast to a high level where students are engaging in discussion, clarification, and explanation as they bring their individual work back to the group[187]. Therefore, groups should be monitored and guided to maximise the groups potential.

Brownell *et al.*[218] report that a team context in PBL requires individuals to learn and teach one another as well as negotiate and compromise to reach a consensus; it also capitalizes on peoples' strength and expertise, and finally they learn to handle inevitable disagreements and conflicts. Miller[219] reports that 'students benefit from the opportunity to share their course problems with each other and brainstorm to develop appropriate measurement tactics to track solution effectiveness. Cooperative work also allows them to disseminate learning they are doing individually, as they work through and learn more about their problems and concepts and principles that address them.'

Teachers as facilitators

The teacher's role is to facilitate a positive, encouraging cooperative learning environment and provide scaffolding at crucial times, as determined by the dynamic process of solving the problem. Allen & Tanner[214] describe how 'the "roving" instructor may also enter into discussions, pose questions, and look for overt signs of behaviours that undermine group function, or otherwise focus on a particular group for a short period of time.' This roving facilitator strategy is particularly effective if the PBL problems are constructed so that instructor-led, whole-class discussions can be inserted at key intervals in the problem-resolving process. Lewis & Lewis[220] describe the role of peer-leaders in a guided inquiry alternative to traditional lectures, where their role was not to introduce new material but instead to check for understanding of the new material as the students progressed through the activities.

Wilkerson[187] puts forward the following ways in which tutors were most helpful in promoting learning in PBL classrooms:

- Balancing student-direction with interaction
- Contributing knowledge and experience
- Creating a pleasant learning environment
- Stimulating critical evaluation of ideas.

Another study[221], based on interviews with tutors involved in the first year of a PBL based medical course in the University of Liverpool, showed that good tutors were seen as those who 'knew' how and when to intervene and who empathised with the students. It is also reported that the role of the PBL tutor to raise students' levels of 'metacognition', that is to help the students learn how to learn[200,222], for example by helping students to understand the questions to ask during the PBL process, including defining the problem, information location and retrieval, and analysis and synthesis of data collected[200].

The effective tutor has an attitude of caring for and interest in the students, a knowledge base relevant to the learning objectives of the course and the ability to translate this knowledge into terms readily accessible by students[187]. However, a conflict exists as to whether tutor expertise in PBL makes a difference. Successful learning in PBL is said to lie in the interactiveness of its sessions and effective group facilitation[222]. Gilkinson[222] reports on various studies of teacher-student interaction in PBL reporting that tutors who rated themselves as having expertise tended to take a more directive role in the tutorial, spoke more often and for longer, provided more direct answers and suggested more discussion topics, in contrast tutors possessing skills in facilitating group dynamics were rated more highly by students (i.e. encouraging students to listen fully to each other, tolerating silence and interrupting infrequently). Therefore, expertise in group dynamics as opposed to a knowledge expert seems to be beneficial to the learning process. Albanese[223] suggests that 'perhaps the real issue is not whether tutors should be content experts, but what is the minimum content expertise and group facilitation expertise needed by tutors to be effective'.

1.4.2: PBL IN CHEMISTRY

There are many examples of the use of PBL in chemistry in third level [136,224,225,226] and second level[227] institutes, especially in the area of analytical chemistry[62,228,229,230,231,232]. The first we shall use as an example is the University of Kansas [228 229], where PBL has been introduced as part of the Instrumental Analysis course for junior and senior undergraduates combining lectures and laboratory sessions in the course. This has been in use now since the late 1990's. The students are divided into three- to five- member teams, which constitute the analytical group of a real-world enterprise, such as a government laboratory, a consulting firm, or a chemical or pharmaceutical company. The team is presented with a problem for which they must find a solution over the course of a semester. The facilitators report that it is remarkably easy to find suitable problems for students to solve and then enlist support from others in the form of information, materials and in some cases, borrowed or accessible equipment. Activities like information sourcing, problem solving, working as a team member, and communicating orally and in writing form the basis of evaluations since the students would not have had much experience in these areas. It is made clear to the students at the beginning that their grades are based on individual and group performance. The criteria include demonstration of technical knowledge and its application, quality of laboratory work and data interpretation, ability to function in a team framework, individual contribution to the project, quality of written and oral reports, leadership, attitude toward work, and attendance. They describe their experience so far as being very encouraging, and that the course provides a rich learning experience for the teaching assistants and faculty as well as for the students.

Various universities in China promote the use of PBL also in analytical courses.[62 225 230] In one case[230], the approach is quite similar to the University of Kansas, as it involves a one semester long problem-solving project but also small problem solving projects. Another difference is that the course is non-laboratory based. This new course, however, is only in its first year and no results are available as yet. The class is divided into groups of about 4, and most of the discussion and problem solving, both in and out of class, will be performed by the group. The assessment of this is different in that solutions to the problem are not required for grading, however, the final examination questions will be adapted, to some degree, from these assigned problems, so the students are encouraged to work them in conjunction with the lectures and discuss them out of the classroom.

Belt *et al.*[209] report on the use of PBL for analytical and applied chemistry. The problems are presented as case studies, with real life scenarios, which require students to solve them 'by application of prior knowledge, acquisition of new knowledge and by developing a problem solving strategy'. This approach is also non-laboratory based. An evaluation of student experience of one particular case study, 'The Pale Horse', revealed positive results. It is reported that students enthusiasm and engagement increased as they become more involved with the story. Also, that the students increased their transferable skills.

Wenzel[233] reports on PBL, asking 'does Problem-Based Learning sacrifice content and fundamentals?' He cites many examples of programs, which include more problem solving, group interaction and communication than in other more traditional approaches to teaching analytical chemistry. Most of the programs develop PBL by incorporating a project-based laboratory as the basis for the experience, the students are provided with less information and expected to engage in literature searches, interact with instructors and consultants, and contribute and develop ideas based on their own knowledge. He reports that the problems cannot be solved without the development of analytical content and fundamental skills. Even though the experiments are mostly applications of analytical chemistry to real samples, basic laboratory skills are emphasised. He concedes that it is possible to design courses that can simultaneously develop the foundation, content, and problem-solving nature of analytical chemistry.

Maricopa Centre for Learning and Instruction[234,235] report on the use of PBL in a Community College as part of a 'Fundamentals of Chemistry Laboratory' course. Results show that students involved with the PBL acquire knowledge and become proficient in problem solving, self-directed learning and team participation. Studies show that PBL prepares students as well as traditional methods, with PBL students doing as well as their counterparts in traditional classrooms on national exams, but who are in fact better practitioners of their profession. Ying[225] reports on the use of PBL for improving the teaching of electrochemistry to third year undergraduates, using real problems to guide the teaching and learning in order to stimulate the students' learning interests. This is also a non-laboratory based approach. McGarvey[236] reports the use of PBL for physical chemistry practicals. The key aspects were teamwork, deciding what data is needed, formulating an experimental approach, planning an experimental method, drawing on a breadth of knowledge and critical reflection. On reflection, it was concluded that though it had been successful, next time more time would need to be set-aside for the students to plan the experiments.

1.4.3: EVALUATION OF EFFECTIVENESS OF PBL

Though PBL is becoming increasingly popular in chemistry, there has been little evaluation of its effectiveness; therefore investigations into the PBL approach from various subject disciplines, including chemistry and other science disciplines, will now be discussed.

Student experience

Some studies have looked at the experiences of students undertaking a PBL approach, in disciplines ranging from chemical engineering to physics[182,188,191,201,209,237,238]. The extensive study carried out by Albanese & Mitchell[188] reported that studies of students' satisfaction after taking PBL modules uniformly showed high levels of satisfaction. Tan[182] describes results from a study designed to assess students' experience of PBL in terms of the 'problem', the 'tutor' and 'problem-solving'. A 15-item questionnaire was used, where students were asked if they found a particular aspect of their PBL experience useful or effective by indicating on a 10-point Likert scale. The items are grouped into three categories, experiences with the problem, the coaching process and as problem-solvers. An example of an item from each category is given below:

The Problem

'The problem engaged my learning and thinking throughout the PBL cycle'

The Tutor

'I found the tutor's facilitation of the various PBL stages and tutorials helpful'

Problem-solving

'I learned to take different perspectives and to think more deeply'

The students were from various disciplines, in various years, and taking either a hybrid approach to PBL, involving lectures and tutorials and little cross-discipline activity, or a full approach, in which there is full integration of disciplines and lasts through the whole semester. This is described in Table 1.12.

The study found that in general students were positive about their experiences with PBL, with the 'problem' and 'problem solving' aspects having similar means of 34 and 33.4 respectively, whereas the 'coach' had a lower mean of 25.5. This demonstrates that students felt the least satisfaction with the coaching process. Following on from this, 10 students who had scores below the average, and 10 students who had scored above the average were interviewed to give further in-depth analysis of their experience.

Table 1.12: Description of participants[182]

PROGRAMME	YEAR OF STUDY	NO. OF STUDENTS (SAMPLE)	NO. OF STUDENTS IN SAMPLE AS % OF TOTAL NO. OF STUDENTS	PBL APPROACH
Biotechnology	3rd	15	22.4	Hybrid
Chemical Engineering	2nd	15	16.7	Hybrid
Computer Engineering	3rd	18	13.8	Full
Electronics	2nd	14	10.4	Hybrid
Logistics and Operations	3rd	20	34.1	Hybrid
Marketing	3rd	18	15.0	Full

Contrasting views were described for the problems, with some students revealing a frustration with the problems due to the fact that there was neither a model answer nor an overall picture where as other students described the problem as highly motivating. The low score for the coaching process was attributed to the tutors' failure in the facilitation process, such as tutors assuming that the students would start working with each other as soon as they were assigned their groups or the tutor not giving pointers, even when it was in terms of where to get resources etc. Finally, the students reported that in terms of the problem-solving experience resource guides were important, however, foundation knowledge was required and some students expressed insecurity about direction.

Van Kampen *et al.*[201] report on the student experience of an Introductory Thermal Physics PBL Course, designed for 2nd year students. Students reported that thermal physics was significantly more interesting and relevant having completed the PBL course, with an increase from 3.0 and 2.7 in the pre-intervention survey to 3.9 and 4.1 respectively in the post-intervention survey. Student attendance also rose to almost

100%. The only negative aspect was the amount of time required. The students involved in 'The Pale horse' case study[209], a PBL approach to analytical and applied chemistry, were asked to rate their enjoyment of taking part in the activity on a 5-point Likert scale. A mean response of 4.3 (n = 45) indicates a highly positive experience. Chung & Chow[237] report that 76 of 90 students gave positive comments on the PBL experience in a first year occupational therapy course, 10 gave negative comments, and 4 were neutral.

Savin-Baden[191] reports on students' experience of the assessment process in PBL. The study involved 4 universities over 5 years, with students from 3rd year mechanical engineering, 2nd and 4th year auto design engineering, 2nd year nursing and from a diploma course in social work. One-on-one interviews, group interviews, informal discussions and analysis of course documents were the evaluation methods. Students reported that their learning was unrewarded, that they felt disempowered by complex assessment mechanisms and that working in groups was undervalued. Some student comments are given below:

> 'At the end of this degree this course won't actually have counted towards my degree, which is a pity because it's probably one of the courses I shall learn the most in'.
>
> 'We're not graded on any of the information we give in to the group and share with the group – all we're graded on is the individual assessments'.

Assessment in PBL needs to address the process of learning, with students needing both to be enabled to assess how they learn and be equipped so that they know how to provide evidence of this learning. Also, as with all assessment, it is important to de-mystify the assessment criteria and give students the opportunity to become involved with the assessment process, through self and peer assessment[182].

Supporting independent deep-learning

Many institutions see PBL as a way of improving students approach to learning, with the hope of shifting students from surface/strategic learners to deep learners[225,232,239]. Albanese & Mitchell[188] found that overall results suggest that PBL students are less likely to study for short-term recall and more likely to study for understanding or to analyse what they need to know for a given task and study accordingly. Also, they are more likely to use self-directed learning skills, such as having a greater control over their learning efforts and using the library and its resources. It is reported that students taught by PBL methods may show less surface learning, more deep learning and more versatility in learning styles, compared with students taught by traditional didactic methods[195]. Newble & Clarke[195] reported in 1986 that students in a PBL based medical school scored higher in terms of a deep approach to learning and lower in terms of a surface approach in comparison to students from a traditional medical school. The study encompassed students from year 1, 2 and 3 and those in their final year. The trend was observed at all stages.

Another study evaluated the outcomes of PBL packages in Australia and New Zealand[193]. A student survey and focus groups were used as analysis tools. The survey addressed motivation, self-directed learning, and integrated learning issues, all aspects, which promote a deep approach to learning. The results of the study showed that students across two universities and in different year levels of dentistry perceived that the PBL packages provided motivating learning opportunities that supported their independent investigation and enabled them to a certain degree to make links with other knowledge and experience.

However, Chung & Chow[237] reported on the effect of a PBL course on students' approaches to learning in the first year of an occupational therapy course. Pre and post surveys were carried out using Biggs' Study Process Questionnaire[240]. A total of 51 (of 90) students completed the 42-item 5-point Likert scale questionnaire at both the pre- and post-intervention stage. The questionnaire is used to assess students' learning style, with three scales: deep, surface, and achieving. There was no significant change in any of the scales over time, showing that this group of students did not significantly change as a result of the PBL intervention. Similar results were also found for McParland *et al.*[241] who investigated the approach to learning of 2nd year psychiatry students prior to and after a PBL course. This study also used Biggs' Study Process Questionnaire, and there was no significant change in any of the scales over time.

Academic achievement

The issue of academic achievement in PBL is a contentious issue, as many forms of assessment do not actually 'test' the very outcomes which are achieved through PBL. Also, Albanese & Mitchell[188] reported that 'one of the most consistently mentioned outcomes has been lower basic science test scores of PBL students'. This is somewhat backed up in the same literature review, where 6 of 10 studies reporting on basic science examination performance are in favour of the conventional group, however only three of these are significantly higher. Another more recent study, also in the medical area, found fairly inconclusive results[238].

The study reports on effect sizes, the equation for which is given below:

$$\text{Effect size:} = \frac{\text{Mean PBL Group Result} - \text{Mean Control Group Result}}{\text{Pooled Standard Deviation}}$$

$$\text{where Pooled Standard Deviation} = \sqrt{\frac{(n_1 - 1)s_1^{\ 2} + (n_2 - 1)s_2^{\ 2}}{n_1 + n_2 - 2}}$$

n = number in group

s = standard deviation

A positive effect size indicates that the PBL has outperformed the control group in terms of academic performance, whereas a negative effect size favours the control or conventional group. The report presents 14 studies, which have a range of effects sizes from –4.9 to 2.0, with an average effect size of –0.3. Though this means overall the control groups performed better than the PBL groups in terms of 'knowledge', it is not a significant value. Therefore, the report is somewhat inconclusive.

Another more recent study revealed that PBL students did in fact outperform their 'conventional peers' in terms of academic performance[207]. Polanco[207] reports on the effects of a PBL program on engineering students' academic achievement in a Mexican University. The PBL curriculum, designed for 2nd year engineering students, incorporated physics, mathematics and computer science. Three evaluations are reported

- Pre- and post- tests scores on two physics tests
- Students' grade point average (GPA)
- Students' grades in advanced engineering courses

The two physics tests were the 'Mechanics Baseline Test' and 'Force Concept Inventory'. In the latter there was no difference between the control and the PBL group, however, the PBL students had a significantly greater improvement in their 'Mechanics Baseline Test' score than the control. Secondly, the PBL students achieved significantly higher GPA's than the conventional ones. Finally, though the PBL group scored higher, there was no significant statistical difference in their advanced engineering performance. However, the PBL group did score statistically higher in oral communication and probability and statistics courses.

So overall, there is conflicting evidence to the effect of PBL on academic achievement. However, it has been shown to have little negative effects, and mostly neutral or positive effects when compared to control groups.

1.4.4: IMPLEMENTATION OF PBL

Albanese & Mitchell[188] raise five issues in implementing PBL

- What does PBL cost?
- What are the characteristics of appropriate PBL problems?
- Is depth gained at the expense of content coverage?
- How directive should instruction be?
- Should tutors be expert?

These are all relevant issues, some of which have been discussed in Section 1.4.1, such as the difficulty in finding suitable problems which meet the learning outcomes as well as being relevant and motivating and in achieving appropriate facilitation, with the right balance of instruction and knowledge expertise of the facilitator.

With respect to cost, is it essential to ask, before implementing any new educational interventions, whether the costs of changing the curriculum and then maintaining the new program will be justified in terms of learning effectiveness and efficiency.[188] The results of the extensive study carried out by Albanese & Mitchell[188] concluded that the concerns over the cost of PBL are merited, particularly for medical schools with class sizes over 100. The related costs are due to increased student contact hours by faculty members. The time efficiency of PBL i.e. comparing PBL and conventional curricula in terms of content coverage and student learning per unit time, is also a concern. However, the same study also reports better retention of knowledge of PBL students compared to conventional teaching showing that time is well spent by tutors in PBL. Physical and media resources are also a concern. However, studies report ways to reduce the cost such as using peer tutors in PBL[188,242].

In terms of the third point above, there has been great debate on the potential loss of content coverage against depth of understanding. Hung *et al.*[243] comment on the logical reasoning behind this.

"Critics may argue that PBL focuses on relatively finite problems that require students to consider only limited content; therefore, the PBL method limits the possibility of students being exposed to broader content that may be a part of a course or program of studies but may not be directly related to the causes or solutions of the problem under investigation."[243]

They ask the questions: What's wrong with pursuing depth as opposed to breadth? Is less breadth an inevitable trade-off for gaining a more in-depth understanding of content? Since knowledge is constantly changing and expanding, aren't the skills of problem-solving and independent self-directed learning, and a depth of understanding a reasonable trade-off? As Boud & Feletti[208] point out:

"It is more important for students to be able to learn quickly, effectively, and independently when they need it, than it is for them to have assimilated all the information which their teachers believe is desirable."

1.4.5: CONCLUSION

In conclusion, having discussed potential benefits of PBL in chemistry and having cited actual examples where PBL is successful, though there are some cost considerations, as well as some concern over content coverage, it is clear that as a total approach to teaching and learning it can be very useful for the students when implemented correctly. From the examples it also clear that, within chemistry, analytical and application based topics seem to be suited to PBL, with many institutes practicing it using either lectures or the laboratory or a combination of both as the main context. From the literature reviewed however, only through the Maricopa Institute for Learning, in Estrella Mountain Community College, is PBL being investigated for a fundamentals chemistry laboratory course. It is this area of chemistry, which is the focus of this research. A PBL approach for a first year undergraduate general chemistry laboratory course is described, including the development of the course (Chapter 3) and an evaluation of it (Chapter 4).

As PBL is an alternative approach to teaching and learning, is was considered necessary to determine the approaches that science students adopt to their studying and learning, and hence to monitor any changes in their approaches that could be attributed to a PBL influence. Furthermore, a study of undergraduate science students' approach to learning and studying in Australia is described. This puts into context the type of learning which Irish science students are engaged in, and also focuses on the similarities and differences between various cohorts of students, across gender, age and university. This is described in Chapter 2.

Finally, the use of microscale techniques for Leaving Certificate Chemistry is described in Chapter 5, which includes a discussion on the development of the experiments, and evaluation of a selection of these experiments in schools.

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CHAPTER 2

APPROACHES TO LEARNING OF UNDERGRADUATE SCIENCE STUDENTS:

COMPARATIVE STUDIES ACROSS YEAR, UNIVERSITY, GENDER, AND AGE

2.1: APPROACHES TO LEARNING

This chapter focuses on the approach to learning of university science students. In this section the background to the underlying theory of students approach to learning and the development of inventories to describe students approach to learning is described. The factors which influence students approach to learning are also discussed. The next section validates the ASSIST inventory used in this study, and the results are then presented.

2.1.1: BACKGROUND THEORY/DEVELOPMENT OF INVENTORIES

'Learning for understanding does involve learning facts. However, the learning of facts may involve only very limited understanding'[1]. To learn to use previous knowledge, to organise, and to extend meaning are important aspects in understanding and learning. To develop these qualities is to learn how to learn[1], however two extreme ideas of learning are reported[2]:

- Learning as the acquisition of discrete packages of information
- Learning as a change in the students' conceptions of himself/herself and the world around him/her.

The approach to learning adopted by a student depends not just on his/her own attitudes, habits, abilities and personality, but also on the demands made by the teaching staff or the college[2,3,4]. Therefore, what factors contribute to the different level of understanding/outcomes of students all doing the same course, assignments and exams?

The most obvious explanation of why such variations in levels of understanding exist would be to argue that learning depends on prior knowledge. Therefore the differing outcomes could be explained in terms of differing levels of knowledge. Or that the students understand the text in different ways because the students themselves differ or some are brighter than others. Or that if the outcome of learning differs between individuals, then the very process of learning which leads to different outcomes and understanding must also have differed between individuals[5]. This would suggest a very close link between the process of learning and the outcome of learning.

Initial investigations into different levels of processing of information led to the emergence of two distinct approaches to learning; deep and surface. This stemmed from one study[6] on how students approached reading a prose passage. The focus of this study was to investigate the potential relationship between the process and outcome of learning. The prose passage aimed to give the reader a thorough understanding of the effects of education on society and individuals i.e. the output of education systems. The students were asked 'What is meant by the output of an educational system'. Four distinct levels of answer were obtained, ranging from level A answers which contained the intentional content of the author's argument supported by relevant evidence, to level D answers which were virtually empty of content and in most cases, merely contained a translation of the term output. These four levels of response are similar to the four levels of understanding discussed by Entwistle[4]. The level of understanding is based on the types of response students can give having read a given article. These are:

- Conclusion-orientated, detailed
    - Summarises main argument
    - Uses evidence from the article
    - Personal understanding
- Conclusion-orientated, mentioning
    - Summarises main argument
    - Little use of evidence or personal experience to support argument
- Description, detailed
    - Lists main points
- Description, mentioning
    - Makes a few isolated points, some relevant some irrelevant.

This shows that different individuals comprehend the same learning material/content in different ways, leading to individual student meanings. These findings suggested that if there are qualitative differences in the outcome of learning, it is highly likely there are corresponding differences in the process of learning[6].

A further study[7] aimed to determine the relationship between (a) the outcome of learning and (b) the learner's conception of the task. Once again, the students were given a passage to read. The passage, taken from a daily newspaper, was on university reform, which intended to bring the pass rates of universities more in line with those of polytechnic institutes. The students were asked to read that article, knowing that they would be asked questions on it afterwards. Besides the questions about the content of the passage, students were also asked questions designed to discover how they had tackled the task/set about reading the article. It became clear from the interviews that students had interpreted the instructions very differently, and their ability to answer questions about the meaning of the text depended on how they decided to tackle the task. Some students had sought a thorough understanding of the author's message, while others had relied on 'question spotting'- learning just those pieces of information expected to come up in the test[8]. Other students who did not get 'the point' failed to do so simply because they were not looking for it. The paper concluded that students adopt an approach determined by their perceptions of what is expected of them, with two distinct levels of processing apparent; deep-level and surface-level[7].

The key concept emerging from these studies was the approach to learning with its categories of deep and surface, to which an approach to studying described as either strategic or achieving was subsequently added. The inclusion of a strategic factor stemmed from an article by Ramsden[9], where he described students with a 'tendency to determine the implicit rules of the assessment game' as strategic learners.

Learning is related to three elements- intention, process and outcome[10]. Intention can be described as the motivation for learning, whereas process is how students actually go about their learning. The outcome is what students perceive as the result of their learning i.e. a deep level of understanding or high grades with or without understanding. Entwistle *et al.*[10] describe three forms of motivation – extrinsic motivation, and two types of intrinsic motivations as well as three distinct approaches to learning – deep, strategic and surface. Biggs[11] also recognised three dimensions of study process which had both motivational and strategy elements. There are distinct similarities to Entwistles[10] motivation factors and approaches to learning and Biggs three dimensions of study. See Table 2.1.

There are obvious parallels between Biggs' Achieving[11] dimension, Entwistle's motivation for hope of success and strategic approach[10] and Ramsden's strategic[9] learners.

Characteristics of the three main approaches - deep, strategic and surface are now described. The strategic approach is where the intention is to achieve the highest possible grades by using organised study methods, good time-management and adopting strategies considered appropriate to the perceived task requirements and criteria of assessment[4]. A high achieving orientation (strategic approach) was reported to be highly correlated with immediate recall of facts, but not long-term retention[11].

Table 2.1: Comparison of Entwistle's and Biggs' model of learning in terms of intention and process

	ENTWISTLE	BIGGS
Intention (Motivation)	**Extrinsic** Fear of failure	**Utilising** To avoid failure
	Intrinsic Inherent interest in the subject	**Internalising** To realise fully one's potential
	Intrinsic Hope for success	**Achieving** Achieving hallmarks of excellence
Process (Strategy)	**Surface** Memorisation	**Utilising** Syllabus bound – rote strategy
	Deep Meaningful learning	**Internalising** Meaning assimilation
	Strategic Alertness to assessment and Study Skills	**Achieving** High organisation and Study Skills

On the other hand, Entwistle[4] implied that a deep approach related to a deep level of understanding, associated with a better recall of data and longer term retention. The deep learner is characterised as[4]:

- Having the intention to understand the meaning
- Questioning the authors argument
- Relating to previous knowledge and experience
- Trying to determine the extent to which the author's conclusions seemed to be justified by the evidence presented.

Finally the surface learner had the intention to memorise and limits activities to those demanded, leading to students adhering closely to the syllabus and learning by rote for fear of failure. Findings show that there is a clear distinction between deep and surface processes, and it is firmly established as a useful way of describing students' approaches to learning[4].

Research on student learning began with interviews, as with the previous examples, but soon led to the construction of 'inventories', or surveys, to assess the predominant approach being used by a student group[8]. Various inventories have been developed e.g.

'Study Process Questionnaire' by Biggs[11]. A further inventory, the 'Approaches to Studying Inventory' (ASI) [12] measures students approach to learning by asking students about their general approaches to academic work in the normal context of their main courses.

Further development of the ASI has led to the RASI[13] (Revised Approaches to Studying Inventory, 1995) and subsequently the ASSIST inventory[14] (Approaches and Study Skills Inventory for Students, 1996). See Table 2.2 for the categories in terms of approach to learning for the ASSIST inventory.

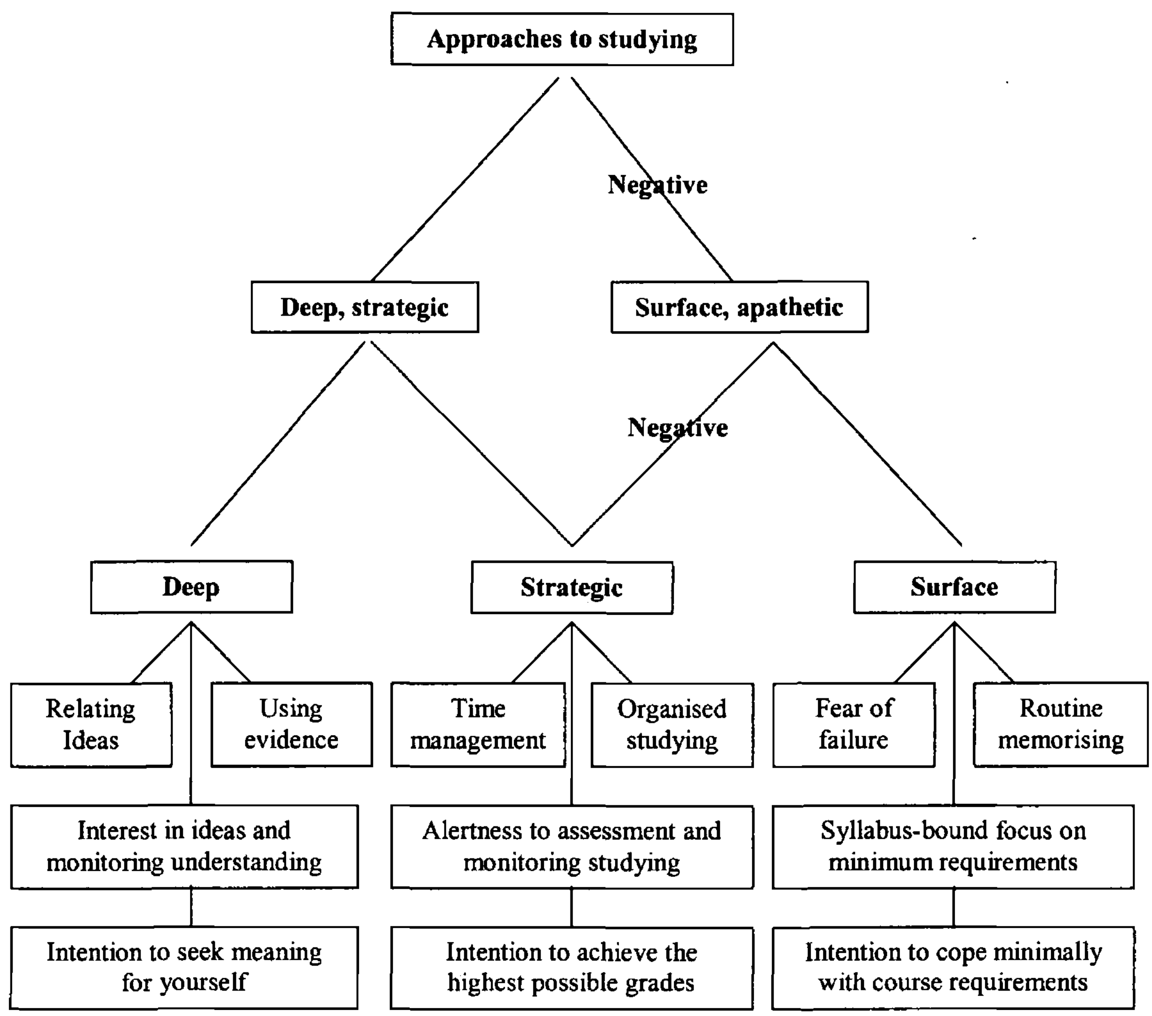
Table 2.2: Categories in the Approaches and Study Skills Inventory for Students[14]

APPROACH	SUBSCALES
Deep	Seeking meaning
	Relating ideas
	Use of evidence
	Interest in ideas
Strategic	Organised studying
	Time management
	Alertness to assessment demands
	Achieving
	Monitoring effectiveness
Surface	Lack of purpose
	Unrelated memorising
	Syllabus boundness
	Fear of failure

The ASSIST inventory is designed to classify learners as predominantly deep, strategic or surface and its structure and workings are discussed in depth in Section 2.2. In brief, it consists of 52 statements, which combine to give 13 subscales as described in Table 2.2. Students respond on a Likert scale to these statements, and the overall scores for the three main approaches are calculated by combining the scores of individual subscales. For example, a deep score is calculated by combining the scores of 'Seeking meaning', 'Relating ideas', 'Use of evidence' and 'Interest in ideas'. Each subscale is in turn computed by combining the score of 4 of the statements.

The way in which the various subscales of the ASSIST inventory come together to define the characteristics of the successful student is illustrated in Figure 2.1. It suggests that a combination of deep and strategic approaches, without any elements of a surface approach or lack of interest (apathy), is generally associated with successful academic performance[8].

Figure 2.1: Components of the ASSIST inventory[8]



In tandem with approaches to learning, students' preferences for different types of course and teaching are also assessed in ASSIST. Two distinct preferences are observed: courses and teaching which support understanding and courses and teaching which transmit information. Similar to the Approaches to Learning, students respond on a Likert scale to a series of 8 statements. These two extreme preferences for styles of teaching are computed by combining the score of 4 of the 8 statements. This is also described in more detail in Section 2.2.

2.1.2: FACTORS INFLUENCING STUDENTS APPROACH TO LEARNING

What encourages a student to adopt a particular approach over the other? Traditionally, poor academic performance by a student at third level was blamed solely on the student without asking how the student came to lose motivation and interest in a subject/area in which the student initially had enough interest in to pursue at third level[2]. Intelligence, motivation, personality and prior knowledge are all important characteristics related to learning, however, the context of learning and teaching also plays a major role in the learning process.

> 'Students are rarely free to learn what they like, when they like, or how they like. Course syllabuses, teaching and assessment all place constraints on the students, constraints which may differ from department to department, course to course, and even assignment to assignment'[4].

Ramsden[9] reported that the approaches to learning of students were very much affected by their perception of their departments and the assessment demands placed on them. Attitudes and the enthusiasm of staff were also important to students.

Biggs[15] puts forward the 3P model of classroom learning: Presage-Process-Product. Presage factors exist prior to actual engagement in learning. Student presage factors include prior knowledge, abilities, preferred style of learning, values and expectations. Presage, in terms of the teaching context, includes the curriculum, teaching method, classroom climate and assessment. These presage factors will affect the students task processing (process) and eventual outcome (product).

Typically, students' academic life is dominated by assessment demands. It is much easier to encourage a surface approach in terms of approach to assessment than a deep one. Different types of assessment can encourage either approach, with essay questions or problems encouraging a deep approach, but only if the questions actually demand a demonstration of understanding by the student[2]. It is reported that 'out of class workload' and time pressure in assessments are of detriment to a deep approach[16]. Also, students, who perceive a situation to be threatening, are more likely to adopt a surface approach. Finally, students' lack of interest in the subject matter is also related to a surface approach[3,4]. However Dahlgren[17] makes the anecdotal comment that there are obvious parallels between the demands put on students in some types of assessment and those put on contestants in quiz programmes; with questions often asking names of person/place/year etc. but seldom asking 'Why'. Since assessments should be easy to construct, to answer and to mark, this is not surprising. It is much easier if answers are recognisably right or wrong, but often they tell you nothing about the quality of learning[17].

In contrast, 'good teaching, greater freedom in learning and an avoidance of overloading are likely to move students away from a surface approach towards a deep approach to learning'[12]. Relevance and interest in the subject matter both evoke a deep approach to the course[2,3]. Also, an appropriate mixture of imaginative teaching, choice and structure in the curriculum, and fitting assessment methods can help students towards personal meaning in learning[3].

Further investigating the factors which influence students' approaches to learning in relation to science subjects suggests that lecturers are more likely to prefer formal, structured approaches to teaching and assessment in Science departments than in Arts and Social Science departments. Learning tasks in science have been described as 'hierarchal, logical, and rule- and procedure-governed' [3], meaning that students are less free to learn what they like or how they like. In Arts and Social Science however, teachers endorse more flexible and individualistic methods. Their tasks are seen to require interpretation, comparison, generalisation, and to be more self-governed and easier. This is based on evidence from students interviewed in a study in 1981[12], with arts and science students agreeing that formal teaching methods, limited choice of topics, clear goals for learning, and vocational relevance are associated with science departments. It also emerged from the interviews that even a deep approach to learning tasks in science departments often demand an initial concentration on detail which is hard to separate from a surface approach, and formal teaching methods[3]. Science students have been described as adopting deep-memorising strategies, similar to students studying for final examinations, and reporting a higher use of surface and strategic approaches in comparison to Arts students[18].

The learning environment however can be managed so as to encourage the deep approach, which is seen as an essential pre-requisite for high quality learning [2]. Learners generating analogies, metaphors, problems, models, and related devices that build meaningful relations between new information and past experience can facilitate understanding in science[19]. This is much in line with the constructivist approach to learning which has been discussed at length previously in Chapter 1, where learning is progressed by means of processes of assimilation and accommodation of constructs and concepts[20]. Chin & Brown[19] suggests that to encourage a deep approach in science, teachers could provide prompts and contextualised scaffolding and encourage students to ask questions, predict, and explain during activities. Case & Gunstone[16] reported that 'unlimited time tests' and 'journal tasks' were supportive of a move towards a deep approach. These assessment tasks forced the students to consider their conceptual understanding and engaged them in conceptual thinking. Similarly, teachers commitment to their subject area, and hence their enthusiasm can help to encourage a positive attitude in the students. However, it is reported that the promotion of the use of deep approaches is not easily achieved[16].

This research aims to determine the main approach to learning of students from Dublin City University and to compare approaches taken by first year students in the University of Wollongong. It is reported that a combination of deep and strategic approaches give rise to high quality learning and academic success. Also, the teaching and learning environment has been suggested as having an effect on students approach to learning. Both of these shall be investigated, as well as a study into differences across university, age and gender and the effect time in university has on their approach. The study was carried out over 4 years. The sample, method and analysis of the study are described in Section 2.3.

2.2: VALIDATION OF ASSIST

The aim of this section is to validate the ASSIST inventory for use with 1st year undergraduate science students in Dublin City University, Ireland and the University of Wollongong, Australia so as to check if the survey could be used as an effective tool to monitor the student group. To validate the survey, the structure of the survey needs to be confirmed and the reliability of the survey needs to be demonstrated. Factor analysis is used for the former, and Cronbach's alpha used for the latter.

For survey research to be reliable it must show that if it were to be carried out on a similar group of respondents in a similar context, then similar results would be obtained. Internal consistency is one measure of reliability and it measures the extent to which individual items are mathematically associated with one another and thus all appear to be measuring the same construct. The formula for calculating Cronbach's alpha is given below[21]:

$$\alpha = \frac{N \times \bar{r}}{1 + (N-1) \times \bar{r}}$$

where N = Number of items

$\bar{r}$ = Average inter-item correlation among the items

It can be seen from this formula that if you increase the number of items, you increase Cronbach's alpha. As the average inter-item correlation increases, Cronbach's alpha increases as well. This makes sense intuitively - if the inter-item correlations are high, then there is evidence that the items are measuring the same underlying construct. This is really what is meant when someone says they have "high" or "good" reliability.

Factor analysis has two main applications; one is to reduce the number of variables, the other is to detect structure in the relationships between the variables. In this research, it is used to detect, and hence confirm the structure of the survey. All the statistical validation was done using the Statistics Package for Social Sciences (SPSS v11.0 for Windows).

2.2.1: STRUCTURE OF ASSIST

The main part of the ASSIST inventory is to classify learners as predominantly deep, strategic, or surface. This is done by asking learners to agree or disagree to a series of 52 statements to which the students respond on a 5-point Likert scale, indicating the strength to which they agree (5) or disagree (1) with each statement. The 52 statements combine to give 13 subscales, with each subscale being made up of 4 statements. Of the 13 subscales, 4 combine to yield a deep approach, 5 to a strategic approach, and 4 to a surface approach. The score for each approach is obtained by summing the scores for each subscale, with a maximum score of 80 for deep and surface, and 100 for strategic. To standardise the scores deep and surface are divided by 4, and strategic by 5 giving a standard, comparable maximum score of 20. See Appendix 2.4 for ASSIST inventory.

Example of statements in the inventory that learners are asked to agree/disagree with:
'It's important for me to be able to follow the argument, or to see the reason behind things' – agreeing with this would indicate a deep approach
'I look carefully at tutors' comments on course work to see how to get higher marks next time' - agreeing with this would indicate a strategic approach
'I tend to read very little beyond what is actually required to pass' - agreeing with this would indicate a surface approach

The second part of the ASSIST inventory is to determine the learners preference for different types of course and teaching. This is done in a similar manner as before, asking students to indicate their level of agreement with a series of statements (8), by responding on a Likert scale of 1 to 5. It is structured so that four of the statements combine to make a composite score for courses and teaching which 'support understanding' and the other four combine to make a composite score for courses and teaching which 'transmit information'.

Examples of statements in the inventory that learners are asked to agree/disagree with:
'Lecturers who encourage us to think for ourselves and show us how they themselves think' - agreeing with this would indicate a preference for teaching which supports understanding
'Lecturers who tell us exactly what to put down in our notes' - agreeing with this would indicate a preference for teaching which transmits information

These are two very extreme stances on lecturing style and the other statements are similarly polar opposites of each other with regard to exams, courses and textbooks. Therefore, though the results from this part are analysed and discussed it is done with the proviso that these are only indicators of student preferences and that in reality students are probably not so extreme in their views on teaching style.

The ASSIST inventory also proposes the relationship between a preference for teaching which supports understanding and a deep approach, and the relationship between a preference for teaching which transmits information and a surface approach. Through factor analysis, all these constructs shall be investigated. (The scoring key for the survey is available on the Enhancing Teaching and Learning web page[22].)

2.2.2: RELIABILITY ANALYSIS FOR ASSIST

There are many statistical techniques used to evaluate internal consistency including Cronbach's Alpha[23]. This is a commonly used statistical technique for evaluating the internal consistency of a scale in which several numerical items are added together to arrive at a composite score, as in the ASSIST survey. A high alpha value indicates good internal consistency (>0.7)[24]. In Table 2.3, a series of alpha coefficients are given from various studies on students approach to learning, carried out in various disciplines and the results from this research. Various inventories were used in these studies.

Table 2.3: Comparison of internal reliability for this work to other published data

DISCIPLINE	INVENTORY	DEEP	STRATEGIC	SURFACE
ETL Project[22]	ASSIST	0.84	0.80	0.87
Physics/Chemistry/Psychology[25]	ASSIST	0.83	0.87	0.83
Medical [26]	ALSI	0.66	0.68*[1]	0.64
Pharmacy[27]	ASSIST	0.68	0.84	0.81
Accounting[28]	ASSIST	0.88	0.89	0.79
Business and Management[29]	RASI	0.79	0.83	0.78
Psychology[30]	ASI	0.62	0.58	0.72
Science (Chemistry)[31]	SPQ	0.50		0.80
Chemistry (DCU 01-02)*[2]	ASSIST	0.83	0.84	0.68
Chemistry (DCU 02-03) *[2]	ASSIST	0.81	0.80	0.74
Chemistry (DCU/UOW 03-04) *[2]	ASSIST	0.82	0.83	0.74
Chemistry (DCU 04-05) *[2]	ASSIST	0.84	0.87	0.77

*[1] In the ALSI, a strategic-type approach is represented by two factors: monitoring study and organised study/effort management   *[2] Data from this research

The majority of the results show a high level of reliability (i.e. > 0.7). Results from this research are also included in Table 2.3, and analysis shows high Cronbach's alpha values for all sample cohorts indicating a high level of internal consistency in this work.

The reliability of the 13 individual ASSIST subscales is also important and can be determined in a similar manner by determining a value for Cronbach's alpha. The results of the four first year cohorts from this research were analysed and Cronbach's alpha determined. These values were compared with results from the ETL project[22] (a study of 817 first year university students from 6 British universities who completed ASSIST). See Table 2.4. Values obtained compare favourably to the ETL project (Table 2.4) and other studies.

Table 2.4: Cronbach's alpha for the 13 subscales, comparison of DCU work to ETL project

SUBSCALE	DCU 01-02	DCU 02-03	DCU/UOW 03-04	DCU 04-05	ETL PROJECT[22]
Seeking meaning	0.49	0.59	0.59	0.63	0.57
Relating ideas	0.68	0.53	0.57	0.58	0.59
Use of evidence	0.46	0.49	0.54	0.70	0.53
Interest in ideas	0.47	0.63	0.72	0.76	0.76
Organised studying	0.57	0.58	0.57	0.59	0.54
Time management	0.68	0.70	0.74	0.74	0.68
Alertness to assessment demands	0.55	0.57	0.60	0.59	
Achieving	0.63	0.67	0.63	0.72	0.76
Monitoring effectiveness	0.41	0.61	0.56	0.63	0.62
Lack of purpose	0.67	0.73	0.71	0.80	0.76
Unrelated memorising	0.53	0.56	0.60	0.66	0.57
Syllabus-boundness	0.55	0.58	0.61	0.65	0.55
Fear of failure	0.64	0.74	0.75	0.77	0.69

A study investigating nursing students' approaches to studying[32] using the Approaches to Studying Inventory[12] showed Cronbach's alpha coefficients for each subscale ranging from 0.26 to 0.76. Another study[29] reports that though alpha coefficients were satisfactory for the three defining approaches of the Revised Approaches to Studying Inventory[13], they were inadequate for the 12 subscales. Alpha coefficients ranging from 0.46 to 0.77 were obtained in this research with many of the subscales demonstrating below satisfactory reliability (i.e. < 0.7). 'Time management', 'Lack of purpose', and 'Fear of failure' are the three most reliable subscales, showing consistency over the four cohorts. However, since the three main approaches show high reliability, and the subscales show comparable alpha coefficients to other studies the inventory is reported to be consistent.

The second part of the inventory investigates students' preference for different types of course and teaching. Table 2.5 shows the alpha coefficients for teaching and course preferences for the three first year cohorts. It is clear from the table that the preferences show high reliability with alpha values of 0.64 to 0.78 obtained. These values are overall greater than alpha values reported in the ETL study[22].

Table 2.5: Cronbach's alpha for preferences for different types of teaching and course – comparison of DCU data to ETL project[22]

PREFERENCE	DCU 01-02	DCU 02-03	DCU/UOW 03-04	DCU 04-05	ETL PROJECT[22]
Supporting Understanding	0.69	0.71	0.74	0.68	0.62
Transmitting Information	0.70	0.78	0.69	0.64	0.69

2.2.3: CONSTRUCT VALIDITY

A detailed factor analysis was carried out on the completed inventory data to confirm the structure of the survey, i.e. to check that combining, for example, the scores from the four deep subscales (seeking meaning, relating ideas, use of evidence and interest in ideas) to give one overall factor called deep is in fact statistically valid.

The first step when carrying out a factor analysis is to determine if a factor analysis is useful for the data. This is done by checking sampling adequacy, using the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy, and Bartlett's Test of Sphericity. The KMO Measure of Sampling Adequacy is a statistic, which indicates the proportion of variance in your data that might be caused by underlying variables. Bartlett's test of sphericity tests the hypothesis that your correlation matrix is an identity matrix, which would indicate that your variables are unrelated and therefore unsuitable for structure detection. The next step is to decide which extraction method to use. There are different methods for extracting factors from a set of data, with PCA (principle components analysis) and PFA (principle factors analysis) being the most frequently used. PFA, also called principle axis factoring, is a form of factor analysis, which seeks the least number of factors, which can account for the common correlation of a set of variables,[33] and this is the extraction method used in this research. A rotation method must next be decided. The purpose of rotating the factors is to get the variables to load either very high or very low on each factor. This makes the output more understandable and is usually necessary to facilitate the interpretation of the factors. A varimax solution yields results, which make it as easy as possible to identify each variable with a single factor. This is the most common rotation option, and the one used in this research. The eigenvalue for a given factor measures the variance in all the variables, which is accounted for by that factor. If a factor has a low eigenvalue, then it is contributing little to the explanation of variances in the variables and is often ignored as redundant compared with more important factors[33].

A factor analysis as described above was carried out for each set of data from the four first year cohorts described in this research. The initial tests, KMO Measure of Sampling Adequacy and Bartlett's Test of Sphericity, showed that a factor analysis was useful for the four first year cohorts. The value of KMO was 0.74, 0.77, 0.87 and 0.77 for the four first year cohorts and a value of 0.5 [34] is reported as the cut-off point, below which a factor analysis will not be useful for the data. Thus demonstrating that a factor analysis is useful for each cohort. Secondly, Bartletts's Test of Sphericity supports this, since the four cohorts show significance below 0.05. See Appendix 2.1 for the raw data. The factor analysis in each cohort accounts for 58%, 53%, 52% and 59% of the variance for the four first year cohorts: 01-02, 02-03, 03-04 and 04-05 respectively, comparable to the 54.5% reported in the ETL project[22]. This means that for example 58% of the variance between the subscales is explained by the factor analysis, therefore indicating that the majority of the variance between the subscales can be explained by the three factors in Table 2.6.

Table 2.6 shows the factor analysis for one of the first year cohorts (DCU/UOW, 03-04). It is clear that three distinct factors are extracted, with factor 1 corresponding to a strategic approach, factor 2 to a deep approach, and factor 3 to a surface approach.

Also, the subscales, in the majority of cases, are factored correctly in to each approach. Eigenvalues below 0.3 have been discarded as per other factor analysis studies[22,32].

Table 2.6: Factor analysis for the first year cohort 03-04 with eigenvalues below 0.3 discarded

SUBSCALES\FACTORS	1	2	3	
Seeking meaning	0.324	0.671		Deep
Relating ideas		0.763		
Use of evidence		0.740		
Interest in ideas		0.633		
Organised studying	0.798			Strategic
Time management	0.848			
Alertness to assessment demands	0.385			
Achieving	0.732			
Monitoring effectiveness	0.606	0.423		
Lack of purpose			0.516	Surface
Unrelated memorising			0.673	
Syllabus-boundness			0.648	
Fear of failure			0.717	
Supporting understanding		0.546	-0.349	
Transmitting information			0.463	

It is also clear from the factor analysis that 'supporting understanding' is factored with a deep approach, and 'transmitting information' is factored with a surface approach. This confirms the structure of the survey, and thus validates its construct with this sample. Results from the other two factor analyses show similar findings. See Appendix 2.1. An investigation across the three analyses reveals that the deep subscale 'Seeking meaning' is also factored with a strategic approach in each study. Secondly, that in three of the four studies the strategic subscale 'Monitoring effectiveness' is also factored with a deep approach. This is also reported in the ETL project[22], where monitoring effectiveness has a loading of 0.45 in deep, as well as a significant loading in strategic. In contrast to the other subscales the 'Alertness to assessment demands' subscale shows very low loadings across the three factors especially in 2002-2003 and 2003-2004. See Table 2.7 for details. Despite these findings, it was decided to maintain 'Seeking meaning' as a deep subscale only and to keep 'monitoring effectiveness' and 'alertness to assessment' as strategic subscales only. In the case of 'seeking meaning' and 'monitoring effectiveness' this was due to the fact that the eigenvalues were highest for these subscales in their intended approaches i.e. deep and strategic and therefore still fit in with the ASSIST structure. Whereas for 'alertness to assessment' there was no definitive trend, however, it was decided that since two of the four cohorts showed the expected trend the original structure of the ASSIST inventory would be adhered to.

Table 2.7: Eigenvalues for 'Alertness to assessment demands' across the three factors

COHORT	STRATEGIC	DEEP	SURFACE
DCU 01-02	0.626	0.242	0.244
DCU 02-03	0.243	0.246	0.315
DCU/UOW 03-04	0.385	0.221	0.228
DCU 04-05	0.591	0.128	-0.152

A cohort of Leaving Certificate students also completed the ASSIST surveys and this data has also been validated. See Appendix 2.1. Overall, ASSIST has been validated for use with all the samples in this study.

2.3 – USE OF ASSIST TO DETERMINE STUDENTS' APPROACH TO LEARNING

The objectives of this study are to determine the approaches to learning of science students at the early stages of their undergraduate degrees, and also to investigate the preferences which these students have for different types of teaching. Similarities and differences between various groups of students will be investigated including gender and age as well as differences across universities. Finally, the relationship between academic achievement and approach to leaning is investigated. However, before discussing the results of these studies, it is necessary to describe the type of statistical tests which are used in the study. All the analysis was carried out using the Statistics Package for Social Sciences (SPSS for Windows, Version 11.) A detailed timescale of the main study, showing which students took part in the surveys and when, is described further on in Section 2.3.3. However, a brief description is given here. An initial investigation was carried out with the 2001-2002 first year intake as well as with the 4th year students from that year. Following analysis of the resulting ASSIST data, a more detailed and comprehensive study was carried out with the three science intakes from 2002-2003, 2003-2004 and 2004-2005 (See Figure 2.5, Pg 123). Each cohort was sampled at the beginning of first year and at various stages after.

2.3.1: STATISTICAL TESTS

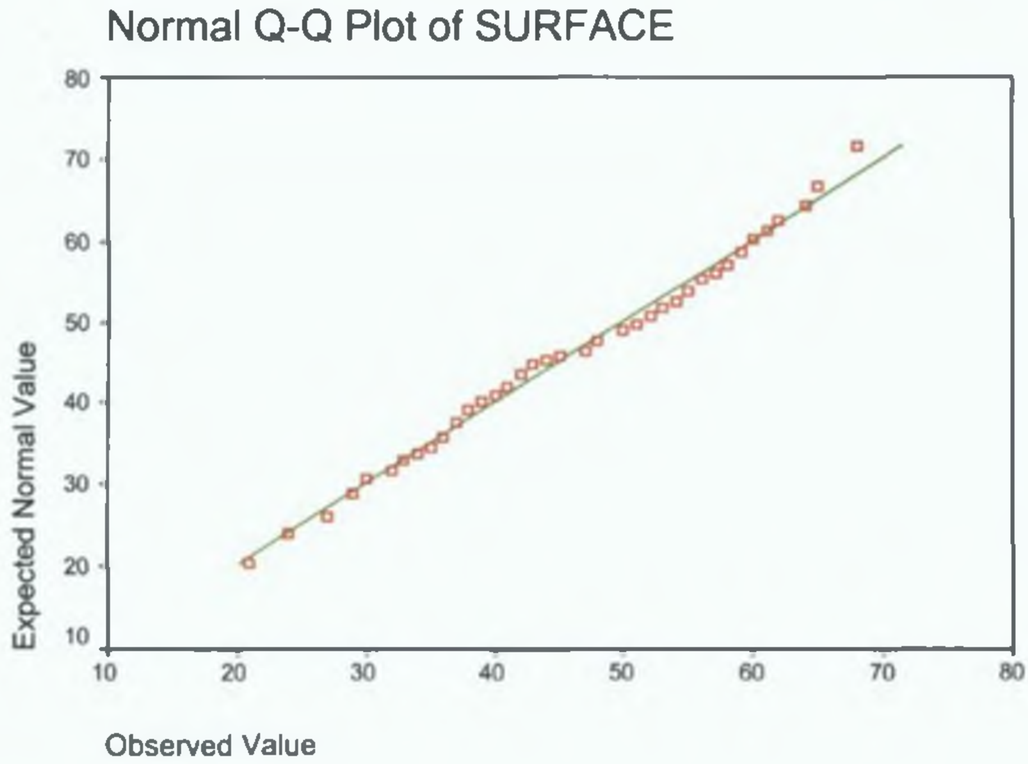
When considering two sets of data, it is not enough just to consider differences in mean values. The differences between the distributions around the means must also be considered. This is done using t-tests. There are two t-tests frequently used to compare the means of two samples: paired and independent t-tests. In both cases, to use the t-test there are three assumptions about the data being analysed[35]:

1. The dependent variables are measured on an interval or ratio scale
2. The underlying population from which the sample data are taken has a normal distribution
3. When differences of statistical association are being analysed between two or more samples, the standard deviations of these samples do not differ significantly.

Therefore, before using the t-tests, we must first determine if these three assumptions are valid for the current research data. In the case of the ASSIST data, the dependent variables (the variables whose values you are trying to summarise e.g. deep, strategic and surface) are measured on a continuous basis (having values within a defined range), and so assumption one is valid.

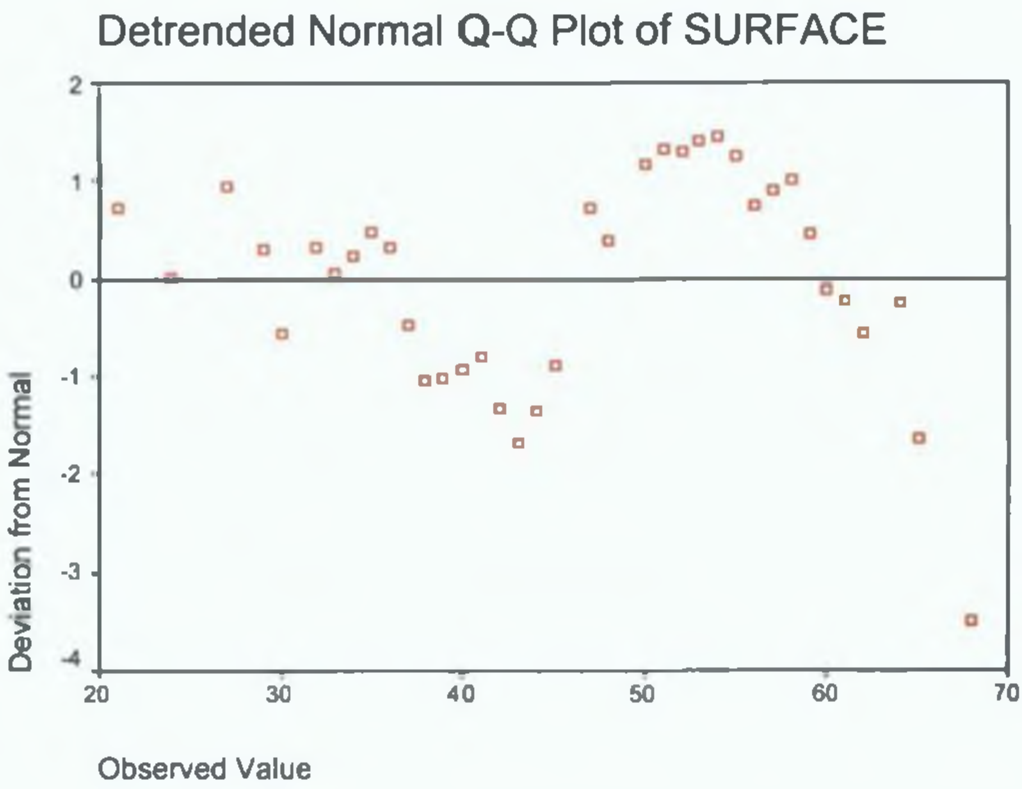
To test for normal distribution, there are a variety of tests available including evaluating the skewness and kurtosis of the data, displaying a normal distribution curve on the histogram of the data, and using a probability plot. It was decided to do probability plots of each approach to determine if the data was normally distributed. In SPSS this is done by choosing 'Q-Q' (Quartile-Quartile) from the 'graphs' menu. Two plots are produced: (a) the normal Q-Q plot which is a plot of the observed value of the variable plotted against the corresponding value if the data is from a standard normal distribution and (b) the detrended Q-Q plot, which is a plot of the differences between the observed values and the corresponding predicted values if the sample is from a normal distribution. If the data is from a normal distribution, then the points in the normal Q-Q plot would be clustering around the straight line[35]. Figure 2.2 shows the normal Q-Q plot for the surface approach for 1st years from the start of semester 1 2002-2003, showing the data as normally distributed.

Figure 2.2: Normal Q-Q plot for the surface approach for 1st year cohort semester 1 2002-2003



If the sample is from a normal distribution, the points in the detrended Q-Q plot (b) would cluster in a horizontal band around zero with no pattern. This is the case for the surface approach for the same sample cohort as above[35]. See Figure 2.3. Q-Q plots were done for each cohort and approach and all showed to be normally distributed. See Appendix 2.2. Therefore assumption two above is shown to hold for this data.

Figure 2.3: Detrended normal Q-Q plot for the surface approach for 1st year cohort semester 1 2002-2003



The third assumption is that there is no significant difference between the variances of the two populations, where variance is the spread of the distribution. SPSS carries out this test automatically by using 'Levene's test for equality of variance'. Levene's test is used to test if samples have equal variances or 'homogeneity of variance'. The variances of two samples are significantly different if $p < 0.05$. Since standard deviation is the square root of the variance it is also possible to do a simple check on the standard deviations, if they are fairly close it is a good indication that there is homogeneity of variance. This test is automatically carried out each time an independent t-test is done.

Once these three assumptions have been shown to hold for the data, the data can be classed as parametric. Paired and independent t-tests can then be carried out to compare the means of two samples. The t-test is used for testing the null hypothesis, H_o that two population means, μ_1 and μ_2, are equal; H_o: $\mu_1 - \mu_2 = 0$. Therefore the null hypothesis is rejected if $\mu_1 - \mu_2 \neq 0$. The 'paired t-test' tests that there is no significant difference between the population means of two matched populations, for example a paired t-test is used in this research to test if a cohorts means for a deep and surface approach are significantly different.

The formula for calculating the t-value is given below[23]:

$$t: \frac{\bar{d}}{Sd\sqrt{n}}$$

where $\bar{d}$ the mean of the differences between the means

Sd the standard deviation

n the number of matched/paired samples

If the t-value is less than the corresponding t-value from the t-tables (see Appendix 2.3), then there is no significant difference between the means. However, if the t-value is greater than the corresponding t-value from the t-tables, then there is a significant difference between the means. For example a paired t-test comparing the means of deep and strategic approaches gives a t-value of 1.302, whereas a paired t-test of deep and surface yields a t-value of 5.972. From the t-tables using the appropriate degrees of freedom (df), $\nu = n-1$, and a confidence level of 95%, the t-value is 1.987 ($\nu = 90$). It is clear then that there is no significant difference between the students preference for a deep or strategic approach, but there is a significant difference between their preference for a deep over a surface approach. Using SPSS, the paired t-test also gives a value for significance, and this takes out the need to use the tables. 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. Table 2.8 shows a portion of the output from the two paired t-test mentioned above, showing no difference between deep and strategic approach since p is greater than 0.05 but showing a significant preference for deep over surface for this cohort since p is less than 0.05.

Table 2.8: Paired t-test data for 1st year cohort start semester 1 2002-2003

	t	df	p
Deep-Strategic	-1.302	87	0.196
Deep-Surface	5.972	90	0.000

In Table 2.8 t is the t-test statistic, df is the degrees of freedom and p is the significance. This is standard notation which is used throughout the results.

An 'independent t-test' tests that there is no significant difference between the population means of two populations. For example, in this research, independent t-tests are carried out to compare the means of male and females cohorts for each approach.

The formula for calculating the t-value is given below[23]:

$$t: \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{Sp^2}{n_1} + \frac{Sp^2}{n_2}}} \quad \text{where } Sp^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

where $\bar{x}_1, \bar{x}_2$: the means of samples 1 and 2

n_1, n_2: the size of samples 1 and 2

S_1^2, S_2^2: the standard deviations of samples 1 and 2

Sp^2: the pooled variance of samples 1 and 2.

The same rules apply for testing significance as for paired t-tests. Table 2.9 below give results from independent t-tests carried out comparing males to females for two of the strategic subscales: alertness to assessment demands, and monitoring effectiveness.

Table 2.9: Independent t-test data for 1st year cohort week 1 semester 1 2002-2003

MALE V FEMALE	Levene's test		t	df	p
	F	p			
Alertness to assessment demands	0.236	0.628	-0.306	92	0.761
Monitoring effectiveness	1.194	0.277	-2.678	91	0.009

where F is Levene's Test statistic, p is the significance

Both tests show that the variances are not significantly different since Levene's significance > 0.05, therefore the independent t-test is appropriate for this data. The tests reveal that male and females are not significantly different in terms of 'Alertness to assessment demands', since significance > 0.05, but are significantly different in terms of 'Monitoring effectiveness', since significance < 0.05. In the event of data not showing homogeneity of variance, a Welch test is carried out which is automatically carried out in SPSS when an independent t-test is selected. This is another basic test which is used to test if the means of two samples differ, but is used when the assumption of equal variances does not hold.

ANOVA (Analysis of Variance) and Repeated Measures ANOVA are used to test the differences between more than two samples, for example a repeated measure ANOVA would be used to test the difference in the mean score for a deep approach at different sampling intervals, such as at week 1, week 12, week 24 etc. This is an extension of the paired t-test since the same students are being analysed. An ANOVA can also be used to test the difference in the score for deep between more than two independent samples, such as between students from different degree classes. This is an extension of the independent t-test.

Correlation investigates if there is a relationship between two or more variables showing if there is positive association, negative association or no association. In this research correlation is used, for example, to investigate the relationship between approach to study and academic performance. A positive association would mean that high values in one variable are correlated with high values in the other variable, whereas a negative correlation would mean that high values in one variable are correlated with low values in the other variable. A scatterplot gives an indication of the type of relationship, and a correlation coefficient, ρ, provides an exact measure of the strength of the relationship. Values from -1 to $+1$ are obtained, with -1 meaning a perfect negative association, 0 meaning no association, and $+1$ meaning a perfect positive association. In reality, there will never be perfect correlations of $+ 1$ or $- 1$, nor correlation coefficients of 0. Instead, 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. There are two important things to note about correlation coefficients: one is that they only measure linear relationships, and secondly, they do not imply 'cause', i.e. that high marks in exams cause a deep approach or vice versa[36].

Figure 2.4 shows a scatterplot for end of semester marks in the practical chemistry module and scores for a surface approach for the Science Education 1st year cohort sampled at the end of semester 1 (including students from the 2003-2004, and 2004-2005 intake). Pearson's r (rho) is used to calculate correlation when both variables are numeric and the data is normally distributed, as in this research. If the calculated value of r is greater than the tabulated critical value, see Appendix 2.3, the null hypothesis, that there is no significant correlation between the two variables, is rejected. As with the t-tests, SPSS automatically displays whether or not correlations are significant. Table 2.10 gives Pearson's r and significance for the same data. It is clear that there is a negative association between performance and a surface approach.

Figure 2.4: Scatterplot for semester 1 laboratory marks against mean score for a surface approach

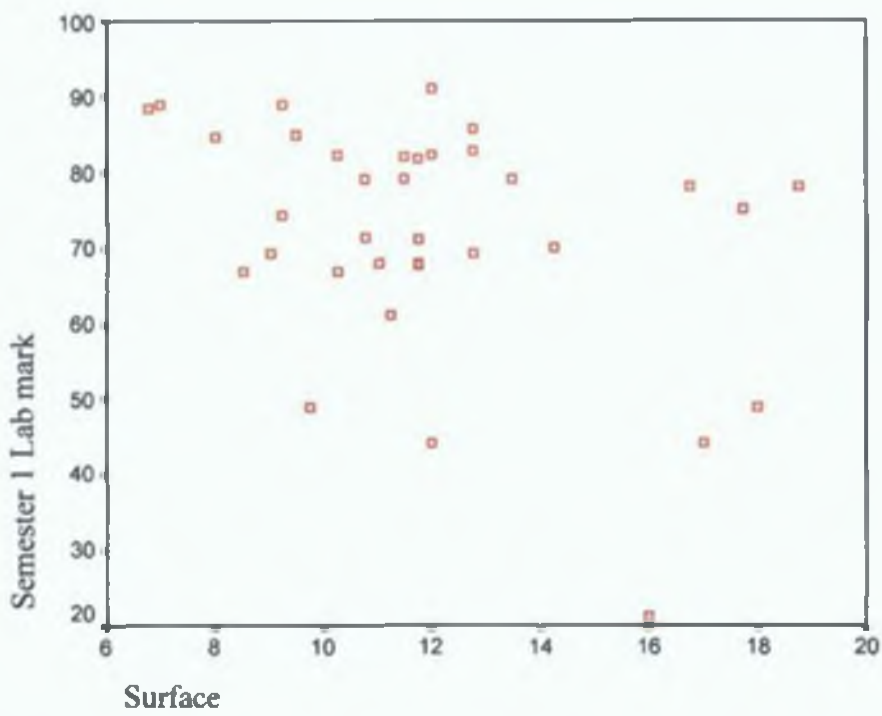


Table 2.10: Pearson's r and significance for semester 1 marks and a surface approach for the Science Education students 2003-2004 & 2004-2005

		SURFACE
SEMESTER 1	Pearson Correlation	**-.389**
	Sig. (2-tailed)	.021
	N	35

Pearson's rho is calculated using the formula below[37]:

$$\frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\left\{\left[\sum(x_i - \bar{x})^2\right]\left[\sum(y_i - \bar{y})^2\right]\right\}^{\frac{1}{2}}}$$

where (x_i, y_i) are co-ordinates and $\bar{x}$ *and* $\bar{y}$ are the means.

Paired and independent tests are used to investigate differences between the means in this research and Pearson's r is used to test the correlation. The use of these tests for this data has been shown to be valid.

2.3.2: INITIAL INVESTIGATION

In the second semester of the academic year 2001-2002, a cohort of 1st year undergraduate science students from the Faculty of Science and Health, taking a compulsory practical chemistry module (CS151) were given the option of completing ASSIST as an initial trial of the inventory. See Appendix 2.4 for ASSIST inventory. Also, a smaller cohort of 4th year students were given the option of completing the survey. These 4th year students were all taking chemistry as their major degree subject. Table 2.11 gives details of the number in each cohort (N), and mean score for each approach with standard deviation. The reason for the difference in number within a particular group of students is due to some students not completing the survey or forgetting to answer a particular question, resulting in incomplete data. For example a student might have a score for deep and surface but not strategic.

Table 2.11: Overview of statistics for the 2001-2002 1st and 4th year cohorts[38]

APPROACH	1ST YEARS 01-02			4TH YEARS 01-02		
	N	MEAN	ST DEV	N	MEAN	ST DEV
Strategic	70	13.45	2.55	18	14.18	2.63
Deep	77	13.23	2.62	17	13.26	2.32
Surface	79	12.73	2.47	18	12.07	2.69

These initial investigations revealed that both cohorts showed the same trend for approaches to learning: strategic, deep then surface. For the 1st year cohort these differences are not significant. However, for the 4th years, there is a significant preference for a strategic approach over both deep and surface at 99% and 90% confidence respectively. Comparison of the 1st and 4th year cohorts reveal that there is no difference in terms of their overall approach to learning but an independent t-test shows that 1st years score the surface subscales 'lack of purpose' and 'fear of failure' significantly higher than their 4th year counterparts but the 4th year cohorts score the strategic subscale 'alertness to assessment demands' significantly higher.

A preliminary investigation into gender differences in this cohort revealed that for the 1st year group there is no difference in terms of overall approach, however, t-tests showed that females scored 'monitoring effectiveness' and 'fear of failure' higher than their male counterparts. 4th year females also scored 'fear of failure' significantly higher than their male counterparts. Table 2.12 shows the breakdown of the two cohorts in terms of gender showing a good spread over both cohorts.

Table 2.12: Cross-tabulation of year and gender for the academic year 2001-2002

	YEAR		
GENDER	1st year	4th year	Total
Male	31	9	40
Female	55	9	64
Total	86	18	104

In terms of preferences for different types of teaching and course, when paired t-tests were carried out both cohorts revealed a highly significant preference for teaching and courses which transmit information over teaching and courses which support understanding. The results for each cohort are given in Table 2.13 where the difference between the means for the two preferences are given. Since the significance is < 0.05 in both cases, the differences are significant at 95% confidence. This preference for teaching which transmits information is in contrast to their preference for a deep approach, associated with a preference for teaching which supports understanding.

Table 2.13: Paired t-test results for preference for teaching for the 1st and 4th years

Supporting understanding – Transmitting information	Mean Difference	St. Dev.	t	df	p
1st years	-5.1	5.2	-8.888	81	0.000
4th years	-2.8	4.8	-2.880	16	0.030

These results suggested ASSIST has the potential to compare and contrast students' approach to learning effectively and their preference for different types of course and teaching. Also, the results showed that the student body had preferences for different style of teaching and tendencies for particular approaches and therefore a more detailed study was embarked on.

2.3.3: INVESTIGATION OF UNDERGRADUATE SCIENCE STUDENTS' APPROACHES TO LEARNING

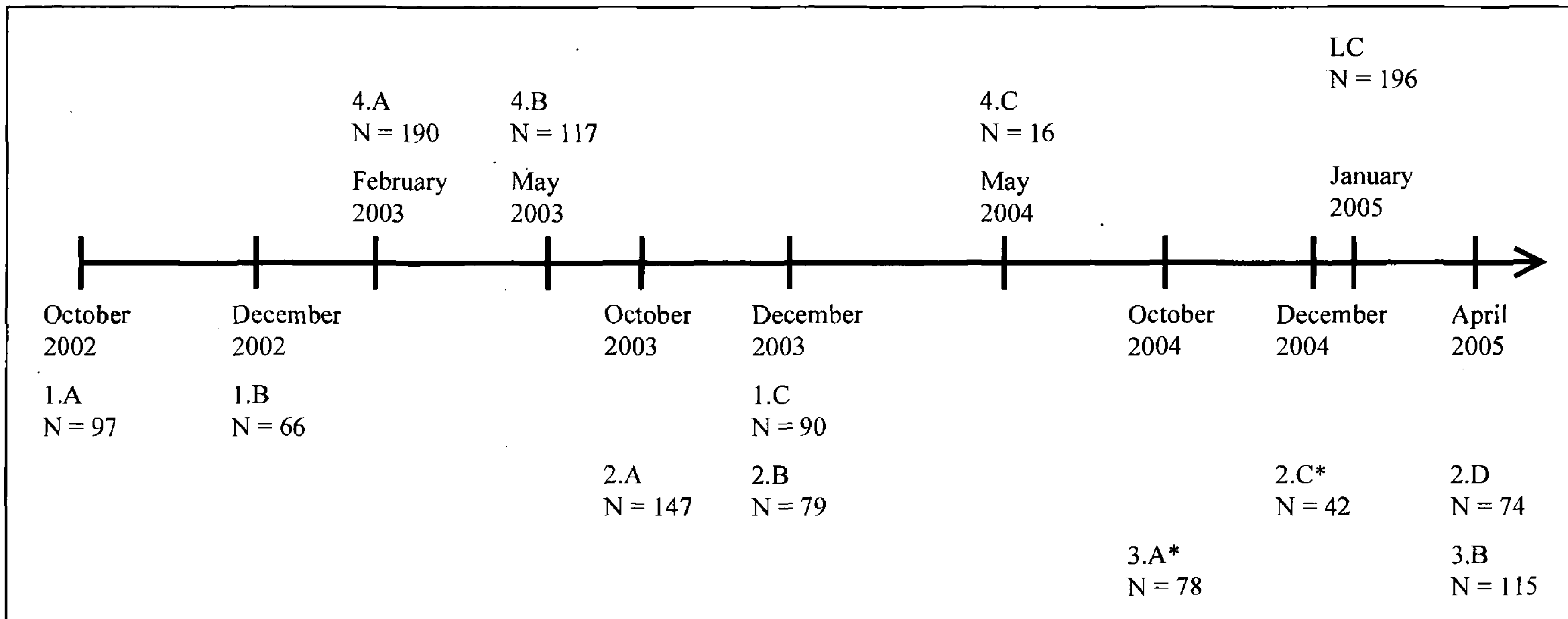
Following the initial investigation, a more comprehensive study was carried out with first year science students starting in October 2002 with a sample of the first year intake. This was repeated in the following two years with the 2003 and 2004 intake. Each of these groups of students were then sampled at various stages during their first and second years according to the 'Timescale for Sampling of ASSIST Inventory' shown in Figure 2.5. To allow for comparison, a first year intake from the University of Wollongong (UOW), Australia was also surveyed in 2003, with follow-up sampling. Similarly, a group of 6th Year Leaving Certificate students were surveyed, to give an indication of approaches to learning of students nearing the end of schooling.

The aim of the study was to investigate:

- The approaches to studying and learning of 1st year science students in DCU
- Students preferences for two extreme styles of teaching in DCU
- Similarities and differences between DCU and UOW
- The effect of gender and age on students approach and preferences for teaching
- The context of first year students' approaches to learning based on their experiences in school
- Correlations between academic achievement and approach to learning.

During the first week of the semester, students taking the Chemistry Laboratory module CS151 (i.e. all students taking Chemistry, Biotechnology, Science Education and Common Entry programmes) were given a short description of the research during their practical class, and were asked to fill out the survey. Data from ASSIST was entered and analysed in SPSS. This was repeated at various other sampling intervals as described. The standard scores for the three main approaches deep, strategic and surface were computed at each sampling interval as well as the scores for the preferences for different types of course and teaching, supporting understanding and transmitting information. The students completed the surveys voluntarily. In the majority of cases it was a hardcopy version, which students filled out by hand. On two occasions it was done electronically, however, this proved to give a low return with fewer students opting to complete it. Therefore, it was proposed that the hardcopy was the better method, despite the time taken to input all the data. However, all data was used and treated idenitically.

Figure 2.5: Timescale for Sampling of ASSIST Inventory



Legend: 2002-2003 DCU intake (1) — Initial survey (A) — 2005 Leaving Certificate (LC)

2003-2004 DCU Intake (2) — Second survey (B) — Electronic version (*)

2004-2005 DCU Intake (3) — Third survey (C)

2003 UOW Intake (4) — Fourth survey (D)

2.3.3.1: The 1st year experience in DCU and UOW

The University of Wollongong (UOW) in New South Wales (NSW) is approximately 100 kilometres south of Sydney. New South Wales is one of the seven states/territories in Australia. Each state/territory has its own education system. The public education and training system in New South Wales provides pre-school education, the compulsory years of schooling (from Kindergarten to Year 10), and senior secondary education leading to the award of the NSW Higher School Certificate (in Years 11 and 12). The Higher School Certificate is a locally, nationally and internationally recognised qualification for students who successfully complete secondary education in NSW. Students take a minimum of five subjects, of which English is the only compulsory subject. It is similar to the Leaving Certificate in Ireland since it gives students the following options: searching for a job, pursuing their studies or a combination of both. Further study can be achieved through TAFE (Technical and Further Education), or through the Universities Admissions Centre. These are both very similar to the PLC (Post Leaving Certificate) and CAO/CAS (Central Applications Office/Central Admission System) options available to students on completion of their Leaving Certificate. TAFE offers certificates, diplomas and advanced diplomas recognised by the Australian Qualifications Framework, and admission to most university courses is based on their performance in the Higher School Certificate. Applicants are ranked on the basis of their Universities Admission Index (UAI).

Wilson[45] commented in 1995 that undergraduate chemistry students in most Australian Universities begin tertiary studies with similar chemistry background – two years of chemistry study for the Higher School Certificate after four years of non-specialist science study. Undergraduates in Ireland have similar backgrounds – two years of specialist subjects after three years of general study, with the option of a transition year between. However, as was discussed in Chapter 1, Section 1.2.2 Australian students have to take compulsory science till 15, and approximately 23% opt to study chemistry for their Higher School Certificate. In contrast, science is not compulsory for Junior Certificate students in Ireland and only about 12% choose to study chemistry for the Leaving Certificate. Australian undergraduates are potentially a year younger than their Irish counterparts, with Australian students having the option of 13 years of school (compulsory to the age of 15) starting no later then the age of 6, whereas Irish students have the option of 14 years of school (compulsory to the age of 15) also starting no later than the age of 6.

UOW is a larger university than DCU, with 20,404 students enrolled in 2003, and 21,148 enrolled in 2004[39]. Of these approximately 14,000 are undergraduates. In comparison, DCU has approximately 10,000 students, with 2,337 students in the Faculty of Science and Health[40]. Within the Faculty of Science and Health there are various undergraduate degree programmes offered by the School of Chemical Sciences (SCS) including Analytical Science, Chemical and Pharmaceutical Science, Science International, Science Education, Environmental Science and Health and Common Entry into Science. The school also contributes to the Biotechnology, Nursing and Sports Science degrees. In UOW, the Department of Chemistry offers courses to the following degrees: Chemistry, Biotechnology, Environment (jointly with chemistry or physical science option), and Medicinal Chemistry. In addition a few Arts, Psychology and Law students enrol for some of the courses offered by the Department of Chemistry.

In DCU all of the students taking the above mentioned degree programmes take module CS151 (Chemistry laboratory) over the first two semesters as well as lecture modules CS101 (Inorganic and Analytical Chemistry) in semester 1, and CS102 (Organic and Physical Chemistry) in semester 2. The Chemistry laboratory module involves 3 hours per week, and similarly for the two lecture modules. UOW offer Chem101/104 in semester 1 and Chem102/105 in semester 2. There are two separate streams in the First year Chemistry course in UOW. Chem 101/102 is for students with a minimum Higher School Certificate grade in chemistry, whereas Chem104/105 is for students without an adequate preparation in chemistry who do not meet the requirement for Chem101/102. Students in this stream sit for the same examinations at the end of each semester as those for Chem 101/102 and therefore attain the same standard on completion, but they do receive more instruction each week. For example in semester 1, the students in Chem 101 have 2 x 1hr lectures per week, plus 1 hr on alternate weeks with invited lecturers, whereas the students in Chem 104 have 3 x 1hr lectures per week. Chem 101 have a tutorial every fortnight, whereas Chem 104 have a tutorial every week. They both do 3 hours practical per week.

The first year chemistry courses in both universities provide a common program in the foundations of Chemistry for all students whether intending to major in chemistry or other disciplines. First year students, from both DCU and UOW, come from varying chemistry backgrounds, from those who have taken specialist courses in chemistry at

Leaving Certificate or Higher School Certificate level in their fifth and sixth years in secondary school to those who have studied no chemistry in their last two years in school and have undertaken perhaps only a general science program to Junior Certificate level or year 10 in Australia. First year programmes must therefore cater for a wide variety of students' needs through a range of strategies which includes instruction through a combination of lectures, tutorials and laboratory classes.

Though both practical modules in DCU and UOW are introductory chemistry modules, they are some differences between them. Table 2.14 outlines the semester 1 course week-by-week for DCU and UOW. It is apparent from this, that DCU cover analytical experiments in the first semester, mainly titrimetric analysis, whereas UOW cover a wider variety of topics. This is also the case in semester two, see Table 2.15, where DCU cover physical chemistry in the first half, and organic chemistry in the second half, and UOW cover a broader range of topics again. However, there are many experiments, which are very similar in both, for example the preparation of aspirin, volumetric analysis and the ideal gas law. In UOW the lecture course runs in tandem with the practical module providing a link between the two.

Another major difference between the two modules is that the UOW cohort is required to do a prelab exercise before each experiment, and the students are not allowed to do the experiment unless it is completed. This can vary from a written prelab to a computer-based exercise. The Multimedia PreLab[41] project was designed to provide opportunity for a well-structured preparation for laboratory classes together with monitoring of student responses to this process, thus ensuring that each student had successfully undertaken the required tasks before they entered the lab. This had the potential to reduce the demand on laboratory staff for routine help and enable them to concentrate more on assisting with a smaller number of individual problems largely related to the chemical fundamentals in which they do have considerable expertise[41]. There is no prelab exercise for the DCU cohort, apart from the Science Education degree course first years who are required to do a prelab as part of a problem-based learning module. This is discussed in detail in Chapters 3 and 4.

Table 2.14: Practical Timetable for DCU 2003-2004 and UOW 2003 Semester 1

	DCU SEMESTER 1 – ANALYTICAL CHEMISTRY	UOW SEMESTER 1 – CHEM 101/104
1	Lab techniques and safety	Safety talk and exercise, Demos
2	Preparation of primary standard and standardisation	Formula of a hydrated salt and acids, bases and salts
3	Analysis of baking powder and lemon squash	Chemistry of aluminium (W)
4	Hardness of water determination by EDTA titration	Thermochemistry (W)
5	Analysis of bleach by sodium thiosulphate titration	Volumetric analysis (CD)
6	NO LAB	Redox reactions (CD)
7	Analysis of iron in iron tablets	Test
8	Analysis of a sodium carbonate/sodium hydroxide mixture	Return of test
9	Determination of water of hydration of oxalic acid	Vanadium Oxidation States (CD)
10	Analysis of a halide mixture	Molar Mass of an Active Metal (CD)
11	Analysis of aspirin by back titration (TEST)	Water quality(W)
12	Qualitative analysis for anions and cations	Revision and shapes of molecules

* (W) – Written prelab, (CD) – Electronic prelab

Table 2.15: Practical Timetable for DCU 2003-2004 and UOW 2003 Semester 2

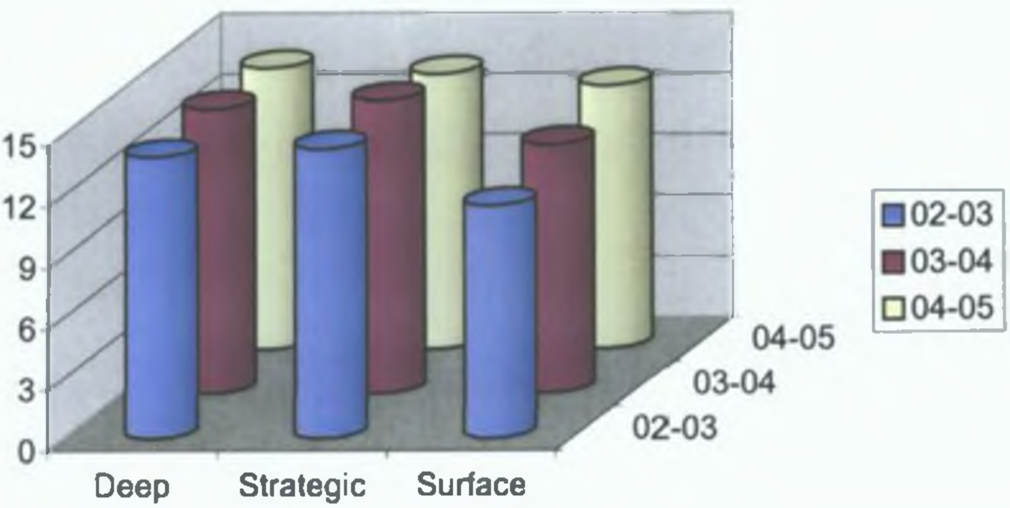
WEEK	DCU SEMESTER 2 - PHYSICAL CHEMSITRY	UOW SEMESTER 2 - CHEM 102/105
Students do 6 of the 9 experiments over 6 weeks.	Determination of the activation energy of a chemical reaction	1. Course information
	Calorimetric measurement of an enthalpy of neutralisation	2. Chromatography (CD)
	Microscale determination of the order of a chemical reaction and evaluation of the rate constant	3. Shapes of organic molecules (W)
	Microscale determination of the distribution ration of succinic acid between water and diethyl ether	4. Preparation of aspirin (CD)
	The comparison of light absorption mters using Jobs Method of Continuous Variation for the determination of the stoichiometry of the Cu(II)-EDTA Complex	5. Determination of vitamin C (CD) 6. Analysis of Radox bath salts (CD)
	Determination of the Ideal Gas Constant	7. Revision workshop
	Microscale Determination of Dissociation Constants of Weak Acids	8. TEST
	The determination of o-acetylsalicylic acid by Ultraviolet radiation	9. Reactions of alcohols (W)
	Simple experiments to illustrate Le Chatelier's Principle	10. Acid-base titrations (CD)
7	NO LAB	
8	Purification and Purity Determination	
9	Separation of an organic acid/base mixture by liquid-liquid extraction	11. Corrosion of metals (CD)
10	Microscale hydrolysis of trimryistin	
11	Dehydration of 4-methylpentan-2-ol and isolation of the products by distillation	12. Revision Workshop
12	Microscale synthesis of acetylsalicylic acid (aspirin)	

* (W) – Written prelab, (CD) – Electronic prelab

2.3.3.2: First year DCU science students approach to learning

At the initial intake, in all three years, there is a general trend in terms of students' approaches to learning. The students, in comparison to a surface approach, consistently score deep and strategic approaches higher. This is shown in Figure 2.6 where the average scores for each approach for each year is represented, and it is clear that deep and strategic approaches are scored higher overall compared to a surface approach.

Figure 2.6: Graph of average scores for each approach for each first year cohort



However, t-tests are needed to investigate if these differences in the mean scores are significant. Paired t-tests reveal that in all three years there is no significant difference between the mean scores for deep and strategic, this is indicated by the results in Table 2.16, where the significance value, p, is greater than 0.05 for all three years. This suggests that students use both deep and strategic approaches to a similar extent.

Table 2.16: Paired t-test for each year between deep and strategic

Deep-Strategic	Mean Difference	St. Dev.	t	df	p
02-03	-0.35	2.52	-1.302	87	0.196
03-04	-0.30	2.41	-1.479	137	0.141
04-05	0.35	2.71	1.117	73	0.268

In contrast, there is a significant difference between the means of the deep and surface scores for both the 2002-2003 and 2003-2004 cohorts, as indicated by the significance value, p, being less than 0.05 in Table 2.17. Also, since it is below 0.01, this difference is significant at 99% confidence. The 2004-2005 cohort also score deep higher but the difference is only significant at 93% confidence. Overall, these results suggest that students are more likely to use a deep approach over a surface approach.

Table 2.17: Paired t-test for each year between deep and surface

Deep-Surface	Mean Difference	St. Dev.	t	df	p
02-03	2.40	3.84	5.972	90	0.000
03-04	1.81	3.98	5.381	139	0.000
04-05	1.03	4.70	1.878	73	0.064

Finally, a paired t-test between the means for strategic and surface approaches reveals that in two of the three cohorts, there is a significant difference between these two approaches in favour of a strategic approach. This is indicated in Table 2.18, where the significance value, p, is less than 0.05 for the 2002-2003 and 2003-2004 cohorts showing that students will adopt a strategic approach over surface. However, though the 2004-2005 cohort has a higher mean for a strategic approach compared to a surface approach, the difference is not significant ($p = 0.275$).

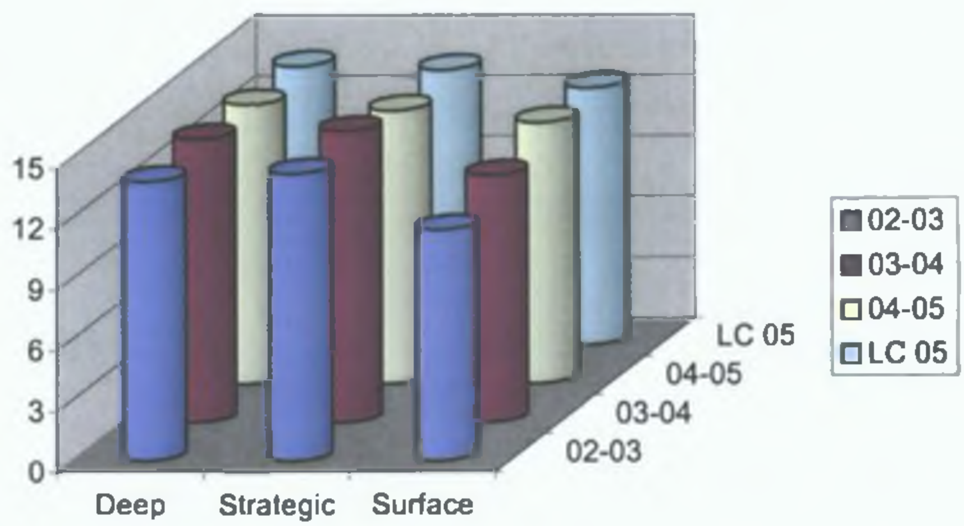
Table 2.18: Paired t-test for each year between strategic and surface

Strategic-Surface	Mean Difference	St. Dev.	t	df	p
02-03	2.79	3.60	7.417	91	0.000
03-04	2.26	3.61	7.295	135	0.000
04-05	0.60	4.68	1.101	72	0.275

The general trend is thus that students show a preference for deep and strategic approaches over surface. The most recent data is the only one which does not support this statistically. However, the trend is the same.

Since these initial surveys were collected in the first weeks of the students' time in university, it more accurately represents their approaches to learning and studying based on their previous experience in terms of studying and learning and how this might influence their future tendencies. The majority of students in these first year cohorts are recent school leavers, therefore it was decided to survey a group of 6th Year students who were in DCU doing a selection of Leaving Certificate chemistry experiments (January 2005). These students were preparing for their final examinations at school, the Leaving Certificate. The ASSIST inventory was adapted slightly to suit school students. See Appendix 2.5. Figure 2.7 shows that the general profile for the Leaving Certificate students is similar to that of the first years, with deep and strategic being scored higher in comparison to a surface approach.

Figure 2.7: Graph of average scores for each approach for each first year cohort and the Leaving Certificate cohort



The trend is supported by the paired t-test results where once again there is no significant difference between the deep and strategic approaches (p = 0.320), but a significant difference between deep and surface (p = 0.001) and strategic and surface (p = 0.018). See Table 2.19. This suggests that students are coming into third level with approaches to learning and studying which are based on their experience in school.

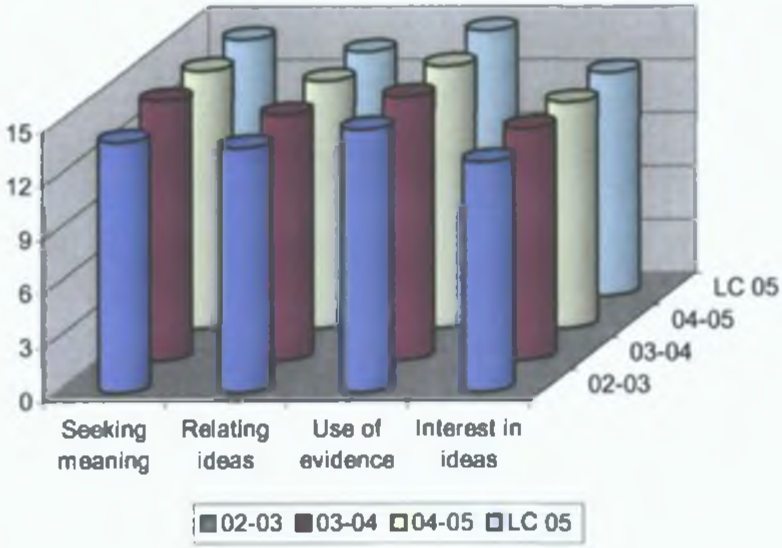
Table 2.19: Paired t-test for the LC cohort between each pair of approaches

LC 05	Mean Difference	St. Dev.	t	df	p
Deep-Strategic	0.23	2.85	0.998	155	0.320
Deep-Surface	1.20	4.73	3.259	163	0.001
Strategic-Surface	0.80	4.24	2.393	159	0.018

If it is that students are coming into college using deep and strategic approaches over surface then this is reassuring. However, perhaps these results indicate instead how students would like to learn but due to other factors, such as assessment demands, the teaching and learning environment etc they end up adopting a surface approach.

An analysis of the subscales for each cohort reveals that the trends are once again fairly similar across the three university cohorts and the Leaving Certificate cohort too. Figure 2.8 shows the average scores for each deep subscale for each first year cohort and the Leaving Certificate cohort.

Figure 2.8: Graph of average scores for each deep subscale for each first year cohort and the Leaving Certificate cohort



In each cohort use of evidence scores the highest, suggesting that this is an important factor for students when studying and learning. In contrast, interest in ideas is the lowest for each cohort, suggesting that an interest in the ideas and concepts which they are meeting in lectures, laboratories etc, has less of an influence over their approach to their studying.

A similar analysis of the strategic subscales reveals that organised studying is the lowest scored subscale within the strategic approach for all cohorts. See Figure 2.9. This suggests that students do not organise their study well. For example students would have scored low on these two statements within the ASSIST inventory.

> 'I'm good at following up some of the reading suggested by lecturers or tutors'.
>
> 'I usually plan out my week's work in advance, either on paper or in my head'.

Interestingly, time management is the second lowest subscale within the strategic approach, does this suggest that students struggle with basic study techniques? In contrast, students score highly on the monitoring effectiveness subscale, showing that students are very aware of how they are doing in their studying and academic work and want to do it to the best of their ability.

Figure 2.9: Graph of average scores for each strategic subscale for each first year cohort and the Leaving Certificate cohort

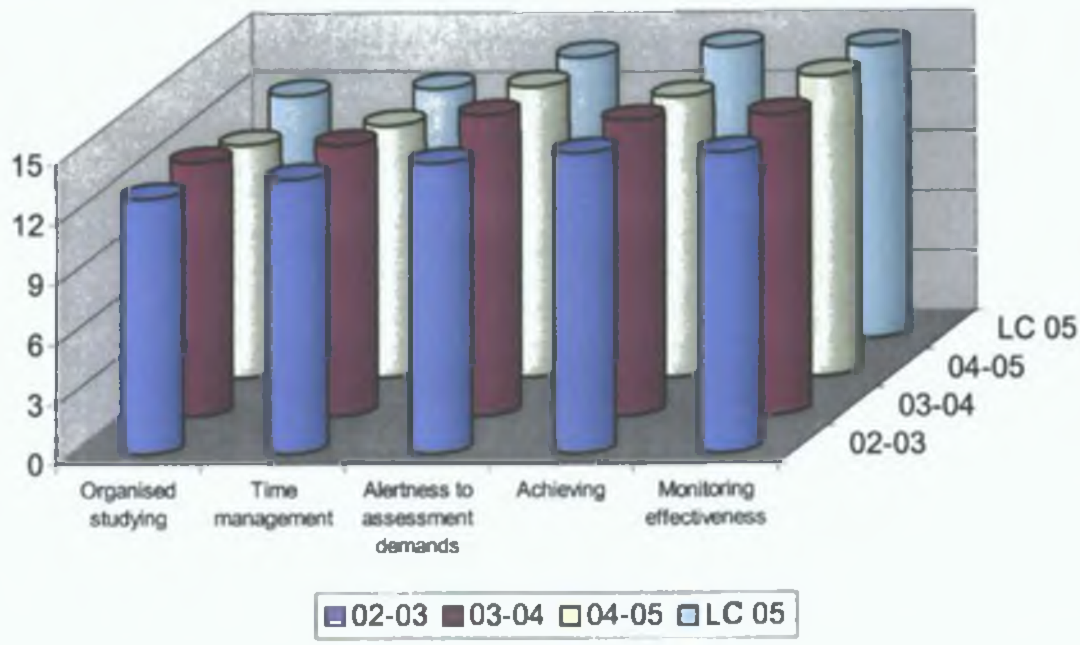
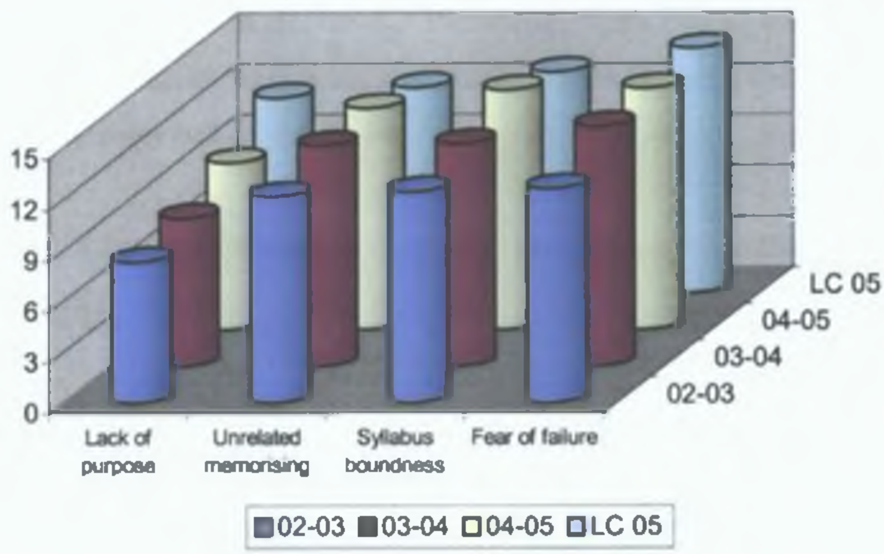


Figure 2.10 shows the average scores for each surface subscale for each first year cohort and the Leaving Certificate cohort. Students in all cohorts reveal that a fear of failure is the biggest influence on them adopting a surface approach, and this is highest in the Leaving Certificate students. This may be due to the pressure students were feeling due to the oncoming Leaving Certificate examination, where high competition for college places means it is important for students to do well. On a positive side, students score lack of purpose the lowest of all subscales, revealing that they generally feel a sense of purpose to what they are doing and would have scored low on statements in the ASSIST inventory such as:

> 'Often I find myself wondering whether the work I am doing here is really worthwhile'.
>
> 'There's not much of the work here that I find interesting or relevant'.

In comparison to the DCU cohorts, the Leaving Certificate cohort scores lack of purpose higher, this may suggest that students by the time they have reached university are more certain about what they are doing, and why they are doing it.

Figure 2.10: Graph of average scores for each surface subscale for each first year cohort and the Leaving Certificate cohort



Overall these trends suggest that students have a good approach to studying and learning combining deep and strategic approaches over surface. Since the majority of the DCU students are recent school leavers this suggests that students experience of studying and learning at school is generally a positive one. However a worrying trend would be the influence of fear of failure on students. Also, the fact that students rated themselves poorly on basic study techniques - time management and organised studying, suggests that though students have successfully completed their Leaving Certificate (or other prior education) they still struggle with study skills. Should study skills programmes be an integral part of undergraduate degrees?

The majority of interest in students approach to learning in literature is reserved for tertiary level students, though some studies have been done into approaches to learning of second level students[19,42]. The former reports on a comparison of deep and surface approaches to learning science in a school in mid-west U.S., whereas the latter investigates accounting students approach to learning in an Irish context. Chin & Brown[19] reports the use of the Learning Approach Questionnaire, which measures students tendency to learn meaningfully using a deep approach or by rote using a surface approach. The Learning Approach Questionnaire was used to assign students in terms of deep or surface and a selection of these students were then identified to take part in a more in-depth study. No overall data is provided with regard to the approach to learning profile of the students, however the report provides an insight into the ways that 'deep' students learn in science compared to 'surface' learners. Deep learners were said to venture ideas more spontaneously, ask more questions which focused on explanations and causes and give more elaborate explanations including relating to personal experience. On the other hand the surface learner asked questions which focused more on basic factual or procedural information and gave explanations which were reformulations of the question. The report suggests that some students were also using a mixed approach, combining aspects of deep and surface approaches[19].

Byrne & Willis[42] comment on the use of a surface approach for examination preparation for Leaving Certificate Accounting, where a high level of repetition and predictability on the examination papers can result in teachers and students restricting the coverage of the course. The report suggests that the predictability of the examination paper motivates students to increase the emphasis on the memorisation of past questions and rote-learning rather than developing an understanding of the principles and practices of accounting. This trend may also be observed in other Leaving Certificate subject examination papers, resulting in students adopting surface approaches based on the predictability of the paper. However, it has already been shown that Leaving Certificate students from this study indicated preferences for deep and strategic approaches.

The second part of the ASSIST inventory investigates the preferences students have for different types of course and teaching, with two extremes being recognised: teaching which transmits information and teaching which supports understanding. The extreme nature of these two styles of teaching has already been commented on (Section 2.1), taking this into consideration however paired t-tests reveal that students from DCU (all three cohorts) indicate a preference for courses and teaching which transmit information. See Table 2.20. This is highly significant at 99% confidence for each year. Might this suggest that students are indicating approaches to teaching which they are comfortable with, i.e. what they have previously experienced at school?

Table 2.20: Paired t-test for each year between teaching which transmits information and teaching which supports understanding

Transmitting information - Supporting understanding	Mean Difference	St. Dev.	t	df	p
02-03	3.41	5.33	-6.303	96	0.000
03-04	3.13	5.15	-7.474	151	0.000
04-05	4.10	5.02	-7.266	78	0.000

The LC cohort was given a shortened version of the preferences for different types of teaching on the ASSIST inventory, which encompassed only the first four of the original items. This was because it was felt that the other statements were not suitable for the Leaving Certificate students. The adapted statements are shown below:

a. Teachers telling us exactly what to put down in our notes
b. Teachers who encourage us to think for ourselves and show us how they themselves think
c. Exams which allow me to show that I've thought about the course material for myself
d. Exams or tests which need only the material provided in our class notes

The scores from statements a and d were combined to give a preference for teaching which transmits information, whereas the scores from b and c were combined to give a preference for teaching which supports understanding. On carrying out an analysis on these results it was decided to do a similar investigation with the DCU cohorts. All results are shown in Table 2.21. It is clear that the differences that were observed previously for the DCU cohorts are still observed even for this reduced test, with the three DCU cohorts scoring teaching which transmits information significantly higher than teaching which supports understanding. In contrast, the Leaving Certificate cohort indicates neither a preference for teaching which transmits information or teaching which supports understanding, with a significance value of p = 0.871. This raises the question are students immediately threatened by the pressures placed on them in college, and therefore feel more comfortable with this transmission mode of teaching, from lecturer to student?

Table 2.21: Paired t-test for each year between teaching which transmits information and teaching which supports understanding using only four of the statements

Transmitting information – Supporting understanding	Mean Difference	St. Dev.	t	df	p
02-03	1.04	3.05	3.365	96	0.001
03-04	0.78	3.09	3.134	153	0.002
04-05	1.26	2.93	3.856	79	0.000
LC 05	-0.04	3.55	-0.163	190	0.871

2.3.3.3: Comparison of DCU with UOW

How do trends with DCU science students compare to science students in UOW? A similar analysis was done initially to determine the overall trend in approach to studying and learning of science students from UOW. Paired t-tests revealed a very similar profile with students adopting deep and strategic approaches over surface. This is shown in Figure 2.11, where the average for each approach for each DCU cohort and the UOW cohort is shown. It is clear that the surface approach scored the lowest. The trend is supported by the paired t-test results where once again there is a significant difference between deep and surface (p = 0.000) and strategic and surface (p = 0.000). See Table 2.22. A significant difference is also observed between the means of the deep and strategic approaches. This is in part due to the large sample size (N = 173) and the low standard deviation (2.45), where despite the very small difference in the means of deep and strategic (mean difference = 0.42) a difference is noted at 95% confidence. This suggests that these students from UOW prefer to adopt a deep approach followed closely by a strategic approach and least of all a surface approach.

Figure 2.11: Graph of average scores for each approach for each DCU first year cohort and the UOW cohort

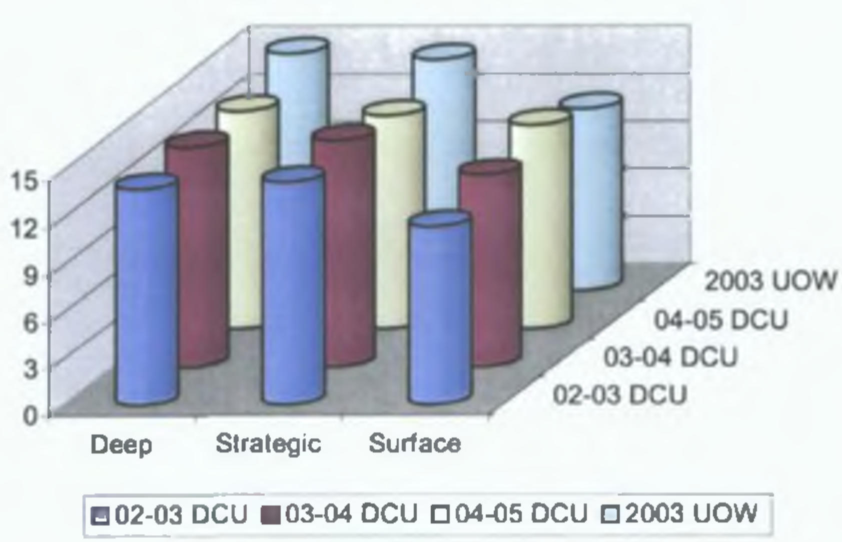
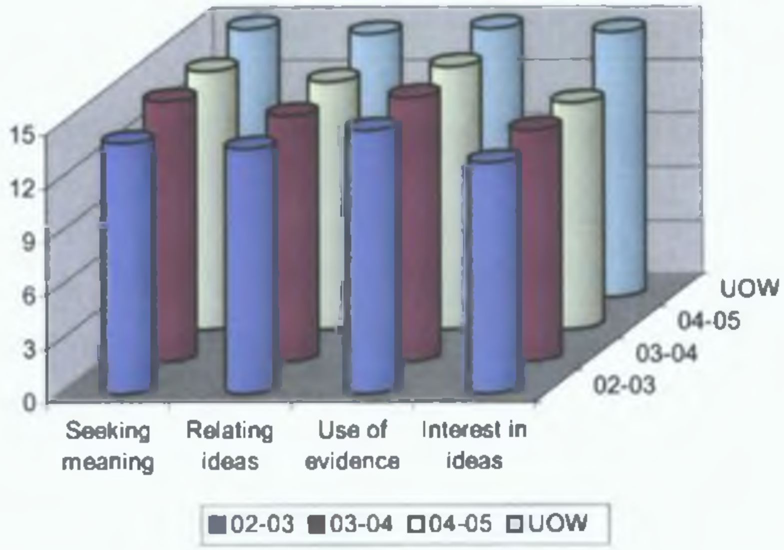


Table 2.22: Paired t-test for the UOW cohort between each pair of approaches

UOW	Mean Difference	St. Dev.	t	df	p
Deep-Strategic	0.42	2.45	2.244	173	0.026
Deep-Surface	3.49	4.15	11.292	179	0.000
Strategic-Surface	3.19	4.01	10.582	176	0.000

In terms of the subscales, the trends are also very similar with organised studying and lack of purpose being scored lowest in the strategic and surface approaches respectively. Also, monitoring effectiveness and fear of failure were scored highest in the strategic and surface approaches respectively. These show the exact same trend as with the Irish students. However, with respect to the deep approach, overall the UOW students score all the subscales high within a range of 14.7-15.4. This highlights the main difference between the UOW and DCU students at the start of their undergraduate programmes. All aspects of a deep approach equally influence the UOW students: Seeking meaning, relating ideas, use of evidence and interest in ideas, whereas the DCU students show a lack of interest in ideas, as well as relating ideas from difference courses and subjects. See Figure 2.12.

Figure 2.12: Graph of average scores for each deep subscale for each first year cohort in DCU and the UOW cohort



Though deep is often the preferred approach to learning over surface, when an analysis of the preference for different types of course and teaching was carried out, the results strongly showed a preference for teaching which transmits information for all cohorts in DCU. This is in direct contrast to previous analysis which has shown that deep approaches are coupled with preferences for teaching which support understanding. In terms of the preferences for different types of course and teaching, the UOW cohort are shown to be similar to the DCU students, indicating a strong preference for teaching and courses which transmit information over teaching and courses which support understanding. The results of the paired t-test are given in Table 2.23. However, UOW scores supporting understanding higher than their Irish counterparts at the first sampling interval, which makes sense since they also scored a deep approach higher.

Table 2.23: Paired t-test for the UOW cohort between teaching which transmits information and teaching which supports understanding

Transmitting information - Supporting understanding	Mean Difference	St. Dev.	t	df	p
UOW	-2.22	4.95	-6.084	184	0.000

Overall, the trends for first year science students in terms of their approach to studying and learning in UOW are quite similar to science students in DCU, with both sets of students indicating a preference for deep and strategic approaches over surface. They are both equally influenced by a fear of failure and reveal poor study techniques of bad time management and unorganised studying. Both cohorts from DCU and UOW show a highly significant preference for teaching and courses which transmit information over teaching and courses which support understanding.

2.3.3.4: Change in approach over time

The 2003-2004 intake have been surveyed at 4 stages during the first and second year of their undergraduate degree - in week 1 of semester 1, next in week 12 of semester 1, then again in week 36 (week 12 of semester 3) and finally in week 48 (week 12 of semester 4). Therefore this cohort will be the focus of the study but results from the other cohorts will also be included to give an overall picture of the change in approach over time. Figure 2.13 shows the change in approach over time for the 2003-2004 intake.

It is clear that for the first three sampling intervals the overall profile remains the same, with students indicating a preference for deep and strategic approaches over surface. However, there is clear shift at the fourth sampling interval, where there seems to be little difference between the three approaches. This will now be discussed in more detail.

Figure 2.13: Mean score for each approach over time for the 2003-2004 intake[43]

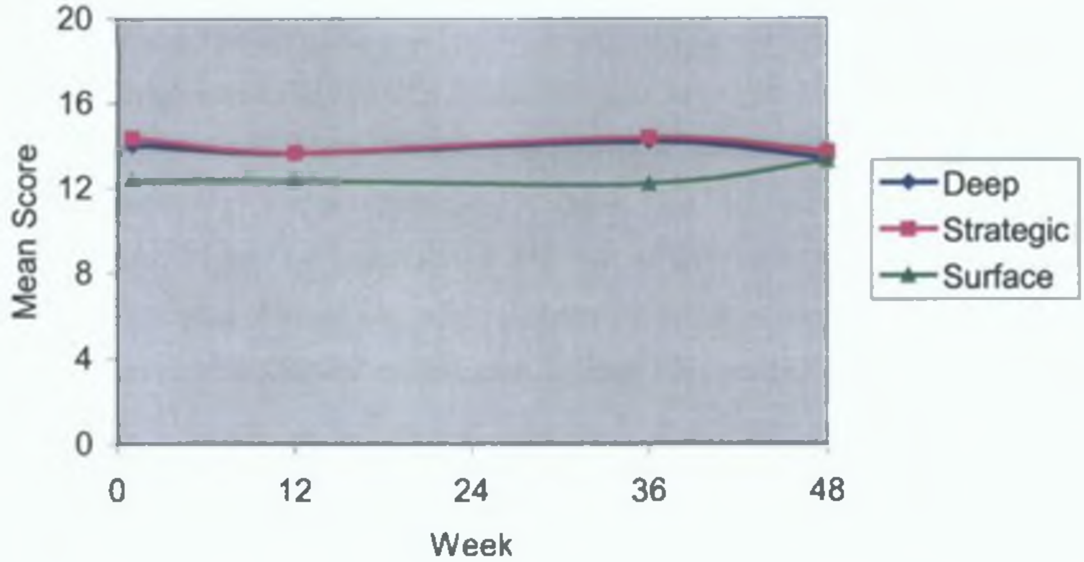


Table 2.24 gives the mean scores for each approach and the subscales at each sampling interval for the 2003-2004 intake. The use of an electronic version of the ASSIST inventory is suggested as the reason for the low return of surveys at the third sampling interval (N=42). Unfortunately over the four sampling intervals only 13 students (7 male and 6 female) filled out all four of the surveys. Therefore, a repeated measures ANOVA, which is used when the same measurement is made several times on each subject, is not used since the sample size would be too small and would disregard a lot of potential information. Instead, a series of paired t-tests were carried out.

An overview of the mean scores for the three main approaches in Table 2.24 reveals that the mean score for deep fluctuates between 13.4 and 14.2 between the four sampling intervals, the strategic fluctuates between 13.7 and 14.4, whereas surface remains at a low of 12.2-12.3 for the first three sampling intervals before increasing to 13.2 at the final sampling interval. This is probably the most significant shift over time. Paired t-tests were done so that the mean score from week 1 for each approach was compared to the mean score from the second, third and final survey respectively. The increase in the surface approach is reflected in the paired t-tests where the mean score for surface is observed to be higher at the fourth sampling than the first at 99% confidence (p = 0.000). This increase in the overall surface approach is due to significant shifts in profile of three of the four surface subscales. 'Lack of purpose', 'Syllabus-boundness' and 'Fear of failure' all show an increase from the first to the final sampling interval. These increases are significant at 99% confidence, with p = 0.001, 0.000 and 0.004

respectively. Therefore, students at the end of second year are turning towards a surface approach. This is coupled with a decline in both deep and strategic approaches as observed in Figure 2.13. From the first to the final sampling interval a significant decrease is observed for a deep approach ($p = 0.007$), a similar decrease is also observed at 99% confidence for a strategic approach. Table 2.25 shows the paired t-test results for the comparison of the three approaches from the first to the final sampling interval for the matched samples i.e. students who filled out both surveys.

Table 2.24: Mean scores for approach and subscales for all students from the 03-04 intake over the four sampling intervals

WEEK	1	12	36	48
N	147	84	42	74
Deep	14.0	13.6	14.2	13.4
Seeking meaning	14.6	13.8	14.5	13.4
Relating ideas	13.7	13.6	13.9	13.0
Use of evidence	14.7	14.0	14.3	13.9
Interest in ideas	12.9	13.0	13.6	12.8
Strategic	14.3	13.7	14.4	13.7
Organised studying	12.7	12.4	12.1	11.9
Time management	13.5	12.4	12.7	11.9
Alertness to assessment demands	15.2	14.7	15.8	15.1
Achieving	14.7	14.0	15.3	14.1
Monitoring effectiveness	15.5	14.5	15.7	15.2
Surface	12.3	12.3	12.2	13.2
Lack of purpose	8.7	9.5	9.1	10.0
Unrelated memorising	13.0	12.3	12.7	12.9
Syllabus boundness	13.1	14.2	13.6	14.7
Fear of failure	14.1	13.0	13.6	15.2

With respect to the subscales, significant decreases in the deep subscales 'Seeking meaning', 'Relating ideas' and 'Use of evidence' are observed from the first to the fourth sampling interval. Significant decreases are also observed for the strategic subscales 'Time management', 'Achieving' and 'Monitoring effectiveness'. How do these trends compare to those found in other years?

Table 2.25: Paired t-test results for each approach from the first to the fourth sampling interval for the matched samples (2003-2004 intake)

APPROACH	WEEK	MEAN	ST DEV	t	df	*p*
Deep	1	14.1	2.4	2.820	55	0.007
	48	13.2	2.6			
Strategic	1	14.6	2.3	3.032	58	0.004
	48	13.8	2.4			
Surface	1	12.1	2.5	-4.388	54	0.000
	48	13.4	2.4			

Note: The reason for the difference in the mean values from this Table to the means in Table 2.24 is because those in Table 2.24 represent all of the students who filled out the surveys at each sampling interval, whereas this Table only represents those who filled out both surveys.

Unfortunately, the 2002-2003 intake, though this cohort of students were sampled three times, were unidentified at the second sampling interval (week 12 semester 1), therefore paired comparisons over time could only be done for the surveys done in week 1 and week 36 (week 12 semester 3). Figure 2.14 shows the change in mean scores of the three main approaches over time at the three sampling intervals. Like the other first year cohorts these students indicate a preference for deep and strategic approaches over surface at the initial intake. By the end of the first semester these students show no significant preference for a particular approach, which indicates a shift away from deep and strategic approaches, and towards a surface approach. By the end of the third semester, they show a preference for strategic over a deep approach at 95% confidence, with surface only a little higher than deep. It is evident from the graph that the preference for a deep approach decreases while the surface approach increases over time. The strategic approach initially decreases but rises again. Paired t-tests confirm that there is a statistically significant decrease in preference for a deep approach from the beginning of semester 1 to the end of semester 3, with a statistically significant increase in surface approach for the same interval. See Table 2.26.

Figure 2.14: Graph of mean score for each approach at each sampling interval

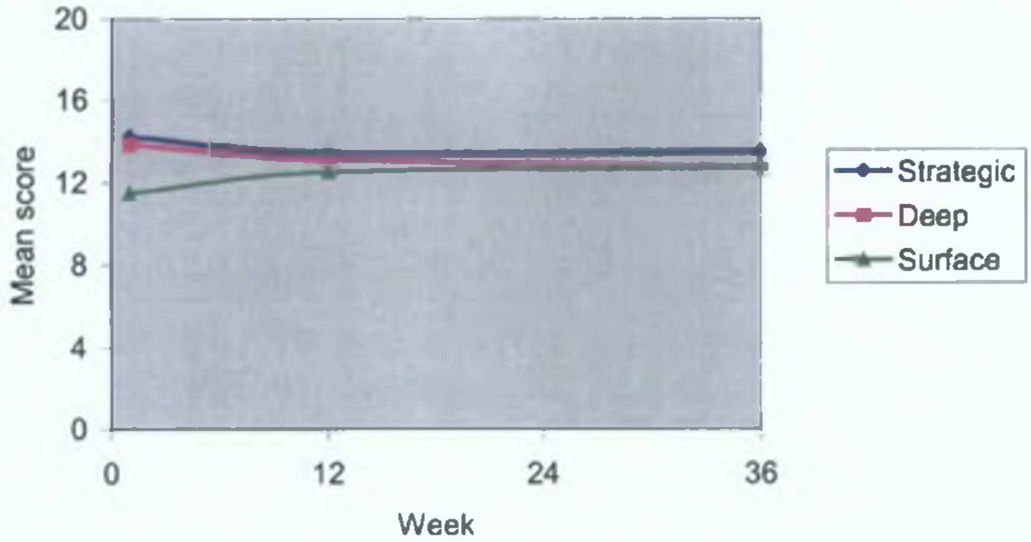


Table 2.26: Paired t-test results for each approach from the first to the third sampling interval for the matched samples (2002-2003 intake)

APPROACH	WEEK	MEAN	ST DEV	t	df	*p*
Deep	1	13.6	2.5	2.402	45	0.021
	36	12.8	2.7			
Strategic	1	14.1	2.4	2.498	45	0.016
	36	13.1	2.8			
Surface	1	11.3	2.8	-3.229	45	0.002
	36	12.6	2.7			

These changes in the overall approaches is influenced by the changes in the subscales. Analysis of the subscales reveal that 'Time management' and 'Achieving' decrease over time and 'Syllabus-boundness' increases, thus giving rise to the shifts in strategic and surface respectively. These shifts are all observed at 99% confidence. These results are also similar to previous findings. In contrast, no one deep subscale is shown to have changed significantly over time, though all show sizeable decreases except seeking meaning.

Paired t-tests were also done on the two surveys completed with the 2004-2005 intake, which were at the beginning and end of their first year. The analysis shows that like other results the deep approach has decreased over time, which is significant at 95% confidence. See Table 2.27. This is due to decreases in the three subscales 'Seeking meaning', 'Relating ideas' and 'Use of evidence', which was the same trend observed with the 2003-2004 intake. There was also significant decrease in the strategic over time similar to the previous cohort, and analysis of the subscales reveal that 'Time management' and 'Monitoring effectiveness' both significantly decreased. Though the surface approach didn't show a significant change over time, 'Syllabus-boundness' has significantly increased. These shifts are all observed at 99% confidence. These results are also similar to previous findings.

Table 2.27: Paired t-test results for each approach from the first to the second sampling interval for the matched samples (2004-2005 intake)

APPROACH	WEEK	MEAN	ST DEV	t	df	*p*
Deep	1	13.92	2.57	3.377	51	0.001
	24	12.85	2.61			
Strategic	1	13.67	2.76	2.485	48	0.017
	24	13.00	2.31			
Surface	1	12.69	2.94	1.062	50	0.293
	24	13.02	2.35			

A similar analysis was carried out on the UOW cohort. Though results from the third sampling cohort (week 36) have been included, these results are given with caution as the sample size is very small and also not representative since the majority of the cohort is female. However for the purpose of giving an overall picture the results are given in Table 2.28.

For both comparisons, the deep approach is shown to have decreased significantly, this is coupled with a decrease in strategic and increase in surface from week 1 to week 12. This is similar to the trends observed in DCU. However, the results from week 36 suggest that the strategic and surface approaches revert to their original state with no difference between week 1 and week 36.It must be remembered though that this sample is by no means representative so this is a finding based solely on those 15 students who filled out both the week 1 and week 36 surveys.

Table 2.28: Paired t-tests results for each approach from the first to the second and first to the third sampling interval for the matched samples (2003 UOW intake)

APPROACH	WEEK	MEAN	ST DEV	t	df	*p*
Deep	1	14.7	2.4	2.802	95	0.006
	12	14.2	2.7			
	1	15.2	2.7	3.246	14	0.006
	36	13.8	3.0			
Strategic	1	14.8	2.3	3.741	91	0.000
	12	14.1	2.4			
	1	14.9	2.8	-0.119	14	0.907
	36	14.9	3.1			
Surface	1	11.4	2.7	-4.195	102	0.000
	12	12.3	2.6			
	1	11.7	2.0	-0.123	14	0.904
	36	11.8	2.3			

In terms of the subscales, 'Organised studying', 'Time management', and 'Monitoring effectiveness' are the subscales giving rise to the decrease in the strategic approach from week 1 to week 12. The surface subscales 'Syllabus-boundness' and 'Lack of purpose' are also found to be significantly higher at the second sampling interval. These findings are very similar to those found for the DCU samples, with 'time management' decreasing and 'syllabus-boundness' increasing significantly for all three DCU cohorts. The four deep subscales are also shown to decrease from week 1 to week 12.

Similar research, using ASSIST, was carried out in the Business School, DCU with first year students taking a management accounting module as part of a BA in Accounting.[28] The data was collected in week nine of the second semester. Paired sample t-tests revealed no significant differences in the mean scores within the group, indicating that students do not have a preference for any particular approach. This is similar to the findings from both the initial investigation carried out in semester 2 in 01-02, and the second sampling intervals for the 02-03 and 04-05 cohorts in week 12 and week 24 respectively. Trinity College, Dublin, and University College Dublin have also carried out similar research using ASSIST. Kelly *et al.*[44] reported that the predominant learning approach was strategic, when a sample of first years, from six schools of the Faculty of Health Sciences, were sampled at the beginning and end of their first undergraduate year. Moran *et al.*[25] report on a sample of first year students from physics, chemistry and psychology, also sampled at the beginning and end of the year. These results showed no change in a deep approach, but a decrease in strategic and an increase in surface. These findings are similar to the results presented in this research.

Zeegers[18] reports on a study of Australian students' approaches to learning, using Biggs Study Process Questionnaire (SPQ). The study lasted 30 months, commencing in 1996 with a survey of a first year class enrolled in an introductory chemistry topic. This cohort, of 200 students, was then surveyed again after 4 months, 8 months, 16 months, and finally 30 months. Though the overall sample was big, only 43 ended up completing all 5 trials. It is reported that mean scores for the three approaches indicate an overall decline in the strategic (achieving) approach over time, an initial fall in the deep approach which then returns to the original level and a rise in a surface approach, which by the third year returned to slightly below the original value. See Table 2.29.

Table 2.29. Mean SPQ scores (SD in parentheses) for all students in any of the five trials[18]

SPQ Scales	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	BIGGS (1987)
	Time zero	T = 4 mths.	T = 8 mths.	T = 16 mths.	T = 30 mths.	science 'norms'
	(N= 200)	(N= 151)	(N= 125)	(N= 73)	(N= 60)	(N= 248)
Achieving						
Motivation	24.6 (4.1)	23.6 (4.2)	23.1 (4.7)	22.8 (4.8)	22. 2 (5.0)	20.5 (4.8)
Strategy	24.6 (5.0)	22.6 (5.3)	21.7 (5.5)	22.6 (5.8)	22.5 (5.1)	21.4 (5.4)
Approach	49.2 (7.4)	46.2 (8.2)	44.8 (8.4)	45.4 (9.3)	44.7 (9.2)	41.8 (8.5)
Deep						
Motivation	23.6 (4.5)	22.3 (4.6)	22.6 (4.3)	22.6 (4.4)	23.2 (4.3)	21.8 (4.5)
Strategy	23.0 (4.5)	22.4 (4.9)	22.5 (4.7)	22.4 (4.9)	22.9 (4.6)	21.9 (4.3)
Approach	46.6 (8.1)	44.7 (8.9)	45.1 (8.4)	45.0 (8.6)	46.1 (7.9)	43.7 (7.8)
Surface						
Motivation	24.4 (4.4)	24.5 (4.7)	24.9 (4.8)	24.6 (4.6)	24.2 (4.7)	21.7 (4.7)
Strategy	22.8 (3.6)	23.3 (4.4)	23.3 (4.5)	22.9 (4.3)	22.4 (4.4)	21.9 (4.2)
Approach	47.2 (6.8)	47.8 (7.8)	48.2 (8.1)	47.5 (7.6)	46.6 (7.8)	43.6 (7.5)

Paired-samples t-tests between trial 1 and trial 3 revealed a significant increase for the mean score for a surface approach with a significant decease in both strategic (achieving) and deep approaches. Again, these are similar to the findings in this research.

Malencia and Bates[27] report on the use of ASSIST to explore cultural influences on learning behaviour. With students from various cultural backgrounds enrolled in the School of Pharmacy, significantly lower scores for the surface approach were found in comparison to both the deep and strategic approaches. The examples suggest that trends found in the Irish and Australian contexts in this research are not specific to location, cultural background or discipline.

Change in preferences for different types of teaching also show similar trends over the three years. At all sampling intervals, students show a significant preference for teaching which transmits information over teaching which supports understanding. However, Table 2.30 shows that the situation gets worse over time, with students reporting an increase in preference for teaching which transmits information. This is observed at 95% confidence for two of the three intakes 2002-2003 and 2003-2004.

Table 2.30: Paired t-test results for the preferences for different types of course and teaching for the matched samples (all DCU intakes)

Intake	APPROACH	WEEK	MEAN	ST	t	Df	*p*
02-03	Supporting understanding	1	13.8	3.4	3.349	49	0.002
		36	12.1	23.7			
	Transmitting information	1	17.1	3.1	-3.242	50	0.002
		36	18.3	2.2			
03-04	Supporting understanding	1	14.6	3.1	4.069	62	0.000
		48	13.1	3.3			
	Transmitting information	1	17.3	2.3	-2.257	63	0.027
		48	18.1	1.9			
04-05	Supporting understanding	1	13.2	3.5	2.906	53	0.005
		24	11.8	4.0			
	Transmitting information	1	18.0	2.4	-0.922	54	0.361
		24	18.2	2.0			

It is worth noting that both results represent shifts in preference from when students started their undergraduate to their preference during second year, the former half way through second year and the latter at the end of second year. This is coupled with decreases in preferences for teaching which supports understanding, this is observed at 99% significance for the three intakes. Overall, these results indicate that students prefer more direct forms of teaching, with teachers as the knowledge givers, and students the knowledge receivers. The longer the time in college, they increasingly prefer teaching which transmits information coupled with a decreasing preference for teaching which supports understanding.

2.3.3.5: Correlation between academic achievement and approach

It was reported earlier that a deep/strategic approach with no surface factors or a lack of interest is a good combination for academic success. Various correlation tests were carried out to determine if there were trends between approach and academic performance for science students sampled in DCU. Individual correlations between mean scores for each approach and each of the written exams (CS101 and CS102) showed similar trends and therefore, it was decided to combine the overall score of the two modules to make interpretation of the overall data easier. Tables 2.31-2.33 give Pearson's r for the DCU Chemistry modules correlated with the mean score for each approach. CS101/102 reflects the overall mark awarded to students, based on their performance in both CS101 and CS102, and CS151 the students overall mark in their laboratory module. Correlations are done for only those ASSIST surveys which were carried out in the first year for each intake i.e. sampling which was carried out while the students were in first year.

Table 2.31: Pearson's correlation coefficient for the DCU chemistry modules correlated with each approach for the first sampling interval for the 02-03 cohort

02-03	WEEK 1, SEMESTER 1		
EXAM	DEEP	STRAT	SURF
CS101/102	-0.016	+0.209	-0.373**
CS151	-0.049	+0.361*	-0.278

* Correlation is significant at 95% confidence

** Correlation is significant at 99% confidence

Looking at these results in more detail, all modules are positively correlated with a strategic approach (except between the laboratory module in 04-05 and the approach at the initial sampling interval), and in some cases this is significant at 95% confidence or higher. In contrast, all modules are negatively correlated with a surface approach and in some cases this is significant at 95% confidence or higher. Finally, the trend for a deep approach is not as obvious. However, in all but one case, the performance in the lecture based exams show a positive correlation with a deep approach (except in 02-03, where there is a very slight negative correlation, r = -0.016). In terms of the laboratory mark, the relationship is not as clear-cut with some cohorts showing a positive relationship and others showing a negative relationship between deep and academic achievement. The overall profile thus shows that deep and strategic approaches are positively correlated with academic performance, and surface approaches, in contrast, are negatively correlated with academic performance. This suggests that students who adopt deep and strategic approaches, with fewer tendencies toward a surface approach are more likely to be successful academically. An investigation into the correlation between academic achievement and students Leaving Certificate (CAO) points is presented in Chapter 4 (Section 4.4).

Table 2.32: Pearson's correlation coefficient for the DCU chemistry modules correlated with each approach for the first two sampling intervals for the 03-04 cohort

03-04	WEEK 1, SEMESTER 1			WEEK 12, SEMESTER 1		
EXAM	DEEP	STRAT	SURF	DEEP	STRAT	SURF
CS101/102	+0.073	+0.0265**	-0.020	+0.157	+0.331**	-0.302*
CS151	-0.063	+0.187*	-0.143	+0.162	+0.316**	-0.362**

* Correlation is significant at 95% confidence

** Correlation is significant at 99% confidence

Table 2.33: Pearson's correlation coefficient for the DCU chemistry modules correlated with each approach for the first two sampling intervals for the 04-05 cohort

04-05	WEEK 4, SEMESTER 1			WEEK 12, SEMESTER 2		
EXAM	DEEP	STRAT	SURF	DEEP	STRAT	SURF
CS101/102	+0.283*	+0.092	-0.159	+0.219*	+0.201*	-0.310**
CS151	+0.085	-0.040	-0.166	+0.008	+0.076	-0.090

* Correlation is significant at 95% confidence

** Correlation is significant at 99% confidence

A similar study was carried with the Australian students. Table 2.34 gives Pearson's r for the semester 1 and 2 UOW modules correlated with the mean score for each approach at the first two sampling intervals. The students taking Chemistry 101/104 and Chemistry 102/105 get two grades at the end of the academic year, one for each module, which comprises of 4 separate test item marks. The practical work makes up 20%, the final written exam 50%, lab-test 15%, and computer assignments 15%. This is in contrast to the DCU cohort who obtain a grade from the practical chemistry module

CS151 (which runs over 2 semesters), and gets another grade, which is the average of the written exams at the end of each semester (CS101/102). It was decided to look only at the correlations between the students' performance in their practical work and in their final written exam, so as to be more comparable to the DCU results.

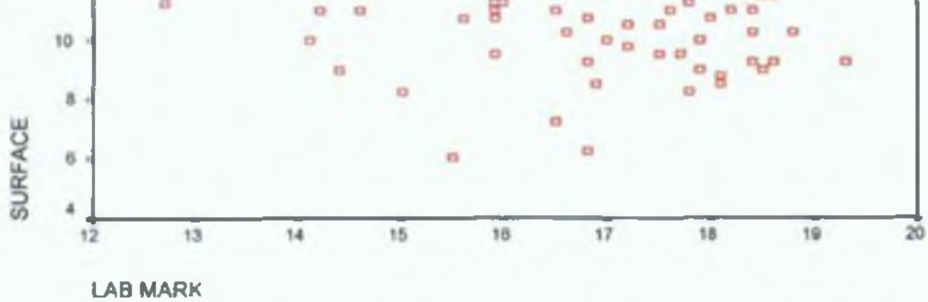
Table 2.34: Pearson's correlation coefficient for the semester 1 and semester 2 UOW modules Chemistry 101/104 and Chemistry 102/105 respectively, in terms of the lab mark and exam performance, correlated with each approach at the first two sampling intervals

SAMPLE		WEEK 1, SEMESTER 1			WEEK 12, SEMESTER 12		
EXAM		DEEP	STRATEGIC	SURFACE	DEEP	STRATEGIC	SURFACE
Sem 1	Lab	-0.046	+0.003	+0.021	-0.0121	+0.189	+0.277**
	Exam	+0.203*	+0.169*	-0.073	+0.267**	+0.211*	-0.058
Sem 2	Lab	+0.132	+0.161	-0.172	+0.059	+0.165	-0.128
	Exam	+0.130	+0.190	-0.164	-0.087	+0.125	+0.084

* Correlation is significant at 95% confidence

** Correlation is significant at 99% confidence

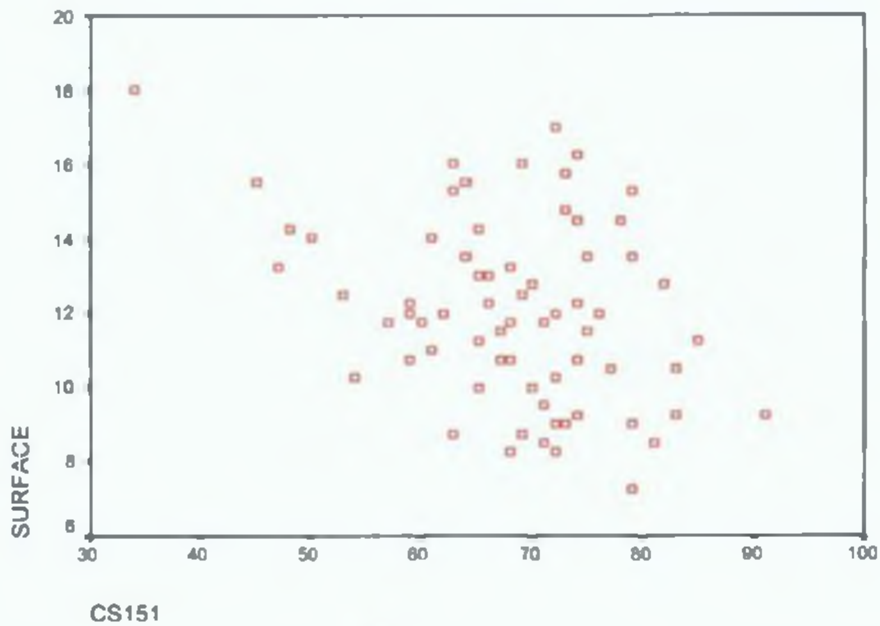
Figure 2.15: Scatter graph of surface approach against laboratory mark for UOW cohort at the second sampling interval



In terms of the written exam, there are generally positive correlations between deep and strategic approaches and academic success over the two sampling intervals and these are significant for the semester 1 exam. Interestingly, there is also a positive association between a surface approach and practical lab marks. This suggests that success in practicals is associated with a surface approach. A scatter graph of the mean score for surface at the second sampling interval against the lab mark for semester 1 is given in Figure 2.15.

It is clear that there is a slightly positive association between high reported levels for surface and performance in labs. This is in direct contrast to the DCU cohort of that year (03-04), where at the same sampling interval a significant negative relationship between academic achievement in the laboratory module, CS151 and a surface approach is observed. See Figure 2.16.

Figure 2.16: Scatter graph of surface approach against laboratory mark for the 03-04 DCU cohort at the second sampling interval



In an Irish context, Byrne *et al.*[28] report significant positive correlations between total mark and both deep and strategic approaches, and a significant negative correlation with a surface approach. This trend was also observed for the problem-solving question, which is reassuring, since this type of assessment lends itself to deep approaches being adopted over surface. See Table 2.35. Moran *et al.*[25] report a weak correlation between end-of-year exam results and approach, for example a surface approach is weakly negatively correlated with exam results. Interestingly, they report that Leaving Certificate points are a strong predictor of end of year performance.

Table 2.35: Correlation of ASSIST main scale with assessment marks[28]

	TOTAL MARK	PROBLEM-SOLVING QUESTIONS	ESSAY QUESTIONS	PRESENTATION
Deep	+0.22*	+0.21*	+0.09	+0.13
Strategic	+0.29*	+0.25*	+0.25*	+0.18
Surface	-0.34*	-0.34*	-0.19	-0.08

* Significant at 95% confidence

Duff *et al.*[29] report on the use of the Revised Approaches to Studying Inventory in a Scottish University. As predicted, they found both deep and strategic approaches were positively correlated with academic performance, whereas surface approach was negatively correlated with academic performance. Also, significant positive correlations are found between a deep approach and two of three applied medical knowledge tests in a medical school in the UK[26]. In an Australian context, Zeegers[18] reports that the overall trend which emerges, is a weak negative correlation between a surface approach and GPA (Grade Point Average), a weak and variable correlation with achieving approach and a consistent and at times strong positive correlation with deep approach.

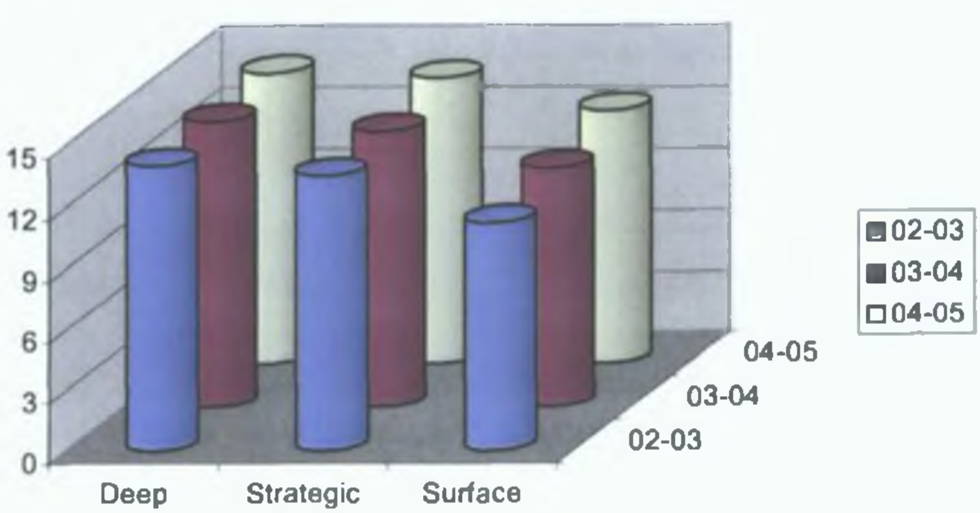
2.4: INFLUENCE OF GENDER AND AGE ON APPROACHES TO LEARNING

Some studies have been done which investigate gender differences in terms of approach to learning[26,28,29,45,46]. This is of great importance, especially at 1st year undergraduate level where the majority of students are recent school leavers, since females have been shown to outperform males in their final secondary school exams in many different countries, including Ireland[47,48]. An investigation into gender differences may reveal reasons for this in terms of motivations and/or study skills.

2.4.1: GENDER DIFFERENCES ON ENTRY TO UNIVERSITY

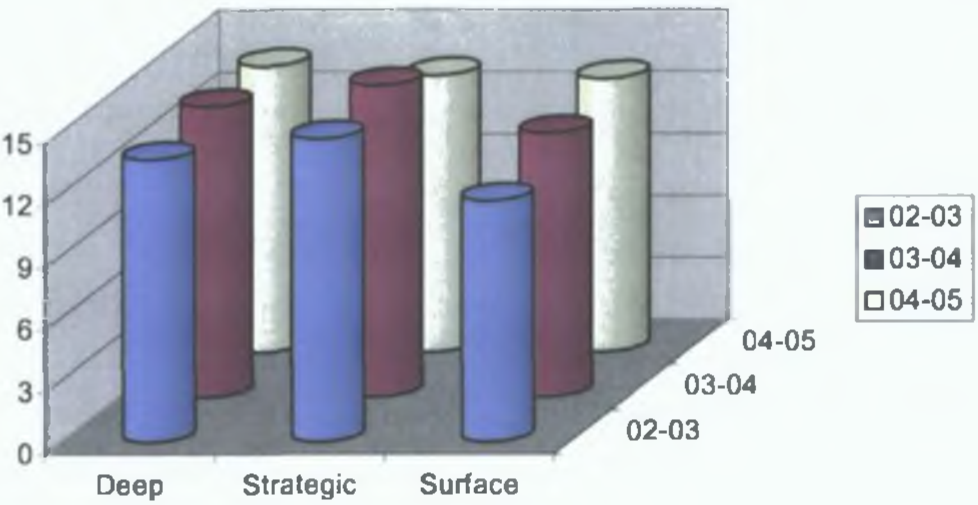
From this research it has been shown that students at the initial stage of their undergraduate degree, generally indicate a preference for deep and strategic approaches over surface. This section investigates the differences in approach to learning of these students in terms of gender. Figure 2.15 and 2.16 show the mean scores for each approach for each male and female cohort respectively at the initial intake.

Figure 2.15: Graph of average scores for each approach for each DCU first year male cohort at the initial intake



It is clear that the general trend is still observed for the male cohorts with each cohort showing higher scores for deep and strategic approaches over surface. This is also found to be the case when paired t-tests were carried out, indicating that male students use deep and strategic approaches over surface. Similarly, the female students are shown to observe the general trend, with deep and strategic approaches preferred over surface. This is also shown to be significant from paired t-tests. However, the graph also suggests that a strategic approach is higher overall (See Figure 2.16). Further investigation revealed that in 2002-2003 and 2003-2004 the female cohorts were found to indicate a preference for strategic over both surface and deep at 95% confidence.

Figure 2.16: Graph of average scores for each approach for each DCU first year female cohort at the initial intake



This manifests itself in the independent t-tests where the mean scores for each approach are compared across gender and the results from 2002-2003 are given as an example. See Table 2.36. A similar trend is also observed in 2003-2004, with females scoring strategic significantly higher than their male counterparts.

Table 2.36: Mean scores for each approach cross-tabulated with gender 2002-2003

	N	DEEP	STRATEGIC	SURFACE
Male	41	13.96	13.54	11.17
Female	53	13.64	14.64	11.58
Difference		**0.32**	**-1.10***	**-0.41**

*Significant at 95% confidence

This is not surprising since academic success is the main motivation behind a strategic approach, and girls, as discussed earlier, have been shown to outperform boys at final secondary school examinations in both Irish and Australian contexts. The majority of this first year cohort are recent school leavers, and so would be basing their answers on their previous study and learning experiences, which in the main would be the preparation for their final school exams. However, further investigation is required to gain more insight into these observed differences. A series of independent t-tests were carried out on the subscales, comparing the subscale scores for males and females at the initial intake. The results are summarised below in Table 2.37.

Table 2.37: Subscales which females scored significantly higher than their male counterparts for each intake at 95% confidence or above

INTAKE	STRATEGIC SUBSCALES	SURFACE SUBSCALES
02-03	Organised studying Monitoring effectiveness	Fear of failure
03-04	Organised studying Time management Alertness to assessment demands Monitoring effectiveness	Unrelated memorising Fear of failure
04-05		Fear of failure *

* Significant at 92% confidence

This suggests that females have better study techniques than males, for example they are better able to organise their study and monitor how effective they are at their studying. However, another interesting finding is that in all three cohorts fear of failure is scored significantly higher for the females than the males. To further delve into these findings, the results from the Leaving Certificate students was also analysed for gender differences and the findings are given in Table 2.38.

Table 2.38: Independent t-tests for the three approaches across gender for the Leaving Certificate cohort

	GENDER	N	MEAN	ST DEV	t	df	*p*
Deep	Male	69	13.8	2.3	-0.428	159	0.670
	Female	94	13.9	2.8			
Strategic	Male	68	12.6	2.2	-3.892	156	0.000
	Female	90	14.1	2.8			
Surface	Male	68	12.2	2.7	-2.167	162	0.032
	Female	96	13.2	3.0			

The table clearly shows that there is no overall difference in the deep approach, whereas both strategic and surface approaches are scored significantly higher for females compared to the males. All five strategic subscales are observed to be significantly higher for the female cohort and the surface subscale 'Fear of failure' is also significantly higher for the females. This further indicates the effect of previous experience on students approach to learning and studying, as there are similarities between the Leaving Certificate cohort and the DCU cohorts in terms of gender. Interestingly, males from single sex schools scored a surface approach significantly lower than males in mixed schools, with the surface subscale 'Lack of purpose' observed to be significantly lower. In contrast females from single sex schools scored a strategic approach higher at 90% confidence than their female counterparts from mixed schools and also scored fear of failure significantly higher.

In terms of preferences for different types of course and teaching, males and females from all three DCU cohorts and the Leaving Certificate cohort indicate the similar trends as were found with the overall DCU cohorts, with both males and females indicating a preference for teaching with transmits information, over teaching which supports understanding.

2.4.1.1: Comparison of DCU with UOW in terms of gender

Similar results are found for the UOW cohort as for the DCU cohorts with both males and females reporting a preference for deep and strategic over surface. Also, the females report a significant preference for strategic over deep as with two of the three DCU female cohorts. The UOW females also score a strategic approach significantly higher than their male counterparts. These results are shown in Table 2.39.

Table 2.39: Mean scores for each approach cross-tabulated with gender

	DEEP	STRATEGIC	SURFACE
UOW Male	14.85	13.79	11.31
UOW Female	14.99	15.14	11.58
Difference	**-0.14**	**-1.35***	**-0.27**

*Significant at 95% confidence

An investigation into subscale differences reveals further similarities between DCU and UOW. The subscales, which give rise to this observed difference in strategic are

'Alertness to assessment demands', 'Time management', 'Organised study' and 'Monitoring effectiveness', with the latter two subscales also reported in the 2002-2003 and 2003-2004 DCU cohorts as higher for females than males. The UOW females also score the surface subscales 'Fear of failure' and 'Syllabus boundness' higher, with 'Fear of failure' having been previously shown to be higher for all three DCU cohorts and the Leaving Certificate cohort. This suggests that fear of failure is a major concern for females and this needs to be addressed.

To analyse gender differences between DCU and UOW the 2003-2004 DCU cohort data was chosen for an independent t-test between the males and females in each university. An important difference between DCU and UOW at the first sampling interval is that both the male and female UOW cohorts score a deep approach higher than their DCU equivalents. 'Interest in Ideas' is significantly higher for both male and females at UOW compared to DCU, and 'Seek meaning' and 'Relate ideas' were higher for UOW males and females respectively. In contrast, the DCU females score surface higher than their female Australian equivalents, with 'syllabus-boundness' and 'unrelated memorising' scored significantly higher. By the second sampling interval however, there is no observed differences between the males and females at each university. This prompts the question, in what way are final year students in Australian secondary schools approaching their learning since they are indicating deeper approaches compared to their Irish counterparts at the initial intake stage? Perhaps school students experience in an Australian context is more conducive to adopting a deep approach. However, this is beyond the scope of this research but there is potential there for future work.

Finally, though there are differences observed over time between the males and females in each of the DCU cohorts and the UOW cohort, the most significant observation is that the females 'Fear of failure' remains constant throughout all the cohorts at all stages. This is a serious issue, which was shown to also be observed for fourth year students in the initial investigation.

Other Irish studies on undergraduate students approaches to learning reported no gender difference in approach to learning[25,28], which is in contrast to the results found in this research. Other international studies have revealed significant, if somewhat contrasting, differences between males and females. Duff[29] gives a summary of studies investigating gender differences using the Approaches to Studying Inventory, and shows that in studies carried out from 1982 to 1990, only two of the six studies reported gender differences. One of the studies did not give information on the gender differences observed[49] whereas the other study reported that males scored higher on both strategic and surface approaches than females[50]. In the same study, Duff reports on his research findings that female business studies students scored higher than males on a surface approach. In contrast, Mattick *et al.*[26] report on undergraduates in medical education using the Approaches to Learning and Studying Inventory (ALSI), with males reporting significantly higher surface approach scores than females, but significantly lower scores on the effort management/organised studying scales. The latter result is similar to the findings on the research reported here, with females scoring a strategic approach higher than males.

2.4.2: INVESTIGATION INTO THE EFFECT OF AGE ON APPROACH TO LEARNING

With the mix of students that are now in third level in Ireland, including a greater number of mature students, it was decided to investigate if there are any differences between mature students and recent school leavers in terms of their approach to learning and how this effects their academic performance.

To investigate this, the UOW cohort was chosen since it contains a good spread for age. Table 2.40 gives an outline of the spread in terms of age, for the DCU and UOW cohorts.

Table 2.40: Age profile for DCU cohorts and UOW

AGE (YRS)	N	17	18	19	20	21	22	23	24	25	26	27	28	29	32	33	36	40+
02-03	96	21	59	12	1				2								1	
03-04	146	37	72	25	6	2	1	2										1
04-05	78	15	41	17	3										1			1
UOW	187	19	89	27	11	8	6	6	5	1	3	4	1	2	1	2		2

It is clear that the UOW cohort has a much broader spread of ages, since combining all three DCU cohorts results in only 20 students aged 20 or above, and only 6 aged 24 and above. Hence the UOW cohort was used to investigate difference in approach to learning for students of different ages, with the assumption that previous similarities observed between the DCU and UOW cohorts would suggest that findings for the UOW cohort could indicate trends in DCU.

Independent t-tests were used on the UOW cohort to see if there were significant differences between the approaches taken by two different age groups; one series of tests investigated differences among those aged below 20 against those aged 20 years or above (cut-point of 20), and the second series of tests investigated differences with a cut-point of 24 years. Table 2.41 gives the mean scores for each cut-point group, and shows whether the differences are significant.

Table 2.41: Mean scores for each approach cross-tabulated with age

CUT-POINT	N	DEEP	STRATEGIC	SURFACE
< 20	135	14.82	14.54	11.72
≥ 20	53	15.22	14.77	10.82
Difference		**-0.40**	**-0.23**	**0.90***
< 24	166	14.77	14.51	11.64
≥ 24	22	16.14	15.28	10.17
Difference		**-1.37***	**-0.77**	**1.47***

* Difference significant at 95% confidence

It is clear that for both cut-points that older cohorts are significantly less inclined towards a surface approach than their younger colleagues. For both older cohorts the surface subscales 'Lack of purpose' and 'Syllabus boundness' are significantly lower than the younger cohorts. For the 24 and over age group, a significant preference for a deep approach is also observed with the deep subscales 'Seeking meaning' and 'Interest in ideas' significantly higher for the older cohort. This suggests that older cohorts use surface approaches "less" and deep approaches "more" compared to their younger counterparts. However, when similar tests are done at the second sampling interval, no such difference is observed for a deep approach, but the older cohorts do remain the same in terms of a surface approach. For both younger cohorts, a significant decrease in a deep approach, coupled with an increase in a surface approach is observed from the first to the second sampling interval. The older cohorts remain unchanged indicating a preference for deep and strategic approaches over surface, and a preference for deep over strategic at 94% confidence. Table 2.42 gives the results from independent t-tests carried out on the data from the second UOW sampling interval (Week 12) comparing those students above and below 24 years of age for the deep and surface subscales, as this is where the most differences are observed between these two cohorts.

It is shown in the table that all four surface subscales are significantly lower for the older cohort compared to the younger group and that 'Interest in ideas' is significantly higher, thus showing that the trends which were observed initially remain at least until week 12. Unfortunately due to the small sample at the third sampling interval, no further tests could be done over time.

Table 2.42: Independent t-test results comparing students ≥ 24 (N = 11) and students < 24 (N = 90) years in terms of the subscales for deep and surface approaches (UOW – Week 12)

WEEK	AGE	MEAN	ST DEV	t	df	p
Seeking meaning	≥ 24	15.6	2.1	1.762	99	0.081
	< 24	14.0	3.0			
Relating ideas	≥ 24	14.5	3.1	0.660	98	0.511
	< 24	13.8	3.4			
Use of evidence	≥ 24	15.2	1.5	0.876	96	0.383
	< 24	14.4	2.8			
Interest in ideas	≥ 24	16.4	2.7	2.330	97	0.022
	< 24	13.7	3.6			
Lack of purpose	≥ 24	7.4	2.7	-2.844	16	0.012
	< 24	9.9	4.0			
Unrelated memorising	≥ 24	9.9	3.0	-2.189	98	0.031
	< 24	12.1	3.1			
Syllabus boundness	≥ 24	12.3	2.5	-2.099	98	0.038
	< 24	14.2	3.0			
Fear of failure	≥ 24	10.5	3.5	-2.888	14	0.012
	< 24	13.9	4.4			

It is suggested that mature/older students use a combination of a deep and strategic approach, with a lower use of a surface approach due to their greater motivation to achieve in their courses, the transferable skills they bring to studying, their positive response to feedback[51] and their active decision to continue with education[26]. Zeegers[18] reported in his study on Australian students approaches to learning (refer back to Pg 146 for further details) that four of the five trials, spanning 30 months, showed the non-school leaver students scored deep significantly higher than the recent-school leavers. Also, there is an initial significant difference between surface approach scores, with the recent school leavers scoring it higher. This study used Biggs Study Process Questionnaire. Zeegers suggests that the Australian secondary school system could be a contributing factor in the development of commencing tertiary students' learning practices, with high pressure, competitive State examinations appearing, to students, to encourage rote learning as a means of success.

Also, Byrne *et al.*[52] reported that older students in Business Studies are less inclined towards a surface approach. Similarly, Larrington[51] reports how undergraduate psychology students aged 25 and over, matched the profile of the graduate diploma in psychology students in terms of their higher mean scores for deep approaches and lower scores for surface apathetic approaches than their students under the age of 25.

Mattick *et al.*[26] report that graduate students had significantly higher deep approach scores and significantly lower surface approach scores than their non-graduate counterparts at the start of medical school, suggesting that older or graduate students are more willing or better prepared to use learning strategies that might be perceived as involving more effort.

Investigating gender differences within the older cohort (age $\geq$ 20) reveals that the females (N = 27) are more inclined toward a strategic approach than their male counterparts (N = 24), which is a trend observed in the overall profile of the students from DCU and UOW. The strategic subscales 'Time management' and 'Achieving' are significantly higher for the female cohort than the male. Interestingly, the males aged 20 years and older indicate a significantly higher score for the surface subscale 'Syllabus boundness'. However these differences are not observed when the 24 years and older cohort are analysed, however this may be due to the small sample sizes since there is only 10 males and 11 females in this cohort.

An investigation into the preferences for different types of course and teaching reveals interesting results. All groups have had a significant preference for teaching that transmits information, including both DCU and UOW cohorts and male and female students; however for both older age cohorts (≥ 20 and ≥ 24) there is no significant difference in preference, whereas for the younger age cohorts, the significant preference for transmitting information is retained. Furthermore, independent t-tests reveal that both older cohorts have a significant preference for supporting understanding over the younger cohorts. These results are shown on Table 2.43.

Table 2.43: Independent t-tests for preferences for teaching for the two UOW age cohorts: <20 v ≥ 20 and <24 v ≥ 24

	AGE	N	MEAN	ST DEV	t	df	*p*
Supporting understanding	≥ 20	51	15.9	3.0	2.531	184	0.012
	< 20	135	14.5	3.4			
Transmitting information	≥ 20	51	16.9	2.6	-0.650	182	0.516
	< 20	133	17.2	2.9			
Supporting understanding	≥ 24	21	17.1	2.5	4.103	30	0.000
	< 24	165	14.6	3.3			
Transmitting information	≥ 24	22	16.5	2.4	-1.158	182	0.248
	< 24	162	17.2	2.8			

2.4.2.1: Correlation of examination performance and approach as a function of age

An investigation into correlations between academic performance and approach with different age groups were carried out. Students in the lower age groups, either <20 years or <24 years, show no significant correlations between performance and approach. However, the older cohorts, ≥ 20 and ≥ 24, reveal a positive correlation between performance and deep and strategic approaches, and a negative correlation with a surface approach. These results shall now be discussed in more detail.

Table 2.44: Pearson's correlation coefficient for the total mark in Chemistry 101/104 and Chemistry 102/105 correlated with each approach at the second sampling intervals for age groups <20 and ≥ 20

	CHEMISTRY 101/104			CHEMISTRY 102/105		
AGE	DEEP	STRATEGIC	SURFACE	DEEP	STRATEGIC	SURFACE
< 20	+0.145	+0.153	+0.093	+0.025	-0.042	+0.032
≥ 20	+0.466*	+0.470*	-0.350	+0.431	+0.570*	-0.319

***Significant at 95% confidence**

Table 2.44 shows the correlation coefficients for the two age groups tested, <20 and ≥ 20 years. This is a measure of the correlation between mean score for each approach and overall performance in the semester 1 and semester 2 Chemistry modules. It is clear from the table that the younger cohorts show no significant correlations between performance and approach. However, the older cohorts show the desired trends: positive associations with performance and deep and strategic approaches, and a negative association with a surface approach. The relationship is significant for both correlations between a strategic approach and academic achievement, and in the case of the first semester module, there is a significant positive relationship with a deep approach. Though neither of the surface correlations are significant, they are at least showing a negative relationship. This is in contrast to the findings from the overall UOW sample, where in some cases there were weak positive and negative correlations between performance and a deep approach, however the correlation between a strategic approach and academic success, which was a key finding in the overall study, is also reported here. Finally, correlations between a surface approach and academic achievement are more predictable for the older cohort, since for the overall UOW cohort, there were both positive and negative relationships.

In conclusion, it has been shown that mature students adopt deep approaches in comparison to their younger counterparts, in combination with a lesser inclination toward a surface approach. They have also been shown to have a preference for teaching which supports understanding over the younger students. Finally, it has been suggested that mature students adopting deep and strategic approaches and not surface, achieve academic success, unlike the younger students who show inconsistent relationships between their approaches to learning and their academic achievement.

2.5: SUMMARY

Overall, 1st year science students on entry into university have been shown to indicate a preference for deep and strategic approaches over surface, which was shown to have been consistent with reported study approaches of Leaving Certificate students. Over time however, the trend shows undesirable shifts, with students indicating significant decreases in their preferences for deep and strategic approaches and significant increases in their preference for a surface approach. Factors such as a 'fear of failure' and 'syllabus boundness' are shown to have influence over students adopting a surface approach. Furthermore, students indicate lack of confidence in 'time management' and 'organised study'. Combined with increasing preferences, over time, for teaching and courses which transmit information, the outlook is not good.

Students are turning away from deep approaches to study and are relying more on rote-memorising techniques. They report poor study techniques and a lack of interest in ideas and concepts. It was reported earlier that combining elements of deep and strategic approaches with an inherent interest in the subject area, without any use of surface approaches, supports successful academic performance. This has been supported to an extent by this research by investigation of the correlations between students reported approach to learning and their academic achievement. Positive correlations were shown between a strategic approach and academic achievement in first year modules, and a negative correlation between a surface approach and academic achievement. This suggests that the assessment used in first year rewards adoption of a strategic approach and not surface. However, the relationship between a deep approach and academic achievement is inconsistent and this needs to be addressed. Students should be rewarded for use of deep and strategic approaches, however, if the assessment does not demand it, students will use others techniques to ensure academic success.

In conclusion, I would suggest that study skills should be an integral part of undergraduate courses, and that students should be given the opportunity to learn about their own learning i.e. metacognition. Secondly, the assessment needs to be adapted so students do not feel so threatened by it, which results in the students adhering closely to the syllabus and being motivated by a fear of failure.

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CHAPTER 3

PROBLEM-BASED LEARNING FOR 1ST YEAR FUNDAMENTAL LABORATORY CHEMISTRY:

DEVELOPMENT & IMPLEMENTATION

3.1: INTRODUCTION

> 'If the assessment system in the laboratory is concerned solely with the terminal outcomes (the numerical result, the pile of crystals or the graph), students can attain this satisfactorily with no more understanding than is necessary to bake a cake.' Johnstone & Sleet 1994[1]

Unfortunately in many University introductory Chemistry courses, the situation that Johnstone & Sleet[1] describes above is not uncommon. For example, when students do practical activities in the Chemistry laboratory, their main concern is often to produce only the terminal outcome. This could range from determining the melting point of their product, producing a graph based on their results or determining the concentration of solution following a titration. These practical activities are often assessed through written reports, which describe how the students did their experiment, the results they obtained and a conclusion, and typically students do well, achieving high marks. This is often coupled with a prescriptive type laboratory activity, where students are given clear and precise instructions, which they must adhere to exactly. This type of laboratory activity is often referred to as a 'recipe lab'. This requires little student engagement with the content, and as Johnstone & Sleet[1] comment, students can be successful in their laboratory class even with little understanding of what they are actually doing.

This is however, being a little unfair to the student who has to grapple with information overload and perhaps unfamiliar techniques and equipment. The student may have little choice except to adopt this passive approach, especially when the preparation for the lab has involved no more then reading the laboratory manual! In another paper, Johnstone[2] reports that the laboratory is a place for information overload, which results in students having little room to process the information and therefore they blindly follow the instructions and seldom interpret the observations or the results made during the experiment.

At this stage, it is important to highlight the expense of running laboratory sessions in third level institutions. Firstly, specialised laboratory space is costly to build, equip and maintain. Secondly, it requires technical and academic staffing, as well as postgraduate demonstrators. Laboratory work is also time consuming, and finally, there is ongoing expense of consumable chemicals and apparatus[1,3]. The question is raised as to whether the students are deriving maximum benefit from these laboratory sessions and if the typical 'recipe lab' format can be justified in the context of such expense.

In 'Recipe labs' the activity is predetermined, with demonstrators, technicians, and staff all clearly knowing what is expected to happen. Therefore errors can be clearly identified by the teaching staff and rectified for the students before they continue with the laboratory work, with students getting little experience of problem-solving in the laboratory. Secondly, all the students are generally carrying out the same experiment and this can lead to students only being concerned with getting the same result as their laboratory neighbour. However, recipe labs have the great advantage that they allow the student direct access to laboratory work as experienced by researchers, and professional scientists, with the student focused primarily on the techniques[4]. They get direct opportunities to develop manipulative and technical skills. This maximises the quantity of practical experience gained by students, and the quality of the results they can potentially obtain. However, the students are not concerned with matching their learning in the laboratory to previous experience or as Johnstone[2] puts it 'consolidating their learning by asking themselves what is going on in their own heads', unlike the researchers and professional scientists who are doing the laboratory work for a particular purpose, which has meaning for them. The other problem with recipe type labs is that the actual practical aspect of any experiment represents only a small part of the whole process of experimental science[4], while in recipe labs the practical aspect is all that is covered.

Hunter *et al.*[5] suggest that the recipe lab 'omits the stages of planning and design, and it encourages 'data processing' rather than 'data interpretation'. Garrett[6] develops this further by commenting on the various steps a research scientist would take before actually getting to the practical aspect of the experiment as follows:

- What questions are we trying to answer?
- What observations would provide an answer to the questions?
- How can we best create conditions for making the desired observations?
- How will we process and evaluate the observations?
- What will we do next?

These are all aspects of a practical problem that students have no association with, as the laboratory instructor and technician make these decisions long before the student gets to grips with the experiment!

It is clear that recipe labs have their advantages and with modifications, could be much more effective in teaching and learning science. Incorporating student ownership, relating experiments to previous experiences, and getting students using higher order cognitive skills would provide authentic investigative processes[7]. Laboratory sessions should provide students with the opportunity to hypothesise, explain, criticise, analyse, and evaluate evidence and arguments. Bailey[8] highlighted the importance of transferable skill development in a UK context, with reports from both graduates in science and chemical industry employers suggesting that an emphasis on transferable skills at third level is highly desirable.

Innovative and alternative approaches to teaching and learning chemistry and science have been discussed in Chapter 1. This chapter focuses on the development and implementation of a Problem-Based Learning (PBL) laboratory-based module for first year undergraduate chemistry. The aim of the module is to develop the students' practical and transferable skills as well as their content knowledge and scientific understanding. The problem-based learning module also encourages students to prepare for their laboratory session in an active and collaborative manner, thus ensuring they are well prepared. By combining elements of group work, discussion, hands-on activities and alternative assessment methods, the students are provided with an environment conducive to meaningful, deep learning. The initial stage of the development was to examine the aims and learning outcomes of typical introductory laboratory modules and to then design a problem-based learning module to achieve these.

3.1.1: AIMS AND LEARNING OUTCOMES OF THE FUNDAMENTAL CHEMISTRY LABORATORY

Aims in education are the direction of learning toward specified goals. As suggested above, learning in the laboratory should provide opportunities to enhance students' manipulative, observational and recording skills and higher order cognitive skills, such as analysis and problem solving[1]. The following typical aims of a general laboratory practical course have been identified by various authors:

- To introduce the students to the laboratory[9]
- To teach basic practical skills in measuring some physical and chemical properties[10,11]
- To develop the students experimental and data analysis skills through a wide range of experiments in the practical laboratories[11,12,13,14]
- To aid in the understanding of the materials covered in lectures by providing students with hands-on practical experience[15]

- To instil in students an understanding of the importance of errors in the treatment of experimental data[10]
- To learn to write laboratory reports based on research data and theoretical background[12].

Gupta[11] attempts to classify specific aims of laboratory instruction in Table 3.1 below, where EM is teaching of experimental method, SL is the supplementing of lecture material, and IA incidental aims. Notice that providing stimulation for independent thinking is given as an 'incidental aim', with the key focus on skills development.

Table 3.1: Specific aims of laboratory instruction

SPECIFIC AIMS		
Familiarisation with	Standard equipment	EM
	Measuring technique	EM
Illustration of	Physical phenomenon	SL
	Concept taught in lectures	SL
Teaching of	Attitude to experimental work	EM
Providing	Closer contact with faculty	IA
	Stimulation to independent thinking	IA
	Feel of R & D labs	IA
Training in	Observation	EM
	Deduction from observation	EM
	Critical awareness	EM
	Keeping lab notebook	EM
	Writing reports	EM
	Acquiring specific information	EM

Similarly, Bennett & O'Neale[3] and Garrett[4] describe the sort of skills that should be developed through laboratory work, see Table 3.2. The laboratory work should also provide experience of designing an experiment, consolidating subject knowledge with practical experience, and the process of science[4]. There are obvious similarities between the range of skills which are promoted by these authors. Skills such as technical and observation skills, confidence in practical work, and data collecting are integral parts of most laboratory sessions, however what of skills such as data interpretation, problem-solving, team-work and communication of findings? Garrett[4] proposes that there is an over-emphasis on the laboratory work as opposed to the planning of the experiment and/or interpretation of results.

Table 3.2: Skills to be developed through practical work

BENNETT & O'NEALE[3]	GARRETT[4]
Manipulation	Technical skill
Lab know-how	Confidence in lab work
Observation	Observational skills
Experiment design	Awareness of Safety
Data collection	Recording skill
Processing & analysis of data	Data manipulation
Interpretation of observations	Data interpretation
Problem-solving	Presentation skills
Team work	Report writing
Communication & presentation	Oral communication

Learning outcomes are an essential part of any module/course, and emphasise what students should be able to do after following a particular module or course. The statement below identifies the key role placed on defining learning outcomes for particular modules, courses and programmes:

> 'To be able to document student learning, colleges first need to identify and define the outcomes of that learning. The statement of learning outcomes at course, program, and institutional levels clarifies for all stakeholders - the knowledge, skills, and abilities a student must possess to successfully complete a course or program and earn a certificate, diploma, or degree from the college. In every course and program in the learning college, in or out of the classroom, learning facilitators design activities to assist learners in achieving the appropriate course, program, and institutional learning outcomes[16].'

This is no different in Chemistry practical classes, and the learning outcomes of a general laboratory practical class usually include a measure of the ability of the student to:

- Manipulate chemicals and apparatus [9]
- Develop relevant practical skills in laboratory work[17]
- Relate experiment to theory[9]

- Perform error analysis, and have an appreciation of the importance of error analysis[10]
- Develop reporting, and numeracy skills[10]
- Develop a variety of transferable skills in such areas as self-management, communication, teamwork, problem-solving, information gathering and research[15,18].

There seems to be a general match between the aims and learning outcomes of laboratory work within the literature cited above. However what of the last learning outcome –

> 'Develop a variety of transferable skills in such areas as self-management, communication, teamwork, problem-solving, information gathering and research'

The question is: do the traditional recipe type lab fulfil the aims stated or fulfil the learning outcomes? Though these skills are identified by Bennett & O'Neale[3] as requiring development, in the traditional recipe laboratory there is little opportunity for students to develop these skills

To fulfil the aims and learning outcomes identified earlier, can the laboratory experience be modified to address the shortcomings of the recipe labs? On adopting a problem-based learning approach, many, if not all, of the original aims are met, but also other aims, which include:

- To provide an intellectually stimulating environment in which students have the opportunity to develop their skills and enthusiasms to the best of their potential[14]
- To provide an introduction in the use of personal computers in experimental science, with an emphasis on the analysis and presentation of experimental data[10]
- To improve students' understanding of the methods of scientific enquiry through experiments, problem solving and project work
- To develop practical skills and the ability to conduct and evaluate experiments.

The same follows for the learning outcomes, as not only are all the learning outcomes identified earlier met, but also:

- Experience in working both as part of a small group and independently, in both cases efficiently and safely[10]

- The ability to produce reports, which are concise, accurate and clear, stating what was done, what was observed, what was measured and what was deduced from experimental observations[10]
- The ability to critically review and compare (sometimes opposing) recent literature and to form a judgement based on sound knowledge[19].

It is clear that through problem-based learning more learning outcomes are possible, with many transferable skills developed, as well as practical experimental skills, and the ability to critique their own work, in terms of errors and literature reviewing. These skills are invaluable to students both during their time at university and also, in the work place. These learning outcomes were used in the development of the problem-based learning approach in the 1st year chemistry laboratory in DCU.

3.1.2: STUDENT PROFILE AND THE 1ST YEAR CHEMISTRY LABORATORY MODULE

Currently in DCU, there are eight-degree programmes taking the 3-hour per week chemistry laboratory module in 1st year (CS151) (Table 3.3). However when this research was initially carried out, two other degree programmes were available (marked with an asterisk in the table) which are now offered through the Science International degree.

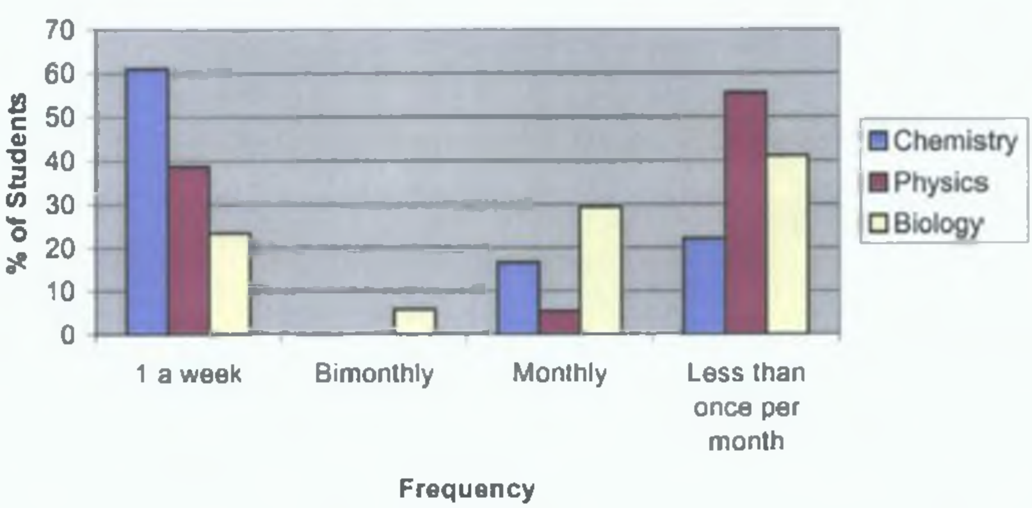
Table 3.3: Course code and description for degree programmes taking first year chemistry laboratory module

Course Code	Course
AC	BSc in Chemical and Pharmaceutical Science
AS	BSc in Analytical Science
BT	BSc in Biotechnology
CES	BSc Common Entry into Science
CF*	BSc in Chemistry with French*
CG*	BSc in Chemistry with German*
ESH	BSc Environmental Science and Health
GCB	BSc Genetics and Cell Biology
SCI	BSc Science International
SE	BSc Science Education

The majority of students in the 1st year cohort are recent secondary school leavers, with a small number of mature students. The programme entry requirements are a minimum of one science subject (chemistry, physics, biology, agricultural science or physics and chemistry) and maths, both either at a grade C3 at ordinary or D3 at higher level Leaving Certificate. This means that students can gain entry into the course with only one science subject, and therefore it is possible to have a high number of students who have little or no chemistry knowledge taking this compulsory module.

Another factor to consider is that some students may have had very little experience with hands-on practical experiments at school level and so, may not be familiar with even some basic apparatus and techniques. A survey (Appendix 3.1) of the Science Education (SE) degree class (1st years from the two academic year intakes 2002-2003 and 2003-2004) yielded interesting results about the frequency of practical work in each of the three basic science subjects, chemistry, physics and biology that they had done at second level school.

Figure 3.1: Frequency of practical work in schools (Data presented as % of SE students of the total number of SE students who had taken that subject)



From Figure 3.1 it is clear that although 61% of the 32 students who reported that they studied Chemistry for Leaving Certificate and were taking part in practical work once a week in their chemistry classes, it can also be seen that 22.2%, 55.5% and 41.2% of chemistry, physics (N = 34) and biology (N = 28) students respectively, were taking part in laboratory work less than once a month. Therefore, it is a realistic problem that many students will not be familiar with laboratory work, even if they have taken chemistry or another science subject to Leaving Certificate. Anecdotally, the fact that 61% of the Science Education cohort report taking part in practical work in chemistry once a week is very encouraging, however, the students are not asked to indicate in which year they carried out the practical work.

The students taking the chemistry laboratory module follow a two semester long course, which covers aspects of analytical, inorganic, physical and organic chemistry. The experiments follow the format of the 'recipe lab' discussed earlier, with content-heavy introductions to each experiment, step-by-step guide through the experiment and often, a sample calculation for the students to follow. The assessment is based on their laboratory report which is submitted after each experiment.

The module aims as outlined in the DCU prospectus are[20]:

- To give students an opportunity to develop manipulative and technical skills in the laboratory
- To develop a positive and careful approach to experimental work
- To develop sound practical skills
- To provide, as appropriate, some support to the theoretical work.

The learning outcomes are that students should[20]:

- Acquire a range of fundamental laboratory skills related to experimental work in chemistry
- Be able to demonstrate an ability to apply a broad range of investigative techniques and analytical procedures appropriately in chemical laboratories
- Develop safe working practices.

Considering that some students will not have studied chemistry and/or will not be familiar with laboratory work, it is necessary that both basic chemical concepts and laboratory skills be introduced to the 1st year cohort in this module. Such issues as safety in the lab, names of experimental apparatus and techniques, and basic procedures must be taught to the whole cohort so 'no one gets left behind', and that by the end of 1st year, the whole cohort has had the opportunity to be at the same level in both theoretical and experimental chemistry. Also, existing aims and learning outcomes are met in the traditional implementation of this module, however, the question I pose is 'is this enough?'

Does the current laboratory module challenge those students who have both a good level of secondary school chemistry and have done a lot of practical work and as important, does it challenge those students who have neither studied chemistry nor done much practical work? Does it provide them with an environment which is supportive to meaningful learning and development of life-long skills?

As discussed in Chapter 1, problem-based learning (PBL) is a learning process, which uses real-world problems to stimulate learning. In this research, a problem-based learning module has been developed with the intention to encourage the students to become deep learners, take ownership of their own learning, become actively involved and engage with their laboratory work. As well as meeting the learning outcomes as described in the prospectus, many other learning outcomes are to be achieved as well. A year-long chemistry problem-based learning module has been developed for a 1st year general chemistry laboratory, and is now at a stage of being tested for its transparency, and transferability to different students, facilitators, and other staff.

Factors that were involved in the development of this PBL module:

- The problems were selected by the design team
- The problems were selected in order to ensure that students cover a pre-defined area of knowledge and to help students learn a set of important concepts, ideas and techniques
- The form that the problems usually took were descriptive statements
- The students worked either in groups or individually
- The students took part in a pre-lab, where the problems were further discussed with the facilitator, to provide further context and/or chemistry help and to point out potential pitfalls and blind alleys likely to generate frustration.

As a sample group, a group of students were selected from the 1st year cohort namely the Science Education students. The reasons for this included that they were a small group – approximately 24 students, they were all in the same laboratory group and finally, that as future teachers, they would have an interest in innovative teaching methods, which may be of use to them in the future. The development of this problem-based learning module is discussed further in this Chapter. However, it is necessary to first describe the traditional module from which the problem-based learning module was developed and adapted.

3.2: TRADITIONAL CHEMISTRY LABORATORY MODULE

The traditional chemistry laboratory year-long module incorporates analytical, inorganic, physical and organic chemistry. The format of the three hour lab class is summarised below:

- Short introduction to the experiment and any relevant practical or safety issues is given by the lecturer
- Students carry out the experiment according to a procedure in their laboratory manual (An example of an experiment is given in Appendix 3.2)
- Demonstrators (typically 1 per 16 students[21]) are on hand to help students with any difficulties they encounter, typically either practical or calculation problems
- Students write a report on their experiment either in the class (in Semester 1) or outside of the assigned time (Semester 2). The typical format of the report is:
    - Brief aim
    - Procedure
    - Reaction equation(s)
    - Results
    - Calculations
    - Discussion
- Assessment is based solely on these weekly submitted laboratory reports.

Semester 1 – Analytical/Inorganic Chemistry

The current 1st semester analytical/inorganic chemistry laboratory involves a series of titrations and qualitative tests. At the end of the twelve weeks, all 1st year students have done all of these experiments. Table 3.4 shows the schedule of traditional experiments for the 1st semester and an overview of the content of the experiments. There is a strong emphasis on titrimetric methods and volumetric calculations.

Semester 2 - Physical Chemistry

The 2nd semester physical chemistry laboratory involves a series of 9 experiments, which the students rotate around for 5 weeks. Therefore, any one student will only complete 5 of the 9 experiments. Table 3.5 shows the schedule of traditional experiments for the 2nd semester physical chemistry laboratory and an overview of the content of these experiments.

Semester 2 - Organic Chemistry

The 2nd semester organic chemistry laboratory involves a series of 6 experiments, and the students complete all of them. They cover a variety of topics including recrystallisation and melting points, separations and functional group reactions. Table 3.6 shows the schedule of traditional experiments for the 2nd semester organic chemistry laboratory and an overview of the content of the experiments. There is a key emphasis on techniques such as reflux, distillation and recrystallisation.

Despite the emphasis on practical techniques and calculations throughout the whole module, anecdotal evidence suggests that students in second year are still not familiar with the techniques covered in first year and forget the principles involved and are still not comfortable with volumetric calculations. This is supported by the fact that at EuraChem Ireland– an Analytical Measurement Competition for second year students, the participants from DCU must be retrained on basic techniques and calculations.

Table 3.4: Traditional experiments for analytical chemistry module, semester 1

WEEK	EXPERIMENTS	CONTENT
1	Fundamental laboratory techniques and safety	Demonstration of correct burette, pipette, balance use and demonstration of preparation of primary standard. Safety talk.
2	Fundamental concepts and calculations	Calculations of atoms, molecules, moles, and grams.
3	Preparation of a primary standard and standarisation	Preparation of Na_2CO_3 primary standard. Titration against HCl.
4	Analysis of baking powder and lemon squash	Preparation of volumetric standards of Baking Powder ($NaHCO_3$) and Lemon Squash ($HOOCCH_2COH(COOH)CH_2COOH$). Titration against HCl and NaOH respectively.
5	Hardness of water determination by EDTA titration	Titration of tap, mineral, rain and river water samples against EDTA
6	Analysis of bleach by sodium thiosulphate titration	Standardisation of $Na_2S_2O_3$ with KI. Titration of bleach sample against standard $Na_2S_2O_3$
7	Analysis of iron in iron tablets	Preparation of Iron volumetric solution. Titration against $Ce(IV)SO_4$ or KMnO4.
8	Analysis of sodium carbonate/sodium hydroxide mixture	Titration of mixed base solution against standard HCl with use of two indicators
9	Determination of water of hydration of oxalic acid	Preparation of Oxalic Acid volumetric solution. Titration agaisnt $KMnO_4$.
10	Analysis of halide mixture	Preparation of NaCl/KCl volumetric solution. Titration against $AgNO_3$.
11	Analysis of aspirin by back titration	Reaction of Aspirin tablet with excess NaOH. Titration of excess NaOH against HCl
12	Qualitative analysis for anion and cations	Qualitative spot tests for cations in well-plates and for anions in test-tubes.

Table 3.5: Traditional experiments for the physical chemistry module, semester 2

EXPERIMENTS	CONTENT
Determination of the Activation Energy of a Chemical Reaction	Evaluation of rate constants by following the reaction of $H_2O_2$with I^- at 20, 28 and 35°C. Estimation of Activation Energy.
Calorimetric measurement of an Enthalpy of Neutralisation	Measurement of the work done when equal moles of NaOH and HNO_3 are reacted in a simple calorimeter
Microscale determination of the Order of a Chemical Reaction and evaluation of a rate constant	Determination of the order of the reaction of Malachite Green with hydroxide ions with respect to Malachite Green and the rate constant.
Microscale determination of the Distribution Ratio of Succinic acid between Water and Diethyl Ether	Determination of the distribution ratio of Succinic Acid between water and diethyl ether using three different weights of Succinic Acid
The comparison of Light Absorption Meters for the determination of the Stoichiometry of the Cu(II)-EDTA Complex	Comparison of the stoichiometry of the Cu(II)-EDTA determined using three different spectrometers
Determination of the Ideal Gas Constant	Reaction of a known number of moles of Na_2CO_3 with excess HCl and measurement of CO_2 produced. Application of PV=NRT
Microscale determination of Dissociation Constants of Weak Acids	Determination of the Dissociation Constant of Acetic Acid using the Henderson-Hasselback equation
The determination of o-Acetylsalicylic acid by UltraViolet radiation	Preparation of Salicylic acid standards and calibration curve. Determination of Acetylsalicylic acid by UV. Application of Beer-Lambert Law.
Simple experiments to Illustrate Le Chateliers Principle	Demonstration of the effect of conc. and temp. changes on the rate of reactions

Table 3.6: Traditional experiments for the organic chemistry module, semester 2

EXPERIMENTS	CONTENT
Purification and Purity Determination	Recrystallisation of acetanilide and p-dibrombenzene and determination of melting points
Separation of an organic Acid/Base Mixture by Liquid-Liquid Extraction	Separation and isolation of Ethyl 4-Aminobenzene and Benzoic Acid
Microscale Solid-Liquid Extraction – Trimyristin from Nutmeg	Solid-Liquid extraction of Trimyristin from Nutmeg using a microscale technique
Microscale hydrolysis of Trimryistin	Hydrolysis of Trimyristin by reflux and separation of Myristic Acid by filtration. Purification of Myristic Acid by recrystallisation.
Dehydration of a 4-Methylpentan-2-ol and Isolation of the products of the products by distillation	Reflux of 4-Methylpentan-2-ol in the presence of acid-catalyst and distillation of product and analysis by GLC
Microscale synthesis of Acetylsalicyclic Acid (Aspirin)	Reaction of Salicylic with Acetic Anhydride to yield Acetylsalicylic Acid. Purification of product by recrystallisation.

3.3: ELEMENTS OF THE PBL METHOD

The aim of the research was to develop a laboratory experience where students engage more fully with the whole process and therefore develop a deep approach to their laboratory learning.. It is suggested that the teaching process associated with a deep approach to learning should include as least one of the following[22]:

- An appropriate motivational context
- A high degree of leaner activity
- Interaction with others, both peers and teachers
- A well-structured knowledge base.

The PBL method in this research provides motivation for learning through relevant problems and has its roots in student centred learning and co-operative group work. Key areas within the laboratory experience were addressed including student preparation for the laboratory, group work, actual practical work and assessment.

Many of the core concepts in science and engineering are complex and counter-intuitive. Hence, university students taking introductory classes in these disciplines, even those with high entry qualifications, often have difficulty learning these concepts and applying them to problem-solving tasks. One way to tackle this difficulty is to engage students in active discussion in situations where their current understandings will be challenged and they can experiment with alternative conceptualisations[23].

Pre-lab

The use of pre-lab session before the laboratory to 'prepare the mind of the learner' is not a new one. Johnstone[2] described the elements of an effective pre-lab exercise as including:

- Revision of theory
- Reacquaintance 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[2]. Also, if students have had direct input into the laboratory experience, for example deciding the procedure or techniques to be used and have an inherent interest in the experiments, due to its relation to everyday life for example, they will have a greater motivation and personal interest in actually doing the experiment.

Johnstone *et al.*[24] reports on 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'.

Also, Sirhan *et al.*[25] comment on pre-lectures in chemistry being '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'. Allen & Duch[26] describe how problems in PBL can be introduced with mini lectures, similar to the form of pre-lab session used in this research.

In preparation for each PBL laboratory, students are expected to engage in discussion with each other. Nicol & Boyle[23] have shown that students discussing concept questions in small groups not only enhanced their conceptual understanding but it also proved to be a powerful motivating force. Students reported a preference for thinking about the problem prior to the discussion, citing two reasons for this. First, the requirement to make an individual response meant that they were forced to think about the problem, and to formulate their own reason for their selected answer, prior to the group discussion. Second, having constructed their own answer, students felt they benefited more from the subsequent peer discussion. They would be more likely to engage in dialogue and to provide reasons for, and defend, their ideas and they would be more likely to be able to identify gaps in their thinking.

Group work

The use of small-group co-operative learning in science has been considered in Chapter 1, Section 1.3.2.1. To recap, through group learning, individuals can pursue their own learning needs within the context of the group, referring to others for support, feedback, and validation. Much learning occurs from interactions between group members, with an emphasis on democratic decision-making and considerations for different points of view.

Practical laboratory session

As highlighted in Chapter 3, Section 3.1, the traditional format of practicals can lead to ineffective learning, and overloading of the students working space, therefore reducing students to a rote-learning approach to their practical classes. However, by slightly adapting the practical by adding elements of student ownership and investigation and reducing the amount of 'noise' in the manual this can lead to a much more realistic practical experience, and hence improve student learning.

Investigations in the science laboratory were discussed in detail in Chapter 1, Section 1.3.2.2. To recap, the main advantages of such an approach to practicals is that students are engaged with all aspects of the experiment, starting from developing their research questions, researching and using appropriate resources, designing their experimental set-up to actually carrying out the experiment and manipulating their data to formulate their conclusions.

Assessment

Savin-Baden[27] reports that assessment currently seems to be one of the most controversial issues in PBL. She goes on to discuss how 'many of the concerns about assessment in higher education seems to relate to the unintended side-effects that undermine staff intentions to encourage students to learn effectively'. Her study reported that students had three main issues with assessment in PBL:

1. Unrewarded learning
2. Disabling assessment mechanisms
3. Impact of assessment on group work

Though PBL does allow for more alternative and varied assessment tools, including oral and poster presentations, written reports, and peer assessment among others, the issue of unrewarded learning and undervalued learning in groups is a difficult one to solve. Overton[28] reports on a variety of assessment tool which have been used in case studies:

> 'Assessment tools which have been successfully used include oral presentations to other scientists, oral presentations to a lay audience, written reports, summaries of data collected, peer assessment of group participation, and individual reflection on skills development.'

Many advocates of PBL promote the use of oral presentations.[29,30,31,32,33] and McGarvey[33]and Wimpfheimer[34] both report the use of poster presentations in chemistry. Wimpfheimer[34] describes the benefits of posters, including that it encourages creativity and it provides another platform for assessment, reaching students who perhaps have been overlooked in the traditional assessment format. Also posters, because of their limited size, stress clear and concise information and can encourage collaborative work in a way than written lab reports cannot. Finally, he reports a positive attitude toward posters both by students and instructors.

Therefore, to promote a deep approach to learning in the practical chemistry laboratory, for reasons outlined above, elements of pre-lab work, discussion, group work and investigative science were combined with alternative assessment in the development of the PBL module.

3.4: INITIAL PROBLEM DEVELOPMENT

The initial task was to adapt the current traditional experiments. The traditional experiments were studied to see how they could be used in a 'real-world' context. Initially, only the analytical experiments were targeted, as there was much resistance to change in the running of the laboratories. The analytical experiments were targeted due to concerns over the perceived benefit of such a large number of similar titrations, in terms of the technical and manipulative skills developed. All students were required to carry out at least seven of the nine titrimetric analyses.

The development of the PBL module has been ongoing for four years. Initially, in the academic year 2001-2002, only a few experiments were adapted to a PBL type approach. This involved giving the students a hand-out with a simple, short description of a problem related to their traditional laboratory task. The aim at this stage was to provide a simple, relevant context for the experiments. The students were given time to think about the problem during the lab session but they were not required to do any extra activities nor were the actual practical activities adapted in any way. However, it was soon realised that with no formal assessment of their thinking on the problem, the students' enthusiasm and commitment to the new approach was low. Initial comments made by the students however were encouraging and so time was spent during the year developing a more focused approach, employing a pre-laboratory discussion and some experimental modifications. In this section, the development process is summarised chronologically. The detail of each PBL experiment and associated learning outcomes is given in detail in Section 3.5.

3.4.1: ACADEMIC YEAR 2002-2003

There were two key aspects to the further development of the PBL module. Firstly, a key area was to identify fundamental concepts that a first year student should know by the end of the first semester and to devise and/or adapt experiments to suit these objectives. For example, students should be familiar with the concept of neutralisation, indicators, and acids and bases and this lead to the development of the experiment titled 'Case of the Unlabelled Bottles'. See Section 3.5 for further detail. Secondly, the importance of a relevant context to the experiment was further appreciated, and therefore each experiment from semester 1 was put in a relevant and interesting context. Furthermore, the results that the students obtained from their experiment had to be given in terms of the problem context.

3.4.1.1: Description of the 2002-2003 PBL module

A more comprehensive approach was taken the following academic year. Week 1 was left as it was, but as an extra feature the PBL cohort were to receive a short talk on the PBL module and how it would be run. Remembering that a few of the students had not done chemistry before, it was decided that the first PBL experiment would be to introduce the students to acids, bases, indicators and neutralisation. This is the only experiment where there was a major deviation from the traditional experiment. From then on, most of the actual PBL experimental work was the same as the traditional in terms that a titrimetric analysis was carried out but was set in a different context. As mentioned before, the students following the traditional approach were given the procedure, and were expected to follow it exactly. The PBL cohort on the other hand were given a problem, and were expected to devise a strategy to solve it. During the pre-lab session, typically no more than 30 minutes, the problem would be discussed, and finally the students decided a suitable procedure to solve it. In the interests of safety, the demonstrator approved the procedure, and set certain restrictions, for example, the amount of reagents that could be used, or the strengths of the acids/bases. In general, the volumes and strengths of reagents used were in line with what the traditional students were using. See Table 3.7 for the schedule of PBL experiments for the analytical module and an overview of their content.

3.4.1.2: Comments on 2002-2003 module

Observations from the demonstrators point of view

In general, the problems worked well from the demonstrators point of view, except for the difficulty which was encountered about half-way through the module. At this stage, as the answers to the problems set were already given in the traditional chemistry manual that all first years had, the students were getting procedures from their colleagues in the other first year science courses. Some students used this to the detriment of their own learning and it defeated the purpose of the PBL module. However, for other students, it just meant that they accessed the information readily and used it effectively to prepare and solve the problem. To improve on this in the future, it was recognised that it would be important to make the experiments significantly different from the traditional ones, and/or separate the PBL module completely from the traditional groups.

Table 3.7: PBL experiments for the analytical module, semester 1, 02-03

WEEK	EXPERIMENTS	CONTENT
1	Fundamental laboratory techniques, safety and PBL talk	Demonstration of correct burette, pipette, balance use and demonstration of preparation of primary standard. Safety talk. Introduction to PBL.
2	Identify the bottles	Well-plate determination of various acids and bases through simple neutralisations. Use of various indicators.
3	Old wives tale	Preparation of volumetric solutions of Antacid and Baking powder and neutralisation with Hydrochloric Acid by titration.
4	Washing machines and hard water	Determination of water hardness by EDTA titration
6	Which bleach is the most effective?	Determination of the concentration of bleach samples by Sodium Thiosulphate titration
7	Iron tablets and anaemia	Determination of the amount of iron in iron tablets by Ceric(IV) Sulphate or Potassium Permanganate
8	Accident in the preparation lab!	Determination of a mixed base ($NaOH/Na_2CO_3$) concentration by Hydrochloric Acid titration
9	Faded label	Determination of the water of hydration on oxalic acid by Potassium Permanganate titration
10	Paws Pet Food	Analysis of a halide mix ($NaCl/KCl$) by titration with Silver Nitrate
11	QC analysis of aspirin	Analysis of aspirin tablet by back titration
12	Testing for ions – Cations and Anions	Qualitative spot tests for cations in well-plates and for anions in test-tubes.

It was apparent from week to week that some of the problems worked better then others. The problems, which I felt worked best were:

- Identify the Bottles
- Old Wive's Tale
- Iron tablets and Anaemia
- QC analysis of Aspirin

The reason why these problems worked well was that the experiments were easy to put into a real context, and the problems provided excellent starting points to learn and acquire new techniques and knowledge. With some of the other experiments, it was hard to find an interesting and stimulating problem to suit. For example, the testing for ions experiment, it was very difficult to provide a real context without altering the experiment. Another example would be the hardness of water, as a stand alone experiment there is very little scope for development of a problem in context.

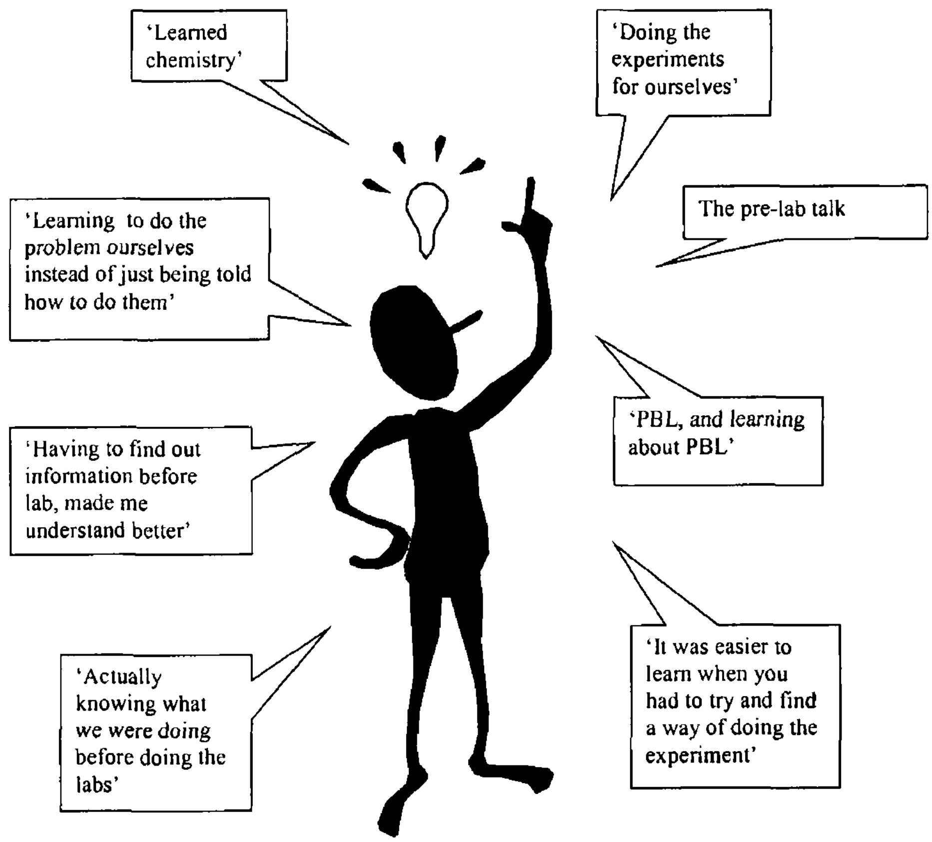
Student survey results

The PBL cohort, at the end of the module, completed a survey. The aim of which was to determine what aspects of the PBL module the students liked and disliked, what was beneficial, what wasn't etc. The students also rated their experience of the PBL module in relation to different factors on a scale of 1 (positive) to 5 (negative). The full layout of the survey can be found in Appendix 3.3. There were twenty-four students in the Science Education class that year and eighteen completed the survey. However, two of the twenty-four had only attended one of the lab sessions anyway, and therefore their contribution would have been invalid. So, to put this in perspective, this survey represents 81% (18/22) of the group.

The first question asked was 'What do you feel was the most beneficial aspect of the lab?' A summary of the answers is given in Figure 3.2. These are exact quotations of the students comments. In most cases the sentiments were expressed a couple of times, just in different ways. To sum up the results, the following factors seemed to be the most beneficial:

- The PBL approach, and learning about it
- Researching the problem/experiment prior to the lab
- The pre-lab discussion
- Developing and doing the experiment themselves.

Figure 3.2: Sample representation of the views expressed about the most beneficial aspect of the lab



On the least beneficial aspect of the labs, the following is a summary of the views expressed. It is important to note that in some cases, aspects that some students felt were beneficial, others felt were not. Every student is different, and needs different motivations!

- Finding out/knowing what PBL was
- Failing to find a solution to the pre-lab, sometimes it was too hard
- Not being given resources for each problem
- Having no procedure book.

3.4.2: SKILLS ANALYSIS

To further develop the Semester 1 module and to develop the Semester 2 module for the 2003-2004 cohort the students taking the PBL module in 2002-2003 and 2003-2004 were asked to complete a skills survey. This was to identify what skills students felt that they were confident using, and which skills the students had little opportunity to develop. The survey was adapted from the RSC's Undergraduate Skills Record (USR)[35]. Various skills were identified in the USR which were seen to be important for first year undergraduate students, such as to interpret laboratory measurements and observations or use feedback to improve on future work. The skills survey asked the students to rate a series of 26 skills on the basis of their confidence in performing each of the skills. The students rated their confidence in each of the skills on a scale of 1 to 5; with 1 meaning they have had no opportunity to develop the skill to date and 5 meaning they can use the skill very well. See Appendix 3.1. The skills were separated into three key areas:

General skills (14 Statements)

Scientific/Practical skills (7 Statements)

Improving learning (5 Statements)

Table 3.8 shows the statements which students had to respond to in the general skills area. Figure 3.3 shows a bar chart of the frequencies of each answer for the general skills from the combined data for the two years (2002-2003 and 2003-2004).

Table 3.8: Description of General skills statements

My ability to...

1. Plan ahead and demonstrate good time management
2. Plan for practical work and project work
3. Make, organise, and store notes effectively
4. Make the most of group work, and tutorials to support my understanding
5. Make the most of practical work to support my understanding
6. Analyse and evaluate experimental data
7. Interpret laboratory measurements and observations
8. Interpret chemical information (i.e. chemical formulas, equations etc.)
9. Maintain good laboratory notes
10. Provide written reports on time
11. Plan and present an oral presentation
12. Work in groups (i.e. contributing in labs)
13. Assume a range of roles within a group
14. Interact with people to obtain necessary information and assistance

It is clear from the chart that students feel that they can apply skills 12 and 14 with confidence, shown by the large proportion of green and light blue in these columns. Skill 12 is 'work in groups' and Skill 14 is 'interact with people to obtain the necessary information and assistance'. 'Plan and present an oral presentation' (skill 11) was identified as the skill which the students have had the least opportunity to develop and felt least confident in, with skills 6 and 8, 'analyse and evaluate experimental data' and 'interpret chemical information' respectively scoring second and third lowest. This is shown by the larger portions of dark blue and wine in these columns compared to other columns.

Figure 3.3: Bar chart of the frequencies of answer to the 14 general skills

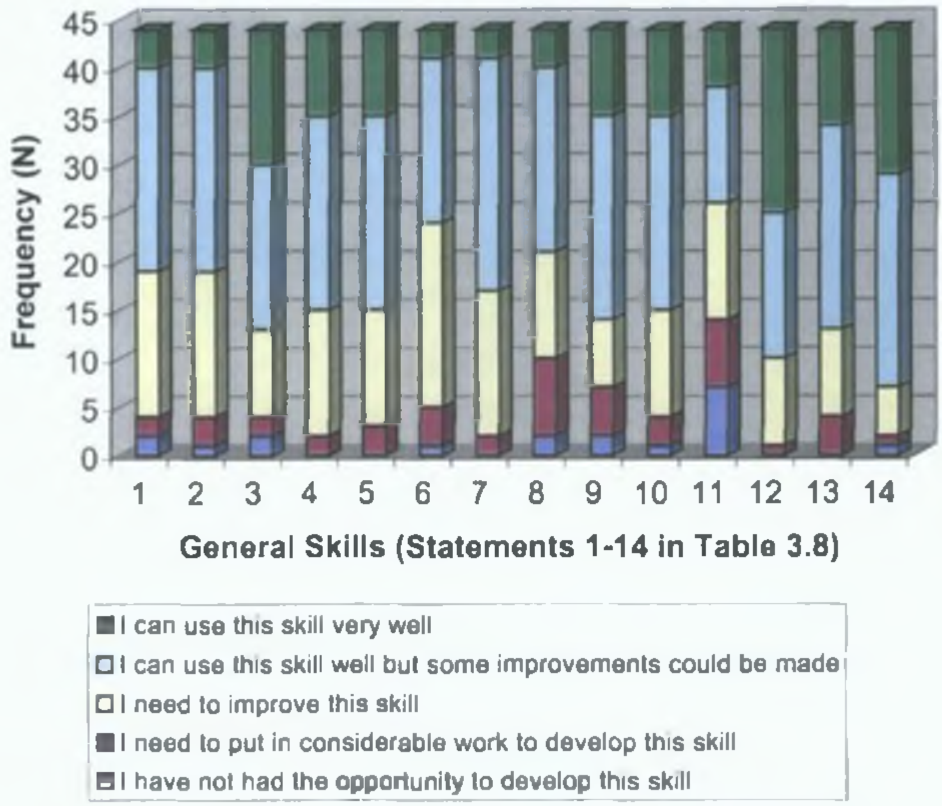


Table 3.9 shows the statements which students had to respond to in the scientific/practical skills area. Figure 3.4 shows a bar chart of the frequencies of each answer for the scientific/practical skills. In terms of these skills, students identified skills 1 and 4 as their most developed in this category, 'maintain awareness of specific hazards relating to chemicals' and 'measure and observe chemical events and changes' respectively. Students feel least confident in skills 7 and 6, 'select appropriate techniques and procedure' and 'understand errors' respectively as shown in Figure 3.4.

Table 3.9: Description of Scientific/Practical skills statements

My ability to...
1. Maintain awareness of the specific hazards relating to chemicals
2. Understand the principles behind experiments
3. Understand the processes involved in experiments
4. Measure and observe chemical events and changes
5. Record experimental data coherently
6. Understand errors
7. Select appropriate techniques and procedures for experimental work

Figure 3.4: Bar chart of the frequency of answer to the 7 scientific/practical skills

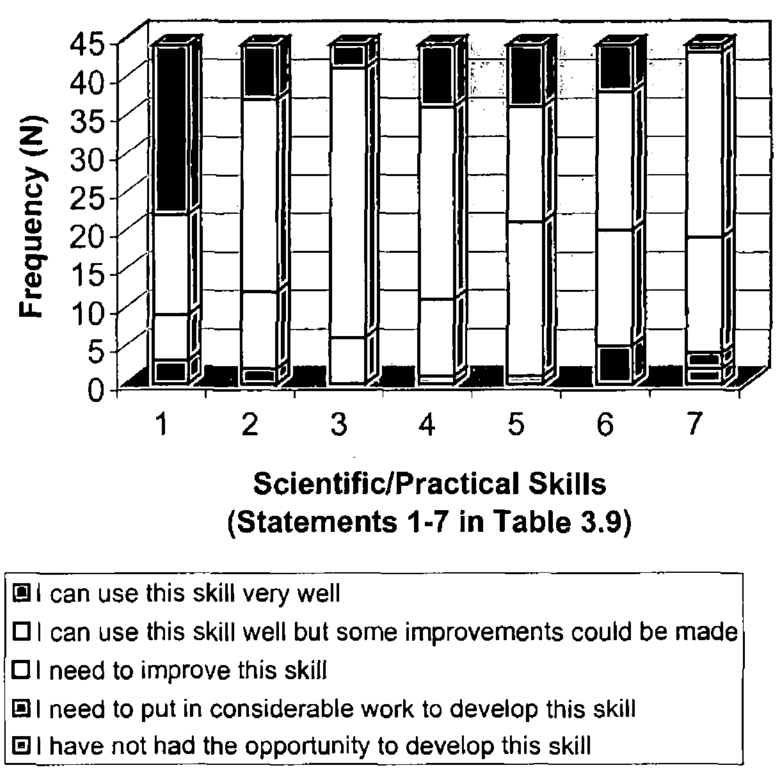


Table 3.10: Description of Skills to Improve Learning

My ability to...
1. Use feedback to improve on future work
2. Maintain an interest in general science issues
3. Use the internet and other resources to gain information
4. Use computers to prepare reports/presentations
5. Apply acquired knowledge to the solution of chemistry problems

Figure 3.5: Bar chart of the frequency of the answer to the 5 improving learning skills

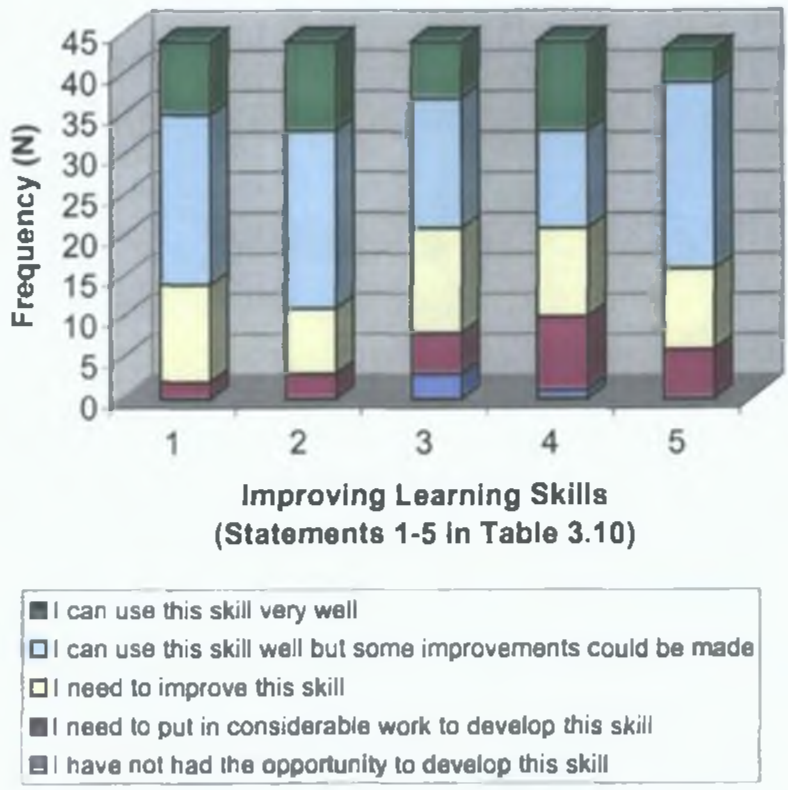


Table 3.10 shows the statements which students had to respond to in the improving learning skills area. Figure 3.4 shows a bar chart of the frequencies of each answer for the improving learning skills for both sets of data. Students revealed that they felt most confident in maintaining an interest in general science issues (skill 2) and least confident in using internet and other resources to gain information (skill 3). Tables 3.11 and 3.12 show summaries of the skills that students felt most and least confident in. It is worth noting the limitations of this skills survey, as some students have limited practical experience, and therefore limited understanding of the statements. Despite this, it is useful tool to identify the strengths and weaknesses of students' perceptions of their own skills.

Table 3.11: Skills which students feel most confident in

Work in groups
Interact with people to obtain the necessary information and assistance
Maintain awareness of specific hazards relating to chemicals
Measure and observe chemical events and changes
Maintain an interest in general science issues

Table 3.13: Skills which students feel least confident in

Plan and present an oral presentation
Analyse and evaluate experimental data
Interpret chemical information
Select appropriate techniques and procedure
Understand errors
Use internet and other resources to gain information

This information was used to develop the PBL module, by focusing on tasks which would develop these skills further and build students' confidence in using the skills. For example, incorporating oral presentations into the labs, and getting students involved with the development of experiments, by researching appropriate techniques and procedures using the internet and other resources. Also, the importance of errors and evaluating the experimental data was a key focus of their write-ups and their oral presentations.

Taking into consideration comments from the demonstrators on the course, and from the students, as well as the skills profile of the students, various recommendations were made for the following year.

These included:

1. Making more use of the pre-lab exercise, by specifying more clearly what was required of the students, including an assessed written pre-lab report
2. Giving students resources and references to help them solve the problem, or at the very minimum pointing them in the right direction
3. Using the pre-lab discussion more effectively, by the demonstrator taking on the role of a facilitator, allowing the students do more of the talking and get more actively involved
4. Using less summative and more formative assessment methods, including written feedback and oral and poster presentations

All these were taken into consideration when developing the PBL module the following year, 2003-2004.

3.4.3: DESCRIPTION OF THE 2003-2004 PBL MODULE

There were some modifications to the analytical content of the existing module. For example the hardness of water and the qualitative tests for anions and cations experiments were combined with a titration to determine dissolved oxygen, and a two-week problem was set up around fish kills in a river. This is described in more detail in Section 3.5. As a further assessment of the analytical problems developed in the revised PBL module, a weekly 'Problem Analysis' was carried out by students from the 2003-2004 cohort in semester 1 to determine their experience of the problems. Results from this will be discussed in the next Section. See Appendix 3.4 for an example of a 'Problem Analysis' questionnaire.

The physical and organic experiments, which are covered in the traditional module were studied to assess their suitability to develop students understanding of the fundamentals of these disciplines. Also, the possibility of setting the experiments in relevant contexts was examined. A selection of these experiments was chosen for use in the PBL module which covered fundamental concepts and techniques, such as rates of reactions, gas laws, Beer-Lambert Law, recrystallisations, and organic preparations.

The pre-lab element was further developed, encouraging more student-student and demonstrator-student interactions during the session. Group work was emphasised in certain experiments through actual group activities in the laboratory. Also students were encouraged to do their pre-lab tasks together and were typically assigned groups to work in. This was not enforced however, resulting in some students working on their own. For the most part students worked together in trying to solve the problem, albeit not in their assigned groups. Furthermore, for the actual practical part of the lab, they always worked in a minimum of pairs. This required them to work closely with each other, assigning tasks, helping each other, discussing their results and concluding their experiment among others activities.

Finally, traditional written reports still made up the bulk of the assessment of the module. However, there was an emphasis on the aims, discussion and conclusions of the problems with approximately 25% of the marks going towards these sections. Also, the pre-lab work got between 20-25% of the marks awarded per week. The use of oral and poster presentations to assess students' achievement in the laboratory was also a part of the revised module.

3.5: THE PBL MODULE (04-05)

Below is a list of the titles of the PBL experiments for each semester, and length of time assigned to each (Tables 3.14 and 3.15). See Appendix 3.5 for the PBL module, as given to the students from week-to-week.

Table 3.14: PBL experiments for semester 1

EXPERIMENTS	WEEK
Safety talk, and demonstration	1
M&M's, Straws and Marbles	2
Apples and Oranges	3
Case of the Unlabelled Bottles	4
StateLab vs. LabAnalysis	5
	6
Assessment	7
Iron tablets and anaemia	8
Old Wives Tale	9
Paws Pet Food	10
Fish Kills at Fisher's Point	11
	12

Table 3.15: PBL experiments for semester 2

EXPERIMENTS	WEEK
Investigation of Gas Behaviour	1/2*
Clock Reactions	1/2
Like dissolves Like	3/4*
Combating Fish Disease	3/4
Purification and Purity Determination	5
Aspirin - Preparation	8
- Back-titration	9/10*
- UV analysis	9/10
Hard-boiled or scrambled?	12

Note: No experiments in week 6/7 due to Public Holidays

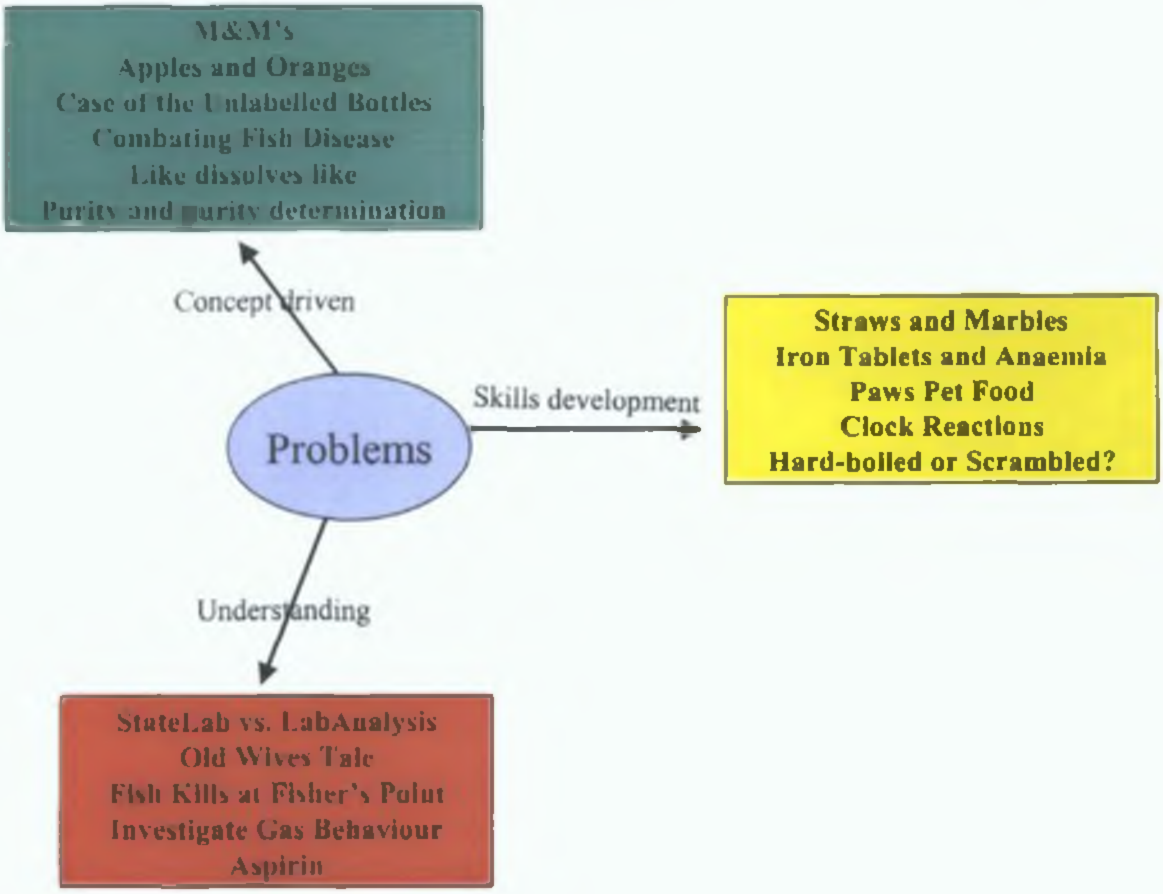
In week 11, the students carried out a traditional experiment

* Half the group did the experiment in week 1 the other half did it in week 2

Problems which challenged and engaged the students were designed. It was hoped that the PBL problems, among other objectives, would provoke free discussion among students both in and outside the laboratory. Anecdotal evidence suggests that this was indeed the case with students often discussing the problems over their coffee break! The problems were developed to cover three main areas – key concepts in chemistry, understanding and laboratory skills development. A detailed account of the various problems is given in the following sections. Furthermore, the experiments which the traditional students were taking at the time are also shown. It is shown that overall the PBL students cover the same content as the traditional students over the course of the year, even if from week to week there are mismatches between the two cohorts. The problems are dealt with under three distinct headings, depending on what the main focus of the problem was (See Figure 3.6):

- Concept driven
- Skills development
- Understanding

Figure 3.6: The breakdown of the problems into three distinct categories



As an introduction to PBL, in the first week of the module students took part in a group exercise – 'Straws and Marbles'. This acted as an introduction to group work, problem-solving and the fact that there are often many ways to solve a problem. This is described in more detail in Section 3.5.2.1. It also acted as an ice-breaker, helping students to get to know each other and the demonstrator(s) in a relaxed atmosphere where chemistry knowledge was not required.

3.5.1: CONCEPT DRIVEN PROBLEMS

These problems were used to help students understand the major concepts of the first year programme, including moles and molarity, acid/base theory, use of indicators, the Beer-Lambert Law, polarity and purification. In the traditional labs, these concepts are often only explained by a small introductory paragraph in the manual. However, students mostly ignore this information and even if the students attempt to read and understand it, according to Byers[36], effective thinking is inhibited because of information overload in the students working memory, leaving no room for information processing and hence understanding. The practical work, which then follows is typically reduced to a recipe style lab, with little or no engagement of the student in the learning process.

These concept driven problems aim to give students a real opportunity to engage with the concepts both prior to the laboratory exercise through the pre-lab and discussion session and during the laboratory through relevant hands-on student driven investigative experiments.

3.5.1.1: M&M's

This is the first practical activity that the students do in the laboratory. The M&M's problem is based on a series of exploratory laboratory activities from Brigham Young University, including M&Ms – Moles and Molecules[37] and How Big is a Mole?[38] The activities and worksheets were adapted to suit the PBL module and other activities were added. The aim of this problem was to introduce students to the concept of moles and molarity. This is one area, which students really struggle with. It was hoped that by using real things to represent atoms and molecules, students would build a solid representation of these in their own heads. The students taking the traditional approach use this lab session to go through a series of problems, mostly calculations, which cover the kinds of questions, which students will encounter over the course of the first semester. See Table 3.16 for an overview of the PBL experiment and a comparison with the traditional activity which was carried out that week, in terms of concepts, hands-on activities and calculations.

Table 3.16: Comparison of the traditional and PBL experiment – Week 2 Sem 1

	TRADITIONAL	PBL
Concepts		Moles and Molarity Accuracy, precision and errors
Hands-on activities		Weighing
Calculations	Fundamental calculations	Fundamental calculations

The use of the M&M's allows the students to have a real visualisation of atoms and molecules and moles. Other activities involve weighing out moles of different substances e.g. water, salt and copper sulfate and making up molar solutions. This helps to make the concept of the 'mole' real. Students have commented after this lab that for those who had done chemistry, it helped to reinforce or make clear their knowledge of the mole and molarity, and for those who hadn't met it before (except in lectures) said that it helped them understand exactly what a 'mole' was.

3.5.1.2: Apples and Oranges

This problem gave the students the challenge of investigating whether apples or oranges were acidic or not, and to determine their acidity. They had to design the investigation themselves, but it was discussed during the pre-lab session. This was to help those who had difficulties gain a better understanding and to check the experiments of those who had successfully designed an investigation. See Table 3.17 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of concepts, hands-on activities and calculations.

This experiment allowed the students to really get to grips with acidity/pH and the different ways of measuring it. The choice of litmus paper, universal indicator paper and other indicators gave students a sense of ownership, as they had to choose which method to use. On discovering that indeed both apples and oranges were acidic, the next step was to develop a method to compare the amount of acid in each. This was done by making up two volumetric solutions giving students experience of fair tests, and titrating them with a base. Most of the students knew from their pre-lab work that a strong base such as sodium hydroxide would be appropriate. They also chose what indicator to use.

Table 3.17: Comparison of the traditional and PBL experiment – Week 3 Sem 1

	TRADITIONAL	PBL
Concepts	Primary standards Standardisation	Acid-Base chemistry Indicator theory Titration as quantitative method
Hands-on activities	Preparation of primary standard Standardisation of HCl	Checking pH Preparation of 'juicy' solutions Titration with NaOH
Calculations	Fundamental calculations	Fundamental calculations Acidity of apple and orange

Overall, this experiment gave the students real experience with designing an investigation. They were involved with every step of the process, and so had feel what it is like to develop an experiment from start to finish. They concepts they met were very basic but imperative to the analytical course both in the practical lab and in the lecture series. Compared to the traditional group, they do similar practical exercises such as preparing volumetric solutions and doing titrations. However, they are presented in context in the PBL module and so the students get more out of it.

Both the demonstrator and the students observed difficulties with this experiment. These included the problematic nature of handling real material for example liquidising the apples and oranges was very time consuming and bits from the orange or apple would get stuck in the pipette despite filtering of the samples. Also, the calculations arising from this are tricky and various assumptions are made including that citric acid is the only acid present. This problem was reviewed by the students using the 'Problem Analysis'. Students surprisingly agreed with the statement 'The problem was sufficiently challenging', and a level of disagreement with 'The experimental/practical aspects of the lab were easy' was observed. Some student comments included:

'Use juice (already squeezed oranges)'

'A little more information/websites to find information'

3.5.1.3: Case of the Unlabelled Bottles

This was also adapted from an exploratory lab at Brigham Young University.[39] The PBL experiment asks students to correctly label five solutions, given the names and concentrations of each. The students are not given any other solutions only indicators. Secondly, having identified the bottles, the students must accurately determine the concentration of one solution by titration. They must decide what other solution to use in the titation and what indicator. The solutions were acids and bases of varying concentrations, namely:

- Acetic Acid 0.05M
- Hydrochloric Acid 0.05M
- Hydrochloric Acid 0.075M
- Sodium Carbonate 0.01M
- Sodium Hydroxide 0.025M

See Table 3.18 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of concepts, hands-on activities and calculations.

Table 3.18: Comparison of the traditional and PBL experiment – Week 4 Sem 1

	TRADITIONAL	PBL
Concepts	Primary standards Standardisation	Acid-Base chemistry Indicator theory Standardisation
Hands-on activities	Preparation of volumetric solutions Titrations x 2	Checking pH Small-scale titrations Standardisation of CH_3COOH
Calculations	Fundamental calculations	Fundamental calculations

This problem aimed to further the student's understanding of acids and bases, indicators and quantitative measurement. From the previous weeks experiments, they should be able to easily distinguish between the acids and bases, but the next level was to determine different strengths of acids and bases so as to distinguish between, for example, the sodium carbonate and the sodium hydroxide, and then also to distinguish between different concentrations of solutions i.e. the 0.05M and 0.075M hydrochloric acid solutions. They could use a variety of techniques, from indicator theory to 'small-scale' titrations to solve this. Given the added challenge of using as little as possible of the solution meant that they were discouraged from using the typical standard titration equipment, and instead encouraged to try well plates and small beakers to carry out small-scale titrations. This encouraged the students to think outside the box, thus developing a better appreciation of alternative methods and adapting their previous knowledge of titrations to a new context.

This problem was also reviewed through the 'Problem Analysis'. Students reported a significant level of disagreement with the statement 'It was difficult to devise a strategy/plan an approach' and again showed a high level of agreement for the statement 'The problem was sufficiently challenging'. Students' comments suggested that some students had difficulty with the calculations 'Maths could be gone over in more detail/calculations'. Also several students highlighted a difficulty with the task, suggesting it was unclear and that they were unsure what to do.

3.5.1.4: Combating Fish Disease

This problem involves the direct use of a procedure from the traditional manual, namely 'Microscale determination of the Order of a Chemical Reaction and Evaluation of the rate constant'. The experiment looks at the reaction between malachite green and sodium hydroxide, forming a colourless carbinol product. However, the context provided in the PBL problem allows for much more engagement and understanding than the traditional experiment, which covers a lot of material and certainly overloads the minds of the learners! See Table 3.19 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of concepts, hands-on activities and calculations.

The PBL students were given a problem concerning a fish collector – Mr T Sharkey, who has noticed that his koi fish have what appears to be a fungal infection and who has decided on a treatment of malachite green. However, when the fish do not show signs of improvement and the normally green malachite has gone colourless – he seeks the help of SE.co. Their challenge is to discover what has happened to the malachite green and to see if they can figure out why the fish have not recovered. The pre-lab exercise involves researching the Beer-Lambert Law and the order of reactions, and also the use of malachite green to combat fish disease. They are also expected to think about the procedure they will take. Having discovered that the fish tank had previously held some sodium hydroxide and had reached a maximum of 30°C, they set up their conditions accordingly for an investigation. This provides students with a reason for the conditions in the experiment, which otherwise would just be another bit of inconsequential information...or at least in the eyes of the students anyway!

Table 3.19: Comparison of the traditional and PBL experiment – Week 3/4 Sem 2

	TRADITIONAL	PBL
Concepts	UV/Vis spectrophotometry Beer-Lambert Law Order of chemical reactions	Colorimetry Beer-Lambert Law Order of chemical reactions
Hands-on activities	Monitoring of rate of loss of malachite green by UV/Vis	Monitoring of rate of loss of malachite green by colorimetry
Calculations	1st and 2nd order reaction rates Rate constant	1st and 2nd order reaction rates Rate constant What has happened to fish?

This problem provides a context for an experiment which is very important in terms of the concepts it introduces, especially the Beer-Lambert Law, but this can get lost when so much factual information is combined with a very prescribed procedure. Overall, the students discover that the malachite green, though loses it colour, is still effective and that it is a misdiagnosis on the part of Mr T Sharkey that has caused the fish to remain ill. The PBL students still have to produce 1st and 2nd order plots to see what is happening in the reaction, and to calculate the rate constant and so are not losing out in comparison to the traditional group.

3.5.1.5: Like Dissolves Like

Similar to the last experiment, this experiment seeks to introduce the students to a very important concept - that of polarity and solubility. See Table 3.20 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of concepts, hands-on activities and calculations.

The concept of polarity is very important, however, it is not given the attention it needs in the traditional experiment, which turns into a calculation-based practical task with little or no engagement on the part of the learner. In the pre-lab task, the PBL students are asked to consider various everyday activities such as using acetone to remove nail varnish, or the use of methylated spirits to remove oil based paints. They are asked to explain these and other scenarios. Finally, they are asked to devise an experiment to hypothetically determine if hydrochloric acid is even partially soluble in acetone. By the end of the pre-lab discussion, the students have a firm grasp of polarity and its relevance in chemistry. This sets up the experiment in a relevant context, which the students can relate to easily. The experiment then has more meaning for the students.

Table 3.20: Comparison of the traditional and PBL experiment – Week 3/4 Sem 2

	TRADITIONAL	PBL
Concepts	Distribution ratio	Polarity Solubility Distribution ratio
Hands-on activities	Microscale Separation	Microscale Separation
Calculations	Distribution ratio	Distribution ratio

3.5.1.6: Purity and Purity Determination

Over the course of the traditional year long chemistry lab module, three experiments involve aspirin i.e. the preparation of aspirin, analysis of aspirin by back titration and analysis of aspirin by UV. It was decided that the PBL group would do these three experiments together as a 3-week long problem. On preparation of their aspirin, acetylsalicylic acid, they have to test the purity and then further purify their sample. However, it was found in 2003-2004 that the students having no previous experience in melting points and recrystallisation struggled with these concepts when they were presented with all the other information involved in these experiments. Therefore, it was decided that it was necessary to do a problem, which gave them the opportunity to meet these concepts prior to applying them in the aspirin problem.

An organic experiment involving the recrystallisation of acetanilide and *p*-dibromobenzene was chosen as a suitable precursor to the aspirin problem. The pre-lab exercise involved them researching acetanilide and its history as a pain-relieving drug. Also, they were instructed to determine chemical and structural formulae of both acetanilide and *p*-dibromobenzene. This lab was effective at introducing the students to the concept of melting points and their significance in terms of purity. They also got a firm grasp of the recrystallisation process and the principles, which underlie it. See Table 3.21 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of concepts, hands-on activities and calculations.

Table 3.21: Comparison of the traditional and PBL experiment – Week 5 Sem 2

	TRADITIONAL	PBL
Concepts	Recrystallisation	Importance of purity Significance of melting points Recrystallisation
Hands-on activities	Recrystallisation: Single solvent Mixed solvent Melting point	Recrystallisation: Single solvent Mixed solvent Melting point
Calculations	% Yield	% Yield

3.5.2: SKILLS DEVELOPMENT PROBLEMS

This group of problems aimed to develop the skill base of the students, both in terms of their transferable skills and their technical skills. Transferable skills developed include group working, problem-solving and communication skills, whereas the technical skills developed include improving accuracy and precision in:

- Making up solutions
- Selection of appropriate apparatus
- Carrying out titrations

3.5.2.1: Straws and Marbles

This problem-solving exercise was taken from a group of problem-solving activities developed by Alison Graham[40]. This particular activity is used to develop problem-solving and group working skills. It also promotes the often unfamiliar concept that there is more than one way to solve a problem and, as important, not always one correct answer. Traditionally, students expect there to be a right way of doing things, and therefore, one clear-cut right answer. However, as scientists know only too well, there are often many routes that can be taken to get to a particular result. This is a difficult expectation to break in students, especially in those who have succeeded well at secondary school by adapting a rote-learning approach, accepting the answer in the book and following the exact procedure to get there!

In this problem students are given the task to build a construction out of 6 straws, and 0.5m of sellotape to support the weight of the marble at the maximum possible vertical height above the bench. However, the students are limited to the equipment given to them and cannot use the sellotape to hold the straws to the table or the marble to the straws!

Table 3.22: Comparison of the traditional and PBL experiment – Week 2 Sem 1

	TRADITIONAL	PBL
Skills	Not applicable	Problem-solving Group skills
Hands-on activities		Using straws and sellotape to support a marble a high as possible from the bench… terms and conditions apply
Calculations		Not applicable

In groups of 4/5, the students are given this task. The students soon realise that there are many ways to go about this exercise and often every group's design is completely different. It is also a good 'ice-breaker' exercise since there is no chemistry or science involved, and therefore no student feels at a disadvantage. It encourages the students to listen to each other and their ideas, and often groups try a couple of structures before deciding on their final design as a group. See Table 3.22 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of skills, hands-on activities and calculations.

3.5.2.2: Iron tablets and Anaemia

This problem involves the students having to prescribe a dosage of iron tablets to a 20-year old woman who is suffering from anaemia. To do this successfully they need to experimentally determine the amount of iron in the iron tablets provided, and then recommend the dosage required per day to maintain her iron at the correct level. To do this requires that the students carry out the experiment as accurately and precisely as possible.

Having carried out numerous titrations at this stage, it is expected that the students accuracy and precision in weighing, preparing solutions, using pipettes and burettes, and observing end-points is well established. Therefore, they are accordingly assessed on their accuracy and precision with respect to their titre values obtained, which is a mark of their overall technical ability. Accuracy is a measure of how close one is to the true or accepted value, and precision is a measure of how reproducible or how close together the values are. Figures 3.7 and 3.8 below give visual descriptions of precision and accuracy[41]. Figure 3.7 below shows how that the points are precise since they all cluster together but they are not accurate as they are not close to the bulleyes. In contrast, Figure 3.8 shows that the points are accurate as they are all very close to the bullseye, but not precise since they are not close together.

Figure 3.7: Precision

Figure 3.8: Accuracy

Assessment of the students technical ability is taken into consideration in their laboratory reports, where, of the marks available, there was a proportion of marks available for their precision (2%) and accuracy (4%) in their experimental results. See Table 3.23 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of skills, hands-on activities and calculations.

The students reviewed this problem through a 'Problem Analysis'. Students were given clear instructions on how to carry out the practical aspects of this problem and students reported that being given the procedure made the lab easier. Despite this, students responded lowest to the statement 'The experimental/practical aspects of the lab were easy'.

Table 3.23: Comparison of the traditional and PBL experiment – Week 8 Sem 1

	TRADITIONAL	PBL
Skills	Technical Observation	Technical Observation
Hands-on activities	Weighing Preparation of volumetric solutions Titration	Weighing Preparation of volumetric solutions Titration
Calculations	Determination of mg of iron per tablet	Determination of mg of iron per tablet Recommendation for dosage of iron tablets for anaemia patient

3.5.2.3: Paws Pet Food

This experiment, similar to the last one, aims to improve and measure the students' technical ability. The context of the experiment is that, as analytical chemists, the students have been asked to carry out an analysis of cat food, to determine the amount of potassium and sodium salts in the finished product. Excellent observation skills are required in the determination as the end-point can be hard to see, and accuracy and precision are required throughout the experiment, if the students are to successfully determine the % sodium and potassium chloride in the mixture. See Table 3.24 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of skills, hands-on activities and calculations.

Table 3.24: Comparison of the traditional and PBL experiment – Week 10 Sem 1

	TRADITIONAL	PBL
Skills		Technical Observation
Hands-on activities	Weighing Preparation of volumetric solutions Titration	Weighing Preparation of volumetric solutions Titration
Calculations	Determination of the % Na and KCl in the mixture	Determination of NaCl and KCl mix in Cat Food

As before, the students were assessed on their technical skill through their experimental results. Overall, 10% of the marks were going towards both accuracy (8%) and precision (2%). Data from the 'Problem Analysis' indicated that students felt that it was easier, than normal, having been given the procedure for the experiment but interestingly, that the experimental/ practical aspects of the lab were hard.

3.5.2.4: Clock Reactions

This experiment is based on rates of reactions, and how the rate of reactions are influenced by various factors such as concentration, temperature and the presence/absence of a catalyst. Though a similar experiment is carried out in the traditional module, it is more complicated and the manual suffers severely from information overload! It was decided that before students could really engage with first order reactions and activation energies, they needed to have some basic knowledge of rates of reactions. This experiment takes place before the 'Combating Fish Disease' problem mentioned earlier, which builds on this.

However, the other reason for this experiment is to observe the technical ability of the students. The challenge for the students is to make their reaction change colour at a specific time in time with music. They are given guidelines to try out various different concentrations of sodium thiosulfate with potassium iodide, starch and acidified hydrogen peroxide to monitor when the solution goes from clear to blue-black. The reaction is based on the oxidising properties of hydrogen peroxide, which in acidic conditions takes part in an oxidation-reduction reaction with potassium iodide according to the half reactions shown below:

$$2I^- \rightarrow I_2 + 2e^-$$

$$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$$

As the iodine is formed, it reacts with the thiosulfate according to the equation below:

$$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$$

When the iodine has reacted with all the thiosulfate, it will then react with the starch to form a blue-black colour. This experiment requires excellent observation and technical skills if they are to get their reaction to be 'on time'. At the end of the lab session each pair of students had two solutions to time to a piece of music. It was obvious which students were more careful in their approach to making the solutions and who were not. Enjoyment and involvement factors were very high here. See Table 3.25 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of skills, hands-on activities and calculations.

Table 3.25: Comparison of the traditional and PBL experiment – Week 1/2 Sem 2

	TRADITIONAL	PBL
Skills	Technical Observation Data manipulation	Technical Observation Data manipulation
Hands-on activities	Preparation of volumetric solutions Titration	Measuring volumes
Calculations	Determination of the Activation Energy	Concentration of thiosulphate

3.5.2.5: Hard-boiled or scrambled?

The final practical exercise, which the students do in their PBL module, is a real practical challenge. It is another group exercise, where the students have to use a chemical reaction to cook an egg! The reaction used is the highly exothermic reaction between calcium oxide and water:

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)} \qquad -\Delta H^{o}_{hyd} = -81.99 kJ/mol$$

They are given a variety of materials, which they can use to insulate the reaction flask and hence cook their egg. As with the previous exercise, typically a wide variety of designs are used, with very diverse outcomes, resulting in eggs which are still completely runny to eggs which are nearly completely hard-boiled! Figure 3.9 shows students working on their design.

See Table 3.26 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of skills, hands-on activities and calculations. Figure 3.10 shows the results from the problem, with each student group having varying degrees of success in cooking their eggs!

Figure 3.9: Students working on their design

Table 3.26: Comparison of the traditional and PBL experiment – Week 12 Sem 2

	TRADITIONAL	PBL
Skills	Not applicable	Problem-solving Group skills
Hands-on activities		Building an 'oven' Insulating the reaction vessel
Calculations		Enthalpy Molarity

Figure 3.10: Results from the egg experiment

1st Place

3rd Place

2nd Place

This is a thoroughly enjoyable experience for all the students, who really get excited when the temperature of their reaction vessel rises and hence, their egg starts to cook. With the added incentive of a prize for those whose egg is 'most cooked' and still intact i.e. in its unbroken shell by the end of the experiment, there is a friendly competition between the groups, thus increasing motivation and participation[42].

3.5.2.6: Communication skills development

There were three experiments where students have an opportunity to present their findings orally over the course of the year. These were:

- StateLab Vs. LabAnalysis
- Fish Kills at Fisher's Point
- Poster presentation

In the first two, the oral presentations were part of the specific problem and required the students to present background and experimental information from their investigations to make a case for or against the issues. These two problems will be discussed in Section 3.5.3.

The poster presentation involved them choosing any one of the problems, which they had met over the year, and to present an informative poster on it. The students had to decide what type of audience their poster was aimed at, and what type of information was to be included. However, both background information on the problem and some chemistry, including experimental details was expected. See Figure 3.11.

Figure 3.11: An example of some of the student posters

3.5.3: UNDERSTANDING PROBLEMS

Throughout the duration of the PBL module, there was an emphasis on group work, communication, problem-solving and researching skills. These were mostly developed through the pre-lab exercise and discussion. Through the pre-lab exercise the students were expected to go and actively research their problem using books and websites, and to solve the problem through collaboration with their peers in small groups. As well as developing the transferable skills mentioned, the aim of the pre-lab exercise was to provide a platform for enhanced understanding by the students. The benefit of working in small groups has been discussed at length in Chapter 1, with special focus on the enhancement of student learning and understanding through positive interactions with their peers. The benefit of pre-lab/lecture exercises has been documented in many publications[1,7,36,25,43] and was discussed in detail in Section 5.3. Suffice to say, that pre-labs are seen as integral in furthering students understanding and experience of the laboratory.

However, other methods can be used to enhance student learning in the laboratory, such as getting students to present their results in oral or poster presentations or to carry out real investigative experiments. Oral and poster presentation encourage them to ensure they understand fully what they have done, and hence can back up their argument. Whereas, investigative laboratories, where students have ownership over the design and implementation of the experiment and the experiments have unknown outcomes, can give rise to real understanding. These next set of experiments use the problem, pre-lab, discussion, experiment, and subsequent report to enhance students' understanding of their experimental results and hence of the experiment and its concepts.

3.5.3.1: StateLab Vs. LabAnalysis

This problem uses a simple titrimetric analysis, that between ethanoic acid and sodium hydroxide, in an interesting context to enhance students' engagement and experience with this technique. The problem is set-up around a customer complaint about the local supermarket's home brand vinegar, which is reported to have a 5% ethanoic acid content. The students are divided into groups of three or four, with half of the groups representing the consumer through the State Laboratory and the other half representing 'Supershopper', the local supermarket, through a private analytical chemistry company 'LabAnalysis'. Their job is to carry out an analysis of the vinegar samples to check the concentration of ethanoic acid in the samples provided and to approve or reject it for future sale.

During these two weeks, the traditional students are also carrying out titrations – determination of hardness in water and analysis of bleach. These both require very similar techniques, and the PBL group carry out the hardness of water later in the module as part of their final problem in semester 1 anyway. See Table 3.27 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of understanding, hands-on activities and calculations.

Table 3.27: Comparison of the traditional and PBL experiment – Week 5/6 Sem 1

	TRADITIONAL	PBL
Understanding	Complexiometric chemistry REDOX chemistry	Acid-Base chemistry pH
Hands-on activities	Dilution of samples Standardisation Titrations	Dilution of samples Titrations Micro-titrations PH probe and dataloggers
Calculations	Fundamental calculations	Fundamental calculations Determine fate of the vinegar

The PBL cohort are expected to use a variety of techniques to determine the % ethanoic acid in the four vinegar samples. They can choose from normal scale titrations, micro-titrations or the use of a pH probe and datalogger to monitor the reaction. They typically use two of the techniques to consolidate their results. Having completed the experiments, the students must then present their findings on OHPs and argue their results with another group, who are on the opposing side of the argument. This has often led to discussions and arguments on errors, for example which particular glassware should have been used and which techniques were more accurate/precise with typically conflicting conclusions! The students have no choice but to get actively involved in this process. Every member of the group is expected to contribute, thus ensuring participation and real collaborative group work.

The assessment of this problem takes into consideration their pre-lab work, their participation in the lab, their written report, their oral presentation and finally the questions and arguments they pose to the other presenting groups. This final point encourages the student to look critically at their fellow students' results, and thus begins an appreciation for evaluating evidence presented in literature resources. In the 'Problem Analysis' the students showed a high level of agreement with the statement 'The overall problem solving experience was enjoyable' and the least agreement with the statement 'It was difficult to devise a strategy/plan an approach'. In terms of the presentation, actually giving the presentation was rated highest, whereas the ease of preparation for the presentation was scored the lowest.

3.5.3.2: Old Wive's Tale

This experiment takes place when the traditional group are doing an experiment to determine the water of hydration on oxalic acid by potassium permanganate titration. The PBL group are given the task of determining if baking soda could be effective at relieving heartburn and indigestion, and if so, how it compares to a commercially available antacid tablet. The students are required to discuss the reaction that takes place in the stomach between these 'antacids' and the gastric juices through a series of guided questions and to describe an experiment, which would be suitable for this experiment. See Table 3.28 for an overview of the PBL experiment and a comparison with the traditional experiment which was carried out that week, in terms of understanding, hands-on activities and calculations.

Table 3.28 Comparison of the traditional and PBL experiment – Week 9 Sem 1

	TRADITIONAL	PBL
Understanding	REDOX chemistry	Acid-Base chemistry Back-titrations
Hands-on activities	Preparation of volumetric solutions Heating Titration	Preparation of volumetric solutions Back-titration
Calculations	Fundamental calculations	Fundamental calculations Is baking soda as effective as the Antacid?

Students typically do well in their pre-lab questions and most suggest a titrimetric analysis to solve the problem. However, few have met the concept of a back-titration before and even if they come across it during their research they do not fully understand it. Therefore, the pre-lab discussion is used to facilitate student understanding of the 'back-titration' and how it can be used for this experiment.

Students perform two sets of titrations during this problem - one on baking soda and the other on an antacid. It is essential that they set up the experiment in such a way that makes comparison of their results possible. This gives them experience in experiment design, the concept of 'controls', experimental design and control of the variables. On successfully completing the practical task, the students must then analyse their results in detail in order to make appropriate conclusions. Since the result is unknown, they are not expecting any particular result, thus making the whole experience more real, and requiring real engagement with their data. Student feedback from the 'Problem Analysis' indicated that students had difficulty with devising a strategy/plan of approach. In contrast the students rated the problem solving experience positively. Generally, students seemed to find the calculations difficult with numerous students suggesting more help with calculations including giving students more time to spend on them and making them clearer.

3.5.3.3: Fish Kills at Fisher's Point

This problem is adapted from a case study developed by Simon Belt, Tina Overton, and Stephen Sumerfield called 'Tales of the Riverbank'[44]. The overall problem is that the local Angling Association has noticed that the number of fish caught at their annual fish competition has been decreasing and they express concerns over potential pollution problems. Similar to the vinegar problem, the class group is divided into groups of approximately 4, and half of the groups are representing DCU Angling Association and the other half are representing DCU River Authority. Each group is given a sample of water from a particular point along the river, and they have to identify any 'problems' with their sample and outline a course of action to be taken. The water samples have been appropriately 'spiked' with various ions such as nitrates, phosphates, lead, and iron. During the course of the two weeks the students are required to carry out various experiments, including determination of pH, hardness and dissolved oxygen, as well as qualitative analysis of the water for anions and cations. In some cases, quantitative analysis of certain cations and anions is possible using dip-sticks. This problem allows the students to do two of the traditional experiments, namely determination of water hardness and qualitative tests for anions and cations, in a relevant context, thus providing a motivating learning experience. The traditional students do an analysis of aspirin by back-titration in week 11, which the PBL students to in semester 2, and the tests for anions and cations in week 12. See Table 3.29 for an overview of the PBL experiment and a comparison with the traditional experiments which was carried out for the two weeks, in terms of understanding, hands-on activities and calculations.

Table 3.29: Comparison of the traditional and PBL experiment – Week 11/12 Sem 1

	TRADITIONAL	PBL
Understanding	Back-titration Anions and Cations	Complexiometric chemistry Winkler method for D.O. Anions and Cations PH Environmental issues Water pollution
Hands-on activities	Back-Titration Spot-tests in well-plates	Micro-titration Spot-tests in well-plates
Calculations	Fundamental calculations	Fundamental calculations Determination of the course of action

The students are given a file of resources for this problem but are also expected to do some further research themselves, and this makes up their pre-lab task. By engaging with recent literature on environmental issues, water pollution and ways of preventing it, the students are coming to the lab session with an inherent interest in the experiment. The students carry out these tasks over the course of the 2 weeks, and are required to present their findings orally and argue their results with the opposing team, who had the same water sample as themselves. However, the groups do not necessarily achieve the same results.

The assessment of this experiment is by their written laboratory report, and an oral presentation. The use of oral presentations is a common feature of chemistry-based PBL modules[45,46,47], for example Belt *et al.*[46] report the use of oral presentations in their PBL approach to analytical and applied chemistry for both transferable skill development and for assessment. Previously, Belt & Phibbs[48] reported the use of oral presentations for promoting the importance of disseminating information to a wide audience, with the students having to report to experts and non-experts.

Because of the 'debate' aspect of the oral presentation, the students want to make sure that they have done the experiments to the best of their ability, and can back up their arguments with their own experimental findings and research from the literature. To do this effectively, they must have a thorough understanding of their experiment and the results.

3.5.3.4: Investigate Gas Behaviour

In this experiment, the students are given a variety of equipment and consumables to design a series of experiments to support the Ideal Gas Law, mainly using a gas chamber (syringe) and pressure and temperature sensors connected to dataloggers. As the groups divides into two for this experiment over two weeks, it is not possible to carry out a pre-lab exercise with the group. Therefore it was necessary to give some guidance and support to the students at the beginning of the lab session. However, once they became familiar with the equipment, especially the dataloggers and sensors, they became more confident in their ability to design experiments and hence obtain results to support the gas laws. See Table 3.30 for an overview of the PBL experiment and a comparison with the traditional experiments which was carried out for the two weeks, in terms of understanding, hands-on activities and calculations.

Table 3.30: Comparison of the traditional and PBL experiment – Week 1/2 Sem 2

	TRADITIONAL	PBL
Understanding	Ideal Gas Law	Boyle's Law Charles' Law Avogadro's Law Ideal Gas Law
Hands-on activities	Measuring the production of gas Titration	Temperature and gas pressure sensing with dataloggers
Calculations		Fundamental calculations Use of Ideal Gas Law

The very nature of this experiment required them to understand what each of the gas laws meant and how they fitted into the Ideal Gas Law. To set up the experiments they needed to take into account what they wanted to measure, what had to be kept constant, how they were going to do it, and from there, develop a fair test. If for example they wanted to measure the effect of volume on pressure, then all the other variables needed to be kept constant i.e. the amount of gas, n, and the temperature, T. They then needed to generate data and manipulate it, to show the correct relationship between the two variables. Because there are no set procedures, the students had to really think about the experiments and they were involved with all steps of the development, and hence involved in 'real research' experiments. Since some students were familiar with the laws and knew the expected outcome having studied them for Leaving Certificate Chemistry or Physics, it was a surprise to them that designing effective experiments to prove the gas laws was not necessarily an easy task.

3.5.3.5: Aspirin

Over the course of the year, the traditional students do three experiments on aspirin so for the PBL students these were all incorporated into a three-week problem. This involved the preparation of aspirin from salicylic acid, and the analysis of aspirin by back-titration and by UV analysis. The problem which the PBL students were given involved them acting as members of a QC team. This involved them approving or rejecting a method for aspirin synthesis, and the evaluation of two methods of aspirin analysis – back-titration and UV. See Table 3.31 for an overview of the PBL experiment and a comparison with the traditional experiments which was carried out for the two weeks, in terms of understanding, hands-on activities and calculations.

The context of this experiment required students to really think about their results and to decide on the fate of the preparation and analysis methods. Having previously had experience with purity determination using recrystallisation and melting points, the students then had to apply this to a new context, that of their prepared aspirin sample. Also, they were required to use a new method to determine the purity of their sample - Thin Layer Chromatography. This provided a second platform on which to base their conclusions. Of the two analysis methods, the students had much more experience with the titration technique and therefore succeeded in getting a high level of accuracy in their results. However, in the UV determination, the students were required to make up stock and standard solutions and the students seemed to have difficulty with this in terms of accuracy and precision with many students failing to get a good standard curve. This meant that they got an inaccurate value for their aspirin content. The students, in general, reported that the back-titration would be a much more satisfactory method to use due to its high accuracy and precision.

Table 3.31: Comparison of the traditional and PBL experiment – Week 8/9/10 Sem 2

	TRADITIONAL	PBL
Understanding	UV Back-titration Purity determination	UV Back-titration Purity determination Method evaluation Accuracy & precision, errors
Hands-on activities	Microscale synthesis Melting point Recrystallisation TLC Back-titration Preparation of standards UV analysis Data manipulation	Microscale synthesis Melting point Recrystallisation TLC Back-titration Preparation of standards UV analysis Data manipulation
Calculations	Fundamental calculations	Fundamental calculations Evaluating preparation method Comparison of two techniques for determination of aspirin

Overall, this problem required the students to really engage with their results. To give valid conclusions, and hence successfully solve the problem, the students had to understand the significance of all their experimental results and use them to back-up their arguments. Having met many of the techniques before e.g. back-titration, UV, recrystallisation, melting point meant that the students could really think about what they were doing rather than be just concentrating on actually doing it. In the 'Problem Analysis' students showed a similar trend to the other problems which required an oral presentation, with students showing the highest level of agreement with the statement 'The overall presentation experience was enjoyable' and least level of agreement with

'It was difficult to devise a plan for the presentation'. This suggests that students enjoy the presentations but have not developed the skills yet to effectively prepare for them.

3.5.4: CONCLUSIONS

Overall, these problems aimed to develop students understanding of particular concepts to enhance their skills, both in terms of transferable skills and technical skills, and finally to promote their understanding of the experimental process and the significance of the subsequent results and data.

The success of the module, in my opinion, was apparent in their final exercise, that of presenting their posters on one of the problems. It was clear from all the students that they understood the fundamental chemical concept behind each of the experiments, and what they were trying to achieve in each case. Some described the experimental procedure and their results; others focused more on the background information and its relevance to the experiment and their results, while some groups described their manipulation of their data to support their conclusions. By presenting their posters to each other it also meant that students got a revision of the whole course over the course of an hour!

In some cases, the students slightly changed the context of the problem and successfully adapted the underlying concepts to a new situation. For example, the two students presenting the poster on 'Apples and Oranges' compared it a battle – the war of the acids and who would win out in the end! By describing the experimental techniques, they were able to contextualise their results and hence conclude that the oranges would win out. Another pair of students presenting on the 'Old Wive's Tale' portrayed themselves as scientists concerned for the local 'old folks'. They described a situation where the 'old folks' were being ripped off by these 'big companies' selling them their expensive antacids tablets, when baking soda would be as effective...and in a twist of the tale, they finished off with offering the 'old folks' a deal on some baking soda at a very reasonable price!

In conclusion, this chapter summarised the aims and intended learning outcomes of this module and compared the traditional and PBL experiments under various headings including concepts, skills, understanding, hands-on activities and calculations. Both the PBL and traditional students cover all the same techniques and the same chemistry concepts. The PBL approach, however, provides more scope for skills development, and understanding of concepts and of the experimental process.

Though the module has now been run for two academic years (in 2003-2004 and 2004-2005), there are still some modifications which might further enhance the course and hence the learning experience of the students. These include:

- Rewriting some of the problem sheets to make the instructions and desired learning outcomes clearer
- Introduce aspects of peer and self- assessment.

The effect of running the PBL module has been thoroughly evaluated, and results from the evaluation are given in the next chapter. The evaluation covers both qualitative data in terms of student feedback and quantitative data in terms of assessment marks. A key part of the evaluation was to determine if the student's approach to learning was influenced/changed by the experience of the PBL module.

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